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AN INTERDISCIPLINARY EVALUATION OF TRANSACTIVE MEMORY IN DISTRIBUTED CYBER TEAMS

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ABSTRACT

In the modern workplace, collaboration is no longer only a face-to-face process. When working together, it is common for teams to rely on technology and operate across geographic, temporal and cultural boundaries. Most research, when looking at distributed teams, takes a uni-disciplinary perspective and fails to address the entire problem space. Because of the technological complexities, deluge of information, and interpersonal interactions, research must address this problem with an interdisciplinary lens.

Rather than looking at collaboration as a broad concept, this dissertation focuses on extracting, and experimenting on the concept of transactive memory. Put simply, transactive memory is the knowledge of “who knows” what in collaborations. Research unanimously agrees that transactive memory is a positive mediator in improving team collaborating. Through transactive memory, teams can encode information on the knowledge possessed by others, and leverage the specializations of each collaborator to improve their performance and reach their goals quicker. To understand how we can move transactive memory into this interdisciplinary space, this dissertation reviews previous research from the cognitive, social/organizational, and technological perspectives on transactive memory. The cognitive outcome focuses on identifying how teams form, store, and leverage transactive memory to improve their performance. On the other hand, the social/organizational side, rather than looking at outcomes at the individual and team level, focuses on how transactive memory systems affects larger social structures and can be leveraged in organizations to improve performance. Finally, the technological perspective focuses on using previous research in the other perspectives as a design rational in a system design process.

Based on a review of each of these perspectives, and an understanding of current interdisciplinary research interests and issues, a set of six propositions for future research in transactive memory are proposed. To address a sample of these directions, this dissertation presents an interdisciplinary study to assess transactive memory systems in the technologically complex environment of cyber security. Specifically, this study focused on answering three main questions to account for the cognitive, social/organizational and technological perspectives:

1. How do distributed teams form, maintain and utilize transactive memory systems?
2. What are the behavioral, social and organizational outcomes of transactive memory systems in distributed collaborations?
3. How to best design collaborative interfaces to better support transactive memory formation, utilization and maintenance in distributed teams?

The understanding of transactive memory, as well as research from cyber security informed the design and development of a new scaled-world simulation to study transactive memory and team collaboration. Set within the context of distributed cyber teams, *teamNETS* supports the collaborative processes, and decision-making tasks that are present in real cyber security environments.

To address the overarching research objectives, 66 teams of three participated in a human-in-the-loop scaled world simulation experiment. The two main independent variables for this study were the presence of shared virtual feedback and the transactive memory structure (integrated vs. differentiated) of the team. In addition to these manipulations, other measures allowed the assessment of transactive memory perceptions, utilization, and content, situation awareness, and team perceptions. While there were no direct effects on team performance for any of the independent variables, there were numerous interesting behavioral findings. The results showed that contrary to expectations, the shared virtual feedback was detrimental to team collaboration. Additionally, while transactive memory structure had no impact on performance, teams in the two conditions took part in very different styles of collaboration.

Contributions of this research include a more informed understanding of transactive memory, and the role of shared virtual feedback in distributed teams. This research also led to the development of a new simulation platform, *teamNETS,* to allow future studies to ask questions that are more complex and study teams in a more realistic collaborative decision making environment. Based on the proposed research directions,

the experimental findings, and the new simulation, this research can be used to inform future interdisciplinary research in not only transactive memory but other constructs of team cognition and collaboration.

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Chapter 1

Introduction

Over the past three decades, computing and technology have evolved to become a ubiquities entity that is an integral part of our personal and professional lives. With the advent of mobile and social computing, people are now able to remain connected to not only information, but also their friends, co-workers and loved ones. Now more than ever, it is common that humans rely on computers and technology to connect with others, find information, make decisions, and empower them in their everyday activities. Using these uninterrupted connections, geographically dispersed individuals are able to socialize and collaborate with others quicker and easier than ever.

This ubiquity of technology has not only improved our individual lives, but also has enabled organizations to leverage employees across geographic, temporal and cultural boundaries to run their everyday operations. These virtual or distributed teams allow organizations to apply multiple perspectives to a problem, offer more flexibility to their employees, and maintain a 24-hour work cycle. Additionally, distributed teams are even more preferable from an operation and cost perspective, as individuals from across the world can be connected immediately, at a fraction of the cost from before. With this shift in the organizational paradigm, researchers from numerous domains have become increasingly interested in understanding and supporting these teams.

From the perspective of fields such as Human Factors, Computer-Supported Cooperative Work, and Human-Computer Interaction, research has focused on designing and/or assessing technological solutions to support distributed collaborations. Much of the early research focused on simple tasks such as collaborative document authoring (e.g., Dourish & Bellotti, 1992; Gutwin, Roseman, & Greenberg, 1996; Johnson-Lenz & Johnson-Lenz, 1981). More recently research has transitioned to more complex and applied domains such as emergency response (McNeese, Connors, et al., 2005; Schafer, Ganoe, & Carroll, 2007; Wu, Zhang, Convertino, & Carroll, 2009), military operations

(Chuah & Roth, 2003; Fleming, Jordan, Madden, Usery, & Welch, 2009), civil planning (Drummond & French, 2008; Li, Bo, Ju, & Guo-xue, 2009) and online learning (Forgues, Koskela, & Lejeune, 2009; Stacey & Mackey, 2009). While pioneering in their field, this body of research does not account for other confounds such as trust, stress, social roles, team efficacy, personal traits, knowledge structures, previous experience and culture (Daily & Steiner, 1998; Ellis, 2006; Kanawattanachai & Yoo, 2002), all which are prevalent in distributed teams. On the other end of the spectrum are fields such as psychology, management, and business, which approach distributed teams from the human and organizational points of view. These research domains often focus on more complex issues such as the cognitive, social and organizational outcomes of distributed teams in the workplace (e.g., Cannon-Bowers, Salas, & Converse, 2001; Edwards, Day, Arthur Jr, & Bell, 2006; Ellis, 2006; J. S. C. Hsu, Parolia, Jiang, & Klein, 2007)

Each of these domains has played an integral role in helping us better understand and enable distributed collaborations, but alone they are not able to paint a complete picture of the problem space. Distributed teams do not exist in a purely technological, cognitive or organizational space, and should not be approached with a uni-disciplinary lens. Distributed teams are an interdisciplinary problem in need of a solution that accounts for the information, technology and people that are present in the system.

Distributed Teams and Transactive Memory

Even with this technological evolution, some researchers continue believe that teams using computer mediated collaboration systems are not, and will never be as effective as face-to-face teams (i.e., Maznevski & Chudoba, 2000; Stone & Posey, 2008; Tutty & Klein, 2008). In distributed collaborations, many of the things in face-to-face interactions that we take for granted, like explicit communication, or body language, are lost in the virtual context (Hill & Gutwin, 2003). Without these affordances, individuals are not able to work as effectively and may not achieve their goals. While the lack of face-to-face affordances is a major issue in supporting distributed collaboration, Table 1 describes other potential problems that may arise in these teams.

Table 1: Examples of Problems Faced by Distributed Teams

Problem	Description
Training Issues	Since distributed teams are not always trained together, it becomes unclear as to whether or not they have received the same training. They are not able to form common bonds during training, and they do not know what each other is good at. This also becomes a problem during conflict resolution and decision making in distributed collaborations.
Cultural/ Language issues	Since distributed team members may come from different cultures, there often are coordination difficulties, difficulties in communication (due to different languages or accents), and different expectations or cultural norms.
Temporal Distribution	If teams are in widely different time-zones they may be operating on different working schedules, and have to rely on asynchronous communication. This makes it difficult because there is rarely any instantaneous feedback, and the workers may have trouble forming interpersonal connections.
High turn-over	Since teams are not centrally located, replacing members in distributed teams costs significantly less. This may add to a lack of trust in the team, as well cause issues in forming interpersonal connections and may have other coordination costs associated with it.

Unfortunately, many of the issues identified in Table 1 are inherent with distributed teams and may not have a solution. Additionally, each of these issues may be too broad for operationalization and extraction for the purposes of research, making it difficult to understand fully. Rather than focusing on these larger, meta-issues, to better support and understand distributed teams, research should look at other potential mediators of team performance.

One theory that has shown to improve team performance is the formation and utilization of effective transactive memory systems (D. W. Liang, Moreland, & Argote, 1995; Moreland, 1999; Moreland & Myaskovsky, 2000; Wegner, Erber, & Raymond, 1991; Wegner, Giuliano, & Hertel, 1985). When working with a team or group, people utilize a special type of memory, transactive memory, to enable them to complete their task quickly and effectively. In general, transactive memory is the knowledge of “who knows what” in a group or team. While formation of transactive memory systems in face-to-face collaborations is easy, there is minimal understanding of their formation and utilization in distributed teams. This dissertation focuses on the formation, maintenance and utilization of transactive memory systems in distributed collaborations. The overarching research question of this dissertation is:

What is the role of transactive memory in technology mediated collaborations for distributed teams?

The notion of transactive memory was first introduced in the year 1985, in a study of the memory structures of romantically linked couples (Wegner, et al., 1985). In this seminal paper, the authors define transactive memory as an individual's memory system that is involved in a larger, organized social memory system that has emergent group mind properties not traceable to individuals. Much of the research in transactive memory suggests that teams who have effective transactive memory systems are able to outperform those with weaker ones.

While moving forward with a new interdisciplinary approach to transactive memory is important, a firm understanding of previous research is necessary. Research in transactive memory can be organized into three major perspectives; (1) cognitive, (2) social/organizational and (3) technological. In the cognitive perspective, researchers assess the performance outcomes of transactive memory, and aim to understand the formation and maintenance in an individual's consciousness. The social/organizational investigates larger teams and organizations and the social outcomes of these systems. Specifically researching utilizing and leveraging transactive memory in teams, and understanding how training mechanisms and policies can support it. Finally, the newest perspective, the technological perspective has focused on how technology can augment transactive memory systems in distributed collaborations. While each of these perspectives provides a unique viewpoint and understanding of transactive memory, there is little work across the disciplines. In order to understand how transactive memory has evolved, and the role it plays in the real world, an interdisciplinary approach is necessary.

Based on this review of the different perspectives of transactive memory, and an understanding of interdisciplinary research, a set of future directions for research are proposed. These directions aim to encourage research in better understanding the role of transactive memory in technologically mediated collaborations.

As a first step in this process, this dissertation focuses on understanding the role of transactive memory in distributed cyber teams. The context of cyber security offers an effective domain for grounding this research, as there is a strong interplay between people, information and technology. Additionally, the complex and dynamic nature of the environment provides rich collaborative decision-making possibilities. Based on previous research within cyber security, as well as experience with the *NeoCITIES* simulation (Hamilton, et al., 2010; Hellar & Hall, 2009; Mancuso, Parr, et al., 2011), a new scaled-world simulation, *teamNETS* was developed. Informed by a qualitative assessment of cyber security analysts (Tyworth, Giacobe, Mancuso, & Dancy, 2012), *teamNETS* was built on top the *NETS* platform to support three functional domains of cyber security and mimic the collaborative processes of real world cyber analysts.

Using this simulation, an experiment was designed to understand the role of transactive memory in distributed cyber teams. Specifically, the role and impact of shared virtual feedback and transactive memory structure were investigated in a team based human-in-the-loop simulation experiment. In addition to the two main research questions, New methods were developed to measure transactive memory content and utilization, and investigated the interplay between transactive memory and other constructs. From this study, numerous theoretical, technological and practical implications are discussed.

Organization of Document

The remainder of this dissertation is organized accordingly:

Chapter 2 provides a literature review on the previous work in transactive memory, specifically on the cognitive, social/organizational and technological research prospective. Using this previous research in transactive memory, as well as an understanding of interdisciplinary research, future research directions are proposed and discussed.

Chapter 3 provides an overview of a new scaled-world simulation developed to answer several of the research propositions discussed in the previous chapter. To address these questions a new team-based simulation, *teamNETS*, set within the context of cyber security was developed. This chapter provides an overview of the development, interface and pilot testing of the simulation

Chapter 4 outlines the research study that was conducted using the *teamNETS* simulation. The methods and materials for a study on transactive memory in distributed cyber teams. Additionally the hypotheses for the study are presented and the expected results discussed.

The statistical findings of this experiment are presented in chapter 5, and further discussed in chapter 6. Finally, chapter 8 provides directions for follow-up analyses and research from the findings, and concludes the dissertation.

Chapter 2

Transactive Memory: An Interdisciplinary Perspective

Introduction

There are three main cognitive processes of memory: the encoding process, the storage process, and the retrieval process (Lang, 2000; Tulving & Thomson, 1973). Information enters memory during the encoding stage; is retained for future access in the storage stage; and accessed for use during in the retrieval stage. Problems such as incorrect encoding, forgetfulness, and memory overload can occur as memory transitions through these stages. For example, when trying to remember a phone number, a person could misread one of the numbers, store it correctly then forget it later, or overload their memory causing them to forget something else they had store.

Prior research on distributed cognition has found that physical objects acting as cognitive artifacts are particularly effective at reducing incorrect encoding errors (Dror, 2011; Hazlehurst, McMullen, & Gorman, 2007; Hutchins & Lintern, 1995). Notepads, meeting calendars and lists are examples of cognitive artifacts employed in everyday life. While useful for maintaining and memory, an individual's internal knowledge is inherently linked to the information stored on a cognitive artifact. Even a highly detailed cognitive artifact, such as detailed notes, or systematic directions, may not be useful help in accomplishing a goal if the individual lacks the necessary internal knowledge to comprehend its meaning. For example, a person writing down a complex mathematical formula will not find the notation very useful as a memory aid if they lack the mathematical knowledge to understand its meaning.   When individuals lack the requisite internal knowledge to make use of cognitive artifacts, they must access their *transactive memory* – or knowledge of others' knowledge – to gain access to use the artifacts effectively.

Transactive Memory

Research on transactive memory has been ongoing for almost thirty years (e.g., Hollingshead, 2001; Lewis, Lange, & Gillis, 2005; Moreland, Swanenburg, Flagg, & Fetterman, 2010; Riedl, Gallenkamp, Picot, & Welpe, 2012; Smith-Jentsch, Kraiger, Cannon-Bowers, & Salas, 2009; Sparrow, Liu, & Wegner, 2011; Wegner, 1987, 1995; Wegner, et al., 1985). Over that period, three theoretical perspectives have come to the forefront of transactive memory research: the cognitive perspective, the social/organizational perspective, and the technological perspective.

The cognitive perspective approaches research from the individual or small groups, to understand the internal processes and outcomes of transactive memory. This research focuses primarily on individuals situated within small teams (2-6 members). Much of the seminal research in transactive memory uses this perspective as the basis for their research.

While the cognitive perspective looks at the individual or team cognitions, the social/organizational perspective uses transactive memory to understand the social outcomes of interactions, and develop team training, organizational policies and strategies to improve collaborations. Rather than focuses on individual teams, this research often focuses on teams within a larger organization or multi-team systems.

Finally, the technological perspective uses research from the other perspectives to inform the design and deployment of systems that augment transactive memory systems for both distributed and co-located teams. While there is some deployment and testing, this perspective focuses more on design solutions to the research from the other perspectives, such as finding new and innovative ways to visualize an individual’s knowledge within a transactive memory system.

Table 2 provides an overview of these three research perspectives, their focus, and the level of analysis they address.

Table 2: Three Perspectives of Transactive Memory Research

Perspective	Focus	Level of Analysis	References
Cognitive	Individuals Small Teams	Individual or Team Cognition	(Austin, 2003; X. Chen, 2009; Gupta & Hollingshead, 2010; Hollingshead, 1998a, 1998b, 2000, 2001; Lewis, 2004; D. W. Liang, et al., 1995; Littlepage, Hollingshead, Drake, & Littlepage, 2008; E. Michinov, Michinov, & Huguet, 2009; Moreland & Myaskovsky, 2000; Wegner, 1987; Wegner, et al., 1985)
Social/ Organizational	Teams Multi-Team Systems Organizations	Larger teams or organizations	(Choi, 2010; Comu, Iorio, Taylor, & Dossick, 2011; Healey, Hodgkinson, & Teo, 2009; S. Hsu, Shih, Chiang, & Liu, 2012; Jackson & Moreland, 2009; A. Liang & Jin, 2010; Moreland, et al., 2010; Smith-Jentsch, et al., 2009; Yuan, Fulk, Monge, & Contractor, 2008)
Technological	System Design	Technology	(Adibhatla, Shapiro, McNeese, & Balakrishnan, 2009; Ariff, Milton, Bosua, & Sharma, 2011; Engelmann, Dehler, Bodemer, & Buder, 2009; Keel, 2007; Riedl, et al., 2012; Schreiber & Engelmann, 2010)

Each of these research domains does an excellent job of capturing and understanding transactive memory within their given focus. The cognitive perspective captures how people and teams collectively encode information to enable and improve their collaborative processes. The social/organizational perspective captures how teams within organizations and larger social structures, leverage their transactive memory systems in their everyday work. Finally, the technological perspective captures how to design systems to improve an individual’s awareness of transactive knowledge that is present in the collaboration. While each of these research perspectives has been invaluable, none of them is able to capture the interplay of information, technology and people.

A holistic theoretical perspective that accounts for the informational, technological, and cognitive dimensions of transactive memory is necessary to advance our understanding of transactive memory as a socio-cognitive phenomenon. A theoretical perspective of transactive memory that accounts for information, technology, and people will provide the lens with which to study many of the trans-disciplinary problems in which transactive memory plays a role. In the prior example, for instance, transactive memory would typically be examined as it relates to the interplay among individuals, teams, and *online collaboration systems*. The proposed perspective, however, provides the means to explore transactive memory as it relates to emerging technologies such as the social web, ubiquitous computing, and human-robot/agent interaction.

Foundations of Transactive Memory

Transactive memory was first introduced by Wegner et. al (1985) in a study of the memory structures of romantic couples where they described it as a unique form of memory which with emergent group mind properties not traceable to individuals that is part of a larger, organized, social memory system. Consider a student working on math homework who is stuck on a problem. The student recalls that their friend received an A in the class the previous year and asks them for help on the problem set. In this example, the student working on the test recalls information about their friend that implies they are good at math, and then asks their friend for help, thus accessing their cognition. This is an example of an individual, using their transactive memory of their social circle, to solve a problem.

Through transactive memory a person, in effect, uses another person as external store of information and knowledge they themselves do not possess (Moreland & Myaskovsky, 2000). Individual knowledge can be broken down into two categories within every transactive memory system: (1) higher-order knowledge; and (2) lower-order knowledge. Higher order knowledge is one’s general knowledge about something specific, Lower-order knowledge is knowledge of the specifics steps or components that comprise the higher order entity (Wegner, et al., 1985). Prior research on transactive memory has shown that typically individuals may have higher order knowledge, and rely on others for lower-order knowledge rather than acquiring the needed lower order knowledge themselves. Performance improves when individuals have knowledge – or transactive memory – of others who retain the lower-order knowledge they lack. Using the math example from the previous paragraph, if the student knew what type of equation they had to use, but didn’t know how to use it they would have higher order, but now lower order knowledge. In this case, they use their higher order knowledge to question their friend, and gain access to their lower order knowledge to complete the problem set.

Similar to individual memory, transactive memory formation and utilization is broken down into three stages. The three stages of transactive memory are directory updating (TM formation), information allocation (TM maintenance) and retrieval coordination (TM utilization) (Wegner, 1995).

Directory updating is the process used to construct the transactive memory system. In the math example, the student updates their directory about their friend based on their class enrollment from semester to semester (among other things). Information allocation is the process that supports the transactive memory system by updating the information with other metadata that may inform their proficiency or knowledge in a given area. For example, whenever the student finds out their friend received an A in the class, they allocate new information to the previous structure to update their system. Finally, retrieval coordination is the process in which the transactive memory system is utilized through connecting an individual to a given specialty or piece of knowledge. For example, when the student made the connection between their problem, and the specialty their friend had based on their grade.

To maximize one’s ability to utilize transactive memory individuals need to properly store and organize knowledge or information. Brandon & Hollingshead (2004), have theorized that transactive memory systems are formed through the collective encoding of task-relevant hierarchical information within the higher/lower order labeling framework as proposed in (Wegner, 1987; Wegner, et al., 1985). Specifically, three components of encoded information: task (T), expertise (E) or people (P); thus forming a TEP unit. Knowledge of a specific person, what their specific expertise is, and the current task that is at hand is an example of a full TEP unit.

TEPs (and thus transactive memory systems), are developed iteratively. A TEP is constructed, evaluated and then utilized. Using the most relevant and current information a person constructs TEP units. After construction, next comes an evaluation of the TEPs credibility. If the TEP is credible, it is encoded into memory. If not credible, TEPs are updated, re-encoded into memory or dismissed. When utilized in a task setting, consistent with the results of the task TEPs are updated and re-encoded.

Task-Expertise-People units can be a guide to allocate different tasks, responsibilities and information within a collaborative system. When a transactive memory system is comprised of complete TEP units individuals are able to function most effectively. Table 3 summarizes the components of a complete TEP unit, and links them to the math example from before.

Table 3: TEP Units from Math Example

Component	Description	Example
Task	What needs to be accomplished	Math problem set
Expertise	What knowledge is needed to complete the task	Strong understanding of Math
People	Who has the given expertise	Friend who received an A in the class

Typically, however, transactive memory systems are comprised of incomplete TEP units, in which the task, person or expertise information is missing or incorrect. As the above example demonstrates the TEP components flow into each other, so if one is missing or incorrect, it negatively affects the other two components. For example, if a person encodes the incorrect expertise, it will cause them to select an incorrect person who cannot complete the task. In the math example, if the student thought chemistry knowledge was necessary, they would access another person’s knowledge, who may not be good at math.

Transactive Memory in Teams

As described above, transactive memory is an individual phenomenon consisting of the interpersonal awareness that is within the individual's head. Transactive memory is, however, conceptually well suited to the team level of analysis. In teams, groups of individuals make use of their transactive memories, or a transactive memory system, in a collaborative setting. A transactive memory system (TMS) is when a group takes part in a cooperative division of labor for learning, remembering and communicating relevant task knowledge to a team or group (Lewis, 2003). Transactive memory systems are comprised of two components: (1) the organized stores of knowledge maintained by an individual team member; an, (2) the interpersonal awareness that other members in the group or team have of that knowledge and the processes around retrieving it (Hollingshead, 2001; Wegner, 1987). In team collaborations, TMS formation is a group wide learning cycle in which transactive processes are used to encode, store and retrieve knowledge about members memories (Lewis, et al., 2005). The *transactive processes* form the TMS through transference of information from one team member.

An effective transactive memory system can be broken down into a set of interrelated components that can improve or detract from a team's ability to complete a task. These components, or dimensions, were initially proposed by Moreland (1999) as accuracy, agreement and complexity. These were later expanded by Austin (2003) to four dimensions. Table 4 provides a comparison of the two sets of dimensions and their descriptions.

Table 4: Dimensions of an Effective Transactive Memory System

Dimension		Description
Austin	**Moreland**	
Group knowledge Stock	Coordination	Combination of the individual knowledge of each person in the group
Consensus about Knowledge Sources	Coordination	Extent to which the group members agree about who has what knowledge
Specialization of Expertise	Specialization	A deeper knowledge base in a narrowly defined area of expertise, and the awareness of who specializes in what
Accuracy of Knowledge Identification	Credibility	Accuracy to which a member who is identified as having a specialization actually has the knowledge in that area

Using these dimensions, in order for a team or group to have an effective transactive memory system there would have to be an adequate amount of knowledge divided amongst the group, agreement about where the knowledge was stored (in terms of who had it), division of specialty or foci, and sufficient accuracy of knowing who had which specialty. These dimensions have served as basis of the majority of the research in transactive memory (e.g., Akgün, Byrne, Keskin, Lynn, & Imamoglu, 2005; Gupta & Hollingshead, 2010; Ilgen, Hollenbeck, Johnson, & Jundt, 2004; Kozlowski & Ilgen, 2006; Lewis, 2004; Smith-Jentsch, et al., 2009) and has lent itself to the development of a field measurement technique to assess transactive memory in work teams (Lewis, 2003).

Transactive Memory has received significant attention in the team literature. Scholars have found that transactive memory is an integral component of effective teamwork and collaboration (e.g., Hollingshead, 1998a, 1998b; D. W. Liang, et al., 1995; Wegner, 1987; Wegner, et al., 1991). Transactive memory systems give members quick and coordinated access to one another’s specialized expertise, and promotes more task-specific knowledge shared within teams (Jackson & Moreland, 2009; Lewis, 2004; Moreland, 1999; Moreland & Myaskovsky, 2000). Research has shown that teams who have better TMS are able to perform collaborative tasks more quickly and with more success than teams with a weak TMS (Ellis, 2006; Lewis, 2004; Moreland & Myaskovsky, 2000; Pearsall & Ellis, 2006).

Perspectives on Transactive Memory

The following section describes the research and contributions from each area, and suggests how to further our understanding from an interdisciplinary perspective.

Cognitive Perspective

The concept of transactive memory originates in cognitive science. Research employing the cognitive perspective has focused primarily on the formation of transactive memory systems and the encoding and use of information. Research adopting the cognitive perspective of transactive memory has typically employed an individual level of analysis; focusing on small groups or teams of individual using ad-hoc groups and in laboratory experiments.

Wegner (1985) was the first to study transactive memory using the cognitive perspective. Wegner studied dyadic pairs performing a group memorization task and measured the effects of group familiarity and explicit knowledge structures. Wegner found that expertise areas and transactive memory systems – whether explicit or naturally formed – could help improve collaborative performance. Subsequently, Hollingshead (1998a) examined how communication prior to the memorization task affected transactive memory. Hollingshead's results confirmed the Wegner study, but highlighted the importance of communication in the formation of transactive memory systems. Effective communication processes during learning phase can facilitate the development of transactive memory between unfamiliar pairs and improve their performance.

Other transactive memory studies adopting the cognitive perspective focused on understanding the effects of individual vs. team training and its effects on performance. Liang, Moreleand and Argote (1995) found that the teams who trained as a team recalled more about how to complete the task and made fewer errors than the teams where individuals trained separately. Teams who trained together were able to recall different aspects of the task, coordinate their activities, and trust one another's expertise, representing support for strong transactive memory systems. Other follow-ups to this study confirmed and built upon the results. In (Hollingshead, 1998b), the authors looked at group vs. individual *practice of task*, finding similar results to the previous study. In this experiment, rather than training as individual, or group, the participants practiced as group or individually. Their results confirmed previous results showing that the teams that practiced together performed the group task better. However, team practice did not improve individual performance, showing that there is collective recall effect. To assess whether the performance benefits were a result of strong transactive memory systems, or just improved group dynamics, Moreland & Myaskovsky (2000) conducted a study in which participants were trained in the task individually, and then assessed themselves on their strengths and weaknesses within the task. Prior to starting the collaborative task results were provided to each team member. Teams who received information on each other's strengths and weaknesses performed as effectively as collaboratively trained teams. This study verified prior results, showing that the formation of transactive memory systems was a major contributor to the improved performance, rather than just improved team dynamics.

The previously discussed studies focused on transactive memory or transactive memory systems as a larger concept, but never addressed underlying mediators. When dealing with transactive memory systems, many researchers believe the specialization of expertise (or simply specialization) is the largest contributor to an effective transactive memory system. Specialization within a team can be further broken down into the concepts of integrated and differentiated structures. In differentiated structures (more specialization), information is distributed across individuals, while an integrated structure (less specialization) focuses on information that is common to all members. For example, consider a web development team; a team with a differentiated structure would have one pure designer, back-end coder and database engineer, while an integrated structure team would have three members that have equal knowledge in all areas. Figure 1 presents a visual representation of each of these teams, with the integrated team on the left, and the differentiated team on the right.

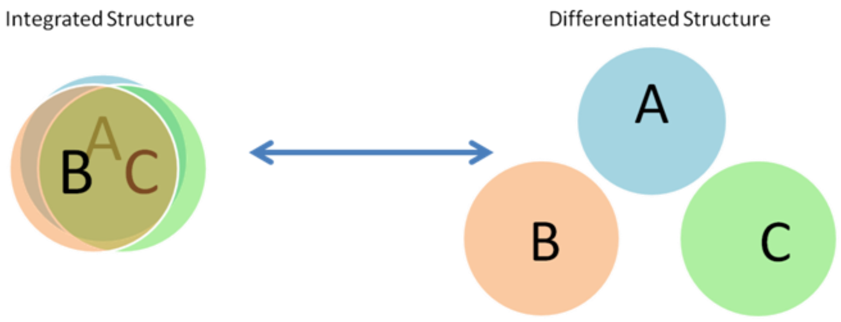

Figure 1: Scale of Specialty Structures in Teams

In an early anecdotal assessment of the concept, Wegner (1987) proposed that the potential for knowledge expansion and production is much greater whenever teams posses an differentiated structure rather than an integrated structure. He suggests that since there is a lack of duplication of effort, and each individual brings something unique to the table, the team is able to store information more efficiently and generate more information than one individual could produce.

Littlepage et al. (2008) studied clerical staff members to understand the effects of specialization, communication, and work allocation on transactive memory systems. Based on a survey that covered multiple domains of knowledge within their job, the authors found that whenever an individual allocated work to other, more proficient members, they were able to improve their team performance. This implied that whenever there were more diverse (and complete) specialties within a group, they were able to achieve higher performance. In another study, Michinov & Michinov (2009) looked at the effects of specialization, coordination and credibility on the performance of students working in groups throughout the semester. Based on an evaluation of their final product, as well as self-report measures of transactive memory they found that a team's performance improved as team members developed specialties within the group. They found that individuals are more likely to learn more about their own specializations if they believe that others possess different expertise and when the task requires team members to know different, yet complimentary information. However, a differing result they found was a direct correlation between the ability to utilize the specialties and their ability to coordinate their actions. This showed that even if a team had a perfect set of specialties, if they were not able to properly coordinate and organize their actions, they would not see the same performance increases. Similar results were found by Austin (2003) in his study of longitudinal worker teams. The findings showed that teams with a broader set of specializations could allocate more resources to “attack the problem” from more directions, allow members to focus on developing their expertise’s in a specific domain, generate higher quality solutions, share and identify more task relevant knowledge and move from task to task with more ease. Although the specializations were important, teams need to effectively communicate with each other and coordinate their actions. Other research that has approached specialization in transactive memory has found that it can help form a clear directive of responsibility to reduce the cost of information sharing (Lewis, 2004), improve the development of other unique specialties (Hollingshead, 2000, 2001; Wittenbaum, Stasser, & Merry, 1996; Wittenbaum, Vaughan, & Stasser, 1998), and improve the consensus and accuracy of the knowledge within a team (Hollingshead, 2000; Lewis, 2004; Wegner, 1987).

In an analysis of specialty structures, Gupta & Hollingshead (2010), looked at the relationship between structure, task type and group performance. They found no performance differences between the two types of transactive memory structures in a group recall task but found teams with the integrated structure outperformed the differentiated teams in a more complex intellective task. Integrated teams were more helpful to each other, helped correct teammates errors, and had more integrated collaboration, while teams with a differentiated structure, divided their labor and worked more interdependently. Similarly, in a study of large open-source software communities, Chen & Dietrich (2009) found that while some level of specialization in the group is a necessary facet of transactive memory, that the knowledge cannot be too disparate. Rather than having only specialists, groups should contain a few generalists or overlapping specialties. This provides somebody who can understand all the skills and knowledge and leverage them correctly to best complete the task. Teams do not want to be on the far right or left end of the specialty structure listed above, since you would want some level of common ground to increase collaboration within the team. These results were similar to those found in team research on military helicopter cockpit crews (van Ginkel, Vogelaar, de Jong, & Berghorst, 2010). When a team is made up of heterogeneous specializations, a strong TMS is needed or else their performance can decrease significantly.

Social/Organizational Perspective

Within the social/organizational perspective, rather than focusing on the cognitive underpinnings of transactive memory formation, maintenance and utilization, the social and organizational outcomes of the systems are the focus. Within this perspective, the main unit of analysis is the larger social or organizational structure, rather than the individual. This perspective considers transactive memory within larger entities such as educational groups, multi-team systems, and organizations. Additionally, researchers within this area take real world constraints such as team dynamics, temporality and complexity into account. This research area provides substantial insight into how transactive memory exists outside of the individual and team mind, and in real world environments.

Several research studies have applied the concept of transactive memory systems to the classroom. Jackson & Moreland (2009) investigated the formation of transactive memory in an undergraduate information systems class during a final project phase. They found that face-to-face communication amongst the group members was the single best predictor of having a strong transactive memory system. In the teams with face-to-face communication, the stronger interpersonal connections developed enabled them to more quickly develop and effectively utilize their transactive memory system thus improving performance. Similar results were also found from a study of 18 real organizational groups where the concept of “who knows what”, was mediated by the strength of communication ties (Yuan, et al., 2008). As the transactive memory system improved, more expertise exchange occurred, implying that as a transactive memory grows its ability to grow increases also. The results of these studies imply that to improve the formation of transactive memory systems, organizations must emphasize the development of effective communication processes.

Outside of the classroom, transactive memory has a strong impact on performance in multi-team systems. In a field study of emergency respondents Healey et al. (2009) observed three multi-team systems during three different emergency response training exercises. The authors used the scale developed by Lewis (2003), as well as an adaptation to assess multi team system transactive memory, and other qualitative methods. Their findings suggested that both team and multi-team performance was contingent upon the development of transactive memory, within teams (intra-team transactive memory) and amongst the greater system (inter-team transactive memory). At both levels, the transactive memory development was contingent on the quality of communication. By using effective communication patterns, teams were able to develop an awareness of each other's expertise's and builds a strong trust in each other's capabilities. In another study, Liang & Jin (2010) assessed multi-team systems within a European automotive manufacturer. They found that in order for teams to form effective transactive memory systems at the intra- and inter- team levels, they must agree upon mechanisms to share and develop knowledge and share information effectively.

From an organization perspective, Hsu et al. (2012) explored the effects of coordination, communication and performance, on the development of transactive memory during a complex information systems development project. Based on surveys of Taiwanese professionals who were involved in Information Systems (IS) Development projects, they found consistent results with previous research, showing that teams with prior familiarity were most effective and had the strongest TMS. They also found that an effective way of overcoming lack of familiarity were effective team interventions prior to the beginning of the project. Interventions proposed in prior literature such as group training (e.g., Hollingshead, 1998b), as well as methods of job rotation, feedback sharing, and increased proximity can improve interactions and foster a transactive memory systems. They suggest that in addition to the formal activities, managers should regularly include informal activities to encourage interaction between teams. The importance of job rotation were also suggested by (Busch & von der Oelsnitz, 2011) who also proposed adding job clarification and job modeling, to help improve meta-knowledge, professional knowledge and interactions amongst teams. In a study of the role of transactive memory in the domain of Air Traffic Control teams (Smith-Jentsch, et al., 2009), teams who reported higher levels of familiarity based on stronger interpersonal ties, were more likely to request and/or ask for back up, resulting in an increase in these teams performance. When forming teams, familiarity between team members is necessary, to aid in faster transactive memory development, team efficiency and credibility and trust amongst team members. This issue of interaction facilitation becomes even stronger issue as you move to more distributed, less coupled teams. In an analysis of global project networks, Comu et al. (2011) looked at the difference between facilitated and non-facilitated networks. They found that using virtual facilitators, teams developed stronger interpersonal links, improved communication and task performance and ultimately lead to strong transactive memory systems within the networks. Their results suggest that the integration of effective facilitators can help enable transactive memory between large dispersed work groups.

Moreland et al. (2010) investigated the influence of technology on the formation and utilization of transactive memory within organizational work groups. The authors insist that even though technology can be a useful tool for strengthening transactive memory systems (*esp*ecially in large organizations), that workers often resist the technology--preferring to locate and share their knowledge using traditional interpersonal methods. Similarly, in an investigation of the role of Information Technology (IT) on teams in large firms in South Korea, Choi (2010) showed that IT had a positive impact on knowledge sharing and knowledge application, both result in a the formation of strong transactive memory systems. Simply sharing knowledge in traditional interpersonal methods may not be enough, and organizations should invest in the development and implementation of new forms of Information Technology. Transactive memory is possible for distributed organizational teams through the implementation better organizational policies and initiatives.

Technological Perspective

Transactive memory research has fallen within the cognitive and social/organizational perspectives. This is primarily a result of researchers often dismissing the idea of transactive memory formation and utilization in virtual teams (e.g., Hollingshead, 1998a; Lewis, 2004), and focusing on face-to-face collaborations. Even with this traditional perspective, several separate reviews and critiques of the literature, calls to action were made for researchers to begin to consider the effects of technology on transactive memory, and begin to understand how it can be designed to support collaborations (e.g., Lewis & Herndon, 2011; Ren & Argote, 2011; Weigel, Ezell, & Hazen, 2012),

While many are reluctant, some researchers propose that properly designed knowledge management systems and stores, that are context aware, can be a technological enabler of transactive memory systems (e.g., Ariff, et al., 2011; Engelmann, et al., 2009; Riedl, et al., 2012). The design of these tools could help inform collaborators about the knowledge and the resources that they have access to amongst their team. These tools could foster communication and coordination, facilitating shared understandings, and encouraging the exchange of unshared information. These solutions not only support distributed collaborations, but also support co-located individuals working together. Additionally much of this research still posits that even with technology, to effectively use transactive memory, there must be face-to-face communication and prior familiarity. This still leaves the question of purely virtual or distributed teams unanswered.

While new to the transactive memory literature, designing systems and interfaces to support distributed collaborations has been prevalent in the Computer Supported Collaborative Work (CSCW) and Human-Computer Interaction (HCI) communities since the early 1990s. The shared workspace (Dourish & Bellotti, 1992) is a design challenge which could further enable distributed collaborators working on fuzzy tasks. While a strong research community is established, the tasks they study are typically simple, informal collaborations (Gutwin, et al., 2008). While not directly related to transactive memory, the research from this area may be applicable as the focus of these systems is improving awareness of collaborators in the interaction. Unlike in face-to-face interactions, in distributed collaborations, the amount of awareness an individual can obtain is directly proportional to what the system provides. Because of this, much of the research attacks this purely as a design problem. Many of these systems are designed to selectively provide behavioral indicators so that collaborators in the interaction can maintain an awareness of each other's activities, locations and knowledge (Gutwin, et al., 2008). For a few examples of the popular interface solutions and techniques that many online collaboration systems use, see Table 5.

Table 5: Awareness Techniques for Online Collaboration Systems

Name	Description	Examples
Expressive Artifacts	Providing feedback information on an action to actors in a shared workspace, rather than just the individual who initiated the action.	Action Indicators (Tuddenham & Robinson, 2009) Process feedthrough (Hill & Gutwin, 2003) Shared annotations (Pinelle, Gutwin, & Greenberg, 2003) Sonification Notifications (McGookin & Brewster, 2007)
Shared Visibility	Components that allow users to ground their actions within the larger context of the shared workspace, as well as see what other actors are working on	Radar Views (J. Carroll, Rosson, Farooq, & Xiao, 2009) Telecarets (Biehl, Czerwinski, Smith, & Robertson, 2007) Telepointers (Wong & Gutwin, 2010) Display Trajectory (Fraser, McCarthy, Shaukat, & Smith, 2007) Shared Feedback (Boddy, Rezgui, Cooper, & Wetherill, 2010)
Embodiments	Visual representation of an actor within the shared workspace	Avatars (Gutwin, et al., 2008) Virtual Embodiments (Ducheneaut, Wen, Yee, & Wadley, 2009) Emotional Embodiments (Bartneck, 2003)
Selective Filtration	Selectively choosing which information a user produces or is exposed to within a shared workspace	Privacy Filter (Dörner, Pipek, & Won, 2007) Temporal Filter (Alarcón, Guerrero, & Pino, 2005) Ghost Operations (Ignat, Papadopoulou, Oster, & Norrie, 2008) Intelligent Filter (Lampe, Johnston, & Resnick, 2007)

Recently, some researchers have begun to apply these concepts to transactive memory formation and utilization in distributed collaborations. In (Adibhatla, et al., 2009) the authors proposed an artifact to enhance the formation of transactive memory systems for crisis management agencies and personnel. Based on prior research, the authors iteratively designed a system to assist in collaboration between multiple agencies using features such as annotations, chatting, different levels of sharing and integration of the common operational picture to help form transactive memory. Another similar prototype, this time focused on supporting object focused thinking and collaborative sense-making is EWall (Keel, 2007). The software explicitly allows users to contribute their findings and information and manage the flow of these between the other members of the team using a virtual transactive memory. The author defines a "virtual transactive memory" as one that does not reside in the minds of people, but is computationally created and maintained rather than in the heads of the users. The system has to recognize important information and leverage it without requiring the user to intervene. While interesting in their implementation and opening a much needed discussion in the literature, neither system was evaluated to determine their impact on distributed teams collaboration or transactive memory.

Another prototype to help support Transactive Memory focused mainly on initiating the processes in the formation of a transactive memory system for newly formed groups (Schreiber & Engelmann, 2010). In this study, the distributed teams solved a hidden-profile task within the domain of a criminal case. The system allowed the users to work on their own concept map of the problem, share their knowledge structures, and background knowledge that they each possessed from the hidden profile task. The design of the system assumed that knowledge and information awareness could initiate a transactive memory system. The interface used shared concept maps (shared workspaces) and a shared working window to implement these concepts. These allowed the people to work individually or collectively, and form an awareness of the information and knowledge possessed by the other participants. In this prototype, the shared concept maps represent each team member's internal memory structure of the task. By seeing how each member organizes and categorizes their information, other collaborators can understand their perspective on the situation and their relative skills. This confirmed that their design methodology could be useful in assisting in the initiation of a transactive memory system, and the tool was successful in establishing information and knowledge awareness amongst the teams. Their system supported the directory updating process via the visualization of team member’s knowledge structures, but no evidence for the other two processes critical to an effective TMS were found.

Unfortunately, this research perspective of the three is not only the newest, but also the least explored. Though other research areas such as shared workspaces and expertise recommender systems have some corollaries, the idea of integrating transactive memory as a technological entity has not yet appeared in the literature.

Summary of Contributions

In the previous sections, three major perspectives on transactive memory research were described; (1) the seminal cognitive perspective, (2) the social/organizational perspective and finally (3) the technological perspective.

The cognitive perspective is most responsible for driving theory and forming our overall understanding of the concept. The majority of this research has focused on understanding the various outcomes of effective transactive memory and transactive memory systems and better understanding how we form, maintain and utilize them from a cognition point of view. Much of the research in this perspective focuses on individuals within small teams. The main contributions of this perspective were not only the concept as a whole, but a better understanding of the specific components of transactive memory systems, and how we cognitively organize and store the information in our memory.

The second perspective focused more on the social and organizational outcomes of transactive memory systems in teams, multi-team systems and larger organizations. Unlike the cognitive perspective, this research focused on real world teams situated within larger social structures. This perspective helps understand the importance of effective coordination and communication amongst individuals to strengthen interpersonal ties and transactive memory systems.

Finally, the technological perspective, which has only recently began to gain traction, took the previous research in transactive memory and interpreted it as a design problem. While there has been very little evaluation in this field, this perspective serves as a first step in pushing others to redefine their understanding of how transactive memory is maintain and utilized in more complex interactions. Though there have been limited contributions in this field to date, the research started the discussion within the community on how to improve transactive memory through technology. A summary of the different perspectives and their major contributions to our understanding of transactive memory is provided in Table 6.

Table 6: Summary of Transactive Memory from Cognitive, Organizational and Technological Perspectives

Research Perspective	**Research Question(s)**	**Enablers to Transactive Memory**
Cognitive	• How are transactive memory systems, formed and encoded in both the individual and group mind • What are the performance outcomes of effective transactive memory systems?	Explicit knowledge structures, Communication during learning, Collaborative training, Collaborative practicing, Integrated vs Differentiated structures, Specialization
Social/Organizational	• How to design, train and assist teams to improve transactive memory systems? • What are the social and organizational effects of transactive memory systems	Face to face communication, Expertise exchange, Quality of communication, Team Interventions, Job rotating, Team member familiarity, potential for technology
Technological	• How to leverage technology to help teams quickly form and utilize transactive memory systems?	Shared workspace, knowledge management systems and stores, virtual transactive memory, shared concept maps

While all perspectives have helped push out understanding of transactive memory, evolve the theory, and apply it to real world contexts and problems, there has been little interactions across the domains. As the world continues to change and evolve, and cognition, organizations and technology continue to become more intertwined, we can no longer focus on uni-disciplinary questions or problems, and must begin bridge the gap between information technology and people.

An Interdisciplinary Perspective of Transactive Memory

One goal of interdisciplinary researchers is to bridge the gap between information technology and people (ITP). While transactive memory provides a perfect platform for this type of research, it is often the case that research silos itself, focusing on only the interaction of one or two aspects of ITP. When considered within the context of the Information, Technology, People, research paradigm, the majority of research discussed in the last two sections tends to focus on the I-P and I-T interactions. When visualized spatially (Figure 2) it is apparent that these research perspectives have created cross-disciplinary domains that are not accounting for the entire picture.

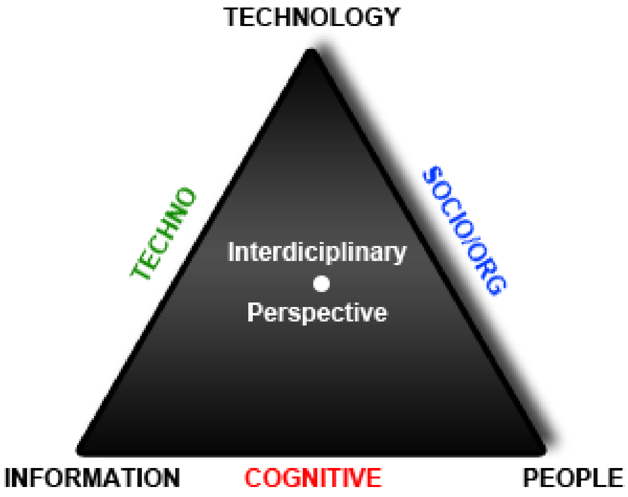

Figure 2: Perspectives of Transactive Memory on ITP Triangle

Using, the visualization above, it is the goal of interdisciplinary research to move as close to the center as possible. Fields such as Human-Computer Interaction (HCI), Human Factors (HF), Computer-Supported Cooperative Work (CSCW), have sought to bridge the gaps between the human, information and technology. While these fields have continued to grow and evolve, influencing research and technology, their knowledge and practices do not account for the changing role of transactive memory. By fusing prior research in transactive memory with the knowledge and experience of these fields, we can both further our understanding of not only transactive memory, but also distributed collaborations as a whole.

The previous section discussed three main perspectives, all of which continue to change drastically. One of the most obvious changes is the pervasiveness of information technology in our personal and professional lives. With the change in technology, how we as humans cognitively function has also evolved. Numerous researchers have shown that as technology continues to become more ubiquities, our cognitions have adapted (e.g., John & Dister, 2009; Sparrow, et al., 2011). Additionally, the organizational landscape has also begun to evolve and adapt to technology. In today‘s workspace, it is not uncommon for organizations to rely on workers made up of geographically dispersed members to run their everyday operations. With this paradigm shift in both our cognition and organizational culture, relying more heavily on information technology, transactive memory itself, has become a perfect interdisciplinary research problem, as it involves people working together to access information (in the form of other peoples knowledge), using technological solutions.

Interdisciplinary Research Directions

Based on an understanding of interdisciplinary research and an assessment of current discussions and interests within each community, this section describes several potential interdisciplinary research directions and their application to transactive memory. For each proposed research direction, I will discuss relevant literature within and outside of transactive memory, propose issues and present interesting research questions. This section does not claim to serve as an all-encompassing assessment of the future of interdisciplinary perspective on transactive memory. The goal of this section is to start a discussion on how we can take prior research and begin to “move to the middle” of the

ITP triangle and improve our understanding of transactive memory systems, and their formation, maintenance and utilization.

Research Direction 1: Online Collaboration Systems

Research must explore the effects of online collaboration and communication systems on transactive memory formation, maintenance and utilization. These results may further inform the interface and interaction design of future tools.

A barrier that plagues this research direction is the assumption that transactive memory formation and utilization requires some level of face-to-face interaction. Without face-to-face interaction, teams may resort to generalizing and stereotyping of the expertise’s on the team, which can lead to confusion and lack of coordination (Walther, 2002). Distributed teams carry other difficulties that aren’t as prevalent in co-located teams, such as, frequent turn-over in membership (Zhang & Jin, 2010), rapidly changing environmental conditions (Majchrzak, Malhotra, Stamps, & Lipnack, 2004), higher levels of conflict (Hinds & Bailey, 2003; Hinds & Mortensen, 2005), and no prior familiarly or experience with members (Majchrzak, et al., 2004; Malhotra & Majchrzak, 2004). While generally agreed upon, some research has shown that it is not necessarily the case. Moreland & Myaskovsky (2000) showed that by providing collaborators with evaluations of each other’s skills, they were able to quickly form and maintain a transactive memory system during a novel task. This study found that the groups who were trained individually, and provided with evaluations of their team members skills, performed equally as good as teams who were collaboratively trained. The study showed that transactive memory formation does not necessarily require face-to-face interaction. While this has been acknowledged, in their study of student project teams, Jackson & Moreland (2009) showed that even if a team had a effective transactive memory system face-to-face interactions were required to utilize it. Currently, research has begun to approach this idea of supporting distributed teams transactive memory. There have been attempts at designing systems to support transactive memory (e.g., Adibhatla, et al., 2009; Keel, 2007; Schreiber & Engelmann, 2010), but it is unclear the resulting effects of the technology and the implications on theory.

Within the context of transactive memory, Online Collaboration Systems should be of particular interest as they continue to become more common in our everyday social and professional lives. Popular technologies such as Google Hangouts, Google docs, Adobe Connect, Microsoft Office Online, Instant Messaging and Skype, enable everyday users to collaborate on documents, spreadsheets, and presentations in a distributed context. It is common for organizations to have their own proprietary collaboration tools. Enabling these distributed collaborations is currently considered mainly a problem of awareness, specifically maintaining an awareness of each other's activities, locations and knowledge (Gutwin, et al., 2008).

This research area has numerous potential implications on not only the design and implementation of technology, but also on current transactive memory theory. Research out of HCI and CSCW has long had interest in designing systems to support distributed collaborations. Properly designed online collaboration systems can improve distributed collaborations. Even with this agreement, numerous questions remain as much of the research focuses on improving broad collaborative concepts, and there is no indication of why they are or are not effective. Since many of the technologies utilized in online collaboration systems focuses on providing awareness (Gutwin & Greenberg, 2002; Tam & Greenberg, 2006) to the end-users, it is reasonable to assume that they can be designed to help improve the interpersonal awareness necessary for transactive memory. Using this research area, researchers could develop technological cognitive offloading devices that would support distributed workers forming, maintaining and utilizing transactive memory systems by situating awareness on the knowledge, actions and specialties of others. This research can serve as a starting point in the design future tools to help enable transactive memory formation, maintenance, and utilization and collaboration between distributed teams.

It is important that we reapproach our traditional understanding of transactive memory theory. Traditional theory states that specialization is the most important aspect of an effective transactive memory system (DeChurch & Mesmer-Magnus, 2010;

Littlepage, et al., 2008; N. Michinov & Michinov, 2009), but in online collaborations it has been shown that trust is a major contributor to team success (Coppola, Hiltz, & Rotter, 2004). This may imply that credibility may have more of an impact than in face-to-face interactions. Additionally, many of these online collaboration systems are not limited to synchronous collaborations, which may require research to assess not only formation, maintenance and utilization, but also understand transactive memory updating.

Research Direction 2: The Social Web

Research must address how the integration of social web technologies such as social networking, media and the "wisdom of the crowd" into our everyday and professional lives has changed how we collectively store information about others knowledge.

Transactive memory was initially conceived was a way of interpreting the "group mind" (Wegner, 1987), and existed between two to five people working in a close collaboration towards a common goal (e.g., Hollingshead, 1998a, 1998b; Wegner, 1987; Wegner, et al., 1985). Recently it been extended to compensate for larger entities such as companies (e.g., Brandon & Hollingshead, 2004; Moreland, et al., 2010), government agencies (Hamid & Salim, 2010) and multi-team systems (e.g., Healey, et al., 2009). Moving forward, the social web allows us to push the theory further, and consider the "crowd mind." Sparrow et al. (2011) suggested that as web 2.0 technologies become more ubiquitous humans will have lower rates of recall on specific information, but higher rates of recall of sources of information. This implies that knowing where to locate knowledge may be just as valuable as possessing the knowledge. While this proposition has major implications on transactive memory research, new social web technologies raise and even more complex and interesting question for exploration.

The social web is on its way to surpassing, and replacing the internet collaboration technologies, from Research Direction 1, as the most pervasive piece of information technology in our lives. These tools enable people to connect to each other on a social level from across the world, and support our ability to leverage the expertise of individuals they have never met (Bernoff & Li, 2008). While the traditional idea of the social web focuses on interpersonal social connections, such as Facebook, other sites such as Linked-In, have applied the concept to connecting people together based on their skills, education, background and professional affiliations. More recently, the focus of Web 2.0 has changed to emphasize utilizing the crowd to provide information, innovation, and perform tasks that are left better to humans. A seminal example, referred to as crowdsourcing (Howe, 2006), is reCaptcha (Von Ahn, Maurer, McMillen, Abraham, & Blum, 2008), is when millions of humans are tasked at performing Optical Character Recognition (OCR) text recognition for old documents. A more applicable example of these are Collective Intelligence stores, such as twitter, Wikipedia, redit, etc., where a large, loosely organized groups of people are providing, generating and editing knowledge (Malone, Laubacher, & Dellarocas, 2009). Within these collective intelligence stores, the social web acts as a vehicle that connects people together based on specific knowledge that they possess, and used to inform others, or innovate upon previous knowledge.

Social web systems act as a transactive memory in the cloud, each with their own specific specialty, source, knowledge stock and perceived accuracy (Austin, 2003). Rather than the traditional perspective of transactive memory existing in our head (Wegner, 1987), we may be able to redefine it as an entity that exists in cyberspace which people can spontaneously access and manipulate. The transactive memory in the cloud would not have the same limitations that we have, it can hold seemingly infinite amount of information, there is lesser chance of losing information, and once stored there is a lower chance of incorrect recall.

One particular direction is to focus on developing technologies to effectively mine, organize, and visualize information, to best enable the use of the transactive memory in the cloud and improve individual and team performance. Future research should focus on how individuals can spontaneously access information that is either stored on the web as an external representation of somebody’s knowledge (e.g. reading a Wikipedia article), access an individual’s knowledge (e.g., asking somebody a question on a web forum), or harness the crowds knowledge to make a decision (e.g., yelp reviews). From a theoretical perspective, this may draw questions to the typical T-E-P units that are theorized to be the building blocks of our transactive memory (Brandon & Hollingshead, 2004). In the case of the social web, it is not necessary that somebody has a full T-E-P unit encoded, in this case, they may only need T-E, and then consult the crowd to ever provide the necessary information, or point them to a person that can help. This may imply, that not only is it important to know *where* to find an expert information as proposed by Sparrow (2011), but also, where to *generate* expert information.

Research Direction 3: Interdisciplinary Domains

Research should continue to use a contextual lens when considering transactive memory, and explore its formation, maintenance and utilization in new, complex and dynamic interdisciplinary domains. These results should inform contextual transactive memory theory of each given domain.

As discussed in the previous section, there has always been a strong interest in applying transactive memory research to new and interesting domains (e.g., X. Chen & Dietrich, 2009; S. Hsu, et al., 2012; Jackson & Moreland, 2009). The results of this research are typically practical advice for improving transactive memory systems and how teams should be comprised (X. Chen & Dietrich, 2009; Smith-Jentsch, et al., 2009; van Ginkel, et al., 2010), trained (S. Hsu, et al., 2012), and how they should interact (Busch & von der Oelsnitz, 2011; Comu, et al., 2011) in order to maximize performance within that context. While many of these studies offer a richer context than the initial lab experiments that spawned transactive memory research, new domains are starting to grow which are exponentially more complex and dynamic than even these. These domains offer a perfect research opportunity, as they include a never-ending interaction between information, technology, and people, at multiple levels of the organization.

As information technology has become an integral part of our everyday work and professional lives, new, complex and dynamic domains for research have begun to immerge within interdisciplinary research. Two recent domains, which are a focus within the interdisciplinary community, is technology in the home, and medical informatics.

Technology in the home assesses the impact of technology and family dynamics and traditional roles (e.g.,Bell, Blythe, Gaver, Sengers, & Wright, 2003; Grimes & Brush, 2008). In medical informatics, the field is studied with a technological lens to understand its impact on social roles, policy, and interactions (e.g., Decheneaux, McNeil, Mouloua, & Alicia, 2011; Hazlehurst, et al., 2007; Jaspers, 2009; Kirk, 2010). Other applications include emergency management/response (e.g., McNeese, Connors, et al., 2005; Terrell, McNeese, & Jefferson, 2004), military operations (e.g., Fleming, et al., 2009; Wellens, 1993), and command & control (e.g., Carley & Ren, 2001; French & Hutchinson, 2002; Hellar & Hall, 2009; N. Stanton, 2007; N. A. Stanton, Salmon, Walker, & Jenkins, 2009). More recently, the cyber domain, is slowly coming to interest in the interdisciplinary research community (e.g., Haack, Fink, Maiden, McKinnon, & Fulp, 2009; Hall, McNeese, Hellar, Panulla, & Shumaker, 2009; Hui, et al., 2010; Mancuso, Minotra, Giacobe, McNeese, & Tyworth, 2012; Tyworth, et al., 2012). Within each of these domains, the application of an interdisciplinary perspective informs not only individual interactions, but also the design of technology and larger organizational issues. The commonality between all these communities, which sets them apart from much of the previous research in transactive memory, is they rely on a strong interplay between humans working in teams and multi-team systems, interacting with technology with large amounts of data. These interplays make these domains perfect for not only transactive memory research, but also interdisciplinary research as a whole.

While researching transactive memory within these interdisciplinary domains has obvious theoretical, organizational and technological implications, the more interesting challenge that comes to the forefront, are the practical and methodological challenges that impede the research. The first concern is how to gain access and properly study each of these domains. With a strong interplay between numerous factors, comes several confounds which cannot be controlled for, making data difficult to gather and even harder to interpret. Additionally, many of these domains, *esp*ecially when they are distributed, are riddled with invisible work (Bardram & Hansen, 2010; Star & Strauss, 1999). One such methodology for handling such domains is the utilization of the Living Lab Framework (McNeese, Connors, et al., 2005; McNeese, Perusich, & Rentsch, 2000).

Using the living lab, research can integrate qualitative fieldwork with in lab experimentation using simulations and scaled worlds, to not only drive our understanding of the domain, but also to design useful technologies and drive theory. While there have been attempts at implementing scaled worlds to study transactive memory (e.g., Adibhatla, et al., 2009), the concept needs to be further operationalized and its components need to be extracted into measurable interactions within the systems.

Another implicit need to study these interdisciplinary domains is the evaluation of old and development of new measurement tools and techniques. In many of the early studies, transactive memory was a simple derivative of performance. For example, in the group recall task, transactive memory was extracted from the number of unique items recalled (Wegner, et al., 1991), while in the group vs. individual training experiments, transactive memory was measured via behavioral measures such as assembly time, total number of mistakes as well as observational measures (Hollingshead, 1998b; Moreland & Myaskovsky, 2000). As a response to these very task specific measures, Lewis (2003) developed a tool that used a 15-question survey based off of the three dimensions of transactive memory (Moreland, 1999), to better enable studying transactive memory in the field or more complex, fuzzy in-lab experiments. Similarly, in their study of open source software teams, Chen & Dietrich (2009), adapted a popular knowledge sharing scale (Faraj & Sproull, 2000), to focus on knowledge location, differentiation and credibility. Other methodologies of measurement include triangulation of observer ratings with self ratings to measure transactive memory structure (Austin, 2003), observational ratings on information providers, seekers and anticipating needs (Sarcevic, Marsic, Lesk, & Burd, 2008), and knowledge coding (Brauner, 2006). While numerous studies utilize these scales, the question of whether they transfer to complex domains, *esp*ecially when distributed collaborations are involved. Additionally, the observational scales may become more difficult, as the interactions and collaborations in these fields are often invisible (Bardram & Hansen, 2010; Tyworth, et al., 2012), so new methodologies will need to be formed, possibly through using knowledge elicitation methods for qualitative work, or developing explicit mechanisms in scaled world simulations. Once these methodological questions are answered we can move forward with developing an understanding on how transactive memory is formed, utilized and maintained in these interdisciplinary domains, and how it differs from our traditional understanding of the theory.

Research Direction 4: Integration with Theory

Research must examine the interrelations, and correlations between transactive memory and other cognitive, social and organizational theories that have shown to improve collaboration and performance. These results can better inform future theory development within and outside transactive memory.

From some the seminal research discussed above, we have known that transactive memory was a distinct concept from general group dynamics (Moreland & Myaskovsky, 2000). While other research has continued to push the concept, discussing the components of transactive memory (Austin, 2003; Moreland, 1999), types of transactive memory structures (Wegner, 1987), and the memory units that make up effective TM (Brandon & Hollingshead, 2004), we still have little information regarding what factors enable the formation, maintenance and utilization of these systems. Since its inception, research out of individual, and team cognition has continued to develop and understanding of, and methodologies for studying, different related concepts, but rarely have they been tied back to transactive memory, other than anecdotally. Additionally, even when approached, research has yet to begin to draw correlations and connections between theories to understand how they inform each other, and how their results can drive future theory development or modification.

Transactive memory has been tied to related concepts such as situation awareness (Richter & Lechner, 2009), team mental models (Austin, 2003; Ellis, 2006), common ground (Oshri, van Fenema, & Kotlarsky, 2008) and collaborative recall/social contagion (Barnier, Sutton, Harris, & Wilson, 2008). Additionally, other research has associated transactive memory to looser concepts such as trust (Ashleigh & Prichard, 2010), creativity (Duanxu & Huijuan, 2011), task difficulty, (Baumann & Bonner, 2011), stress (Ellis, 2006) and affect (E. Michinov, Olivier-Chiron, Rusch, & Chiron, 2008). Other theories, which may be relevant, but have yet to be tied to transactive memory theory include activity awareness (J. M. Carroll, Neale, Isenhour, Rosson, & McCrickard, 2003), boundary objects (Star & Griesemer, 1989), distributed cognition (Hutchins & Lintern, 1995) and situated action (Suchman, 1987), as a few examples. By beginning to explore the interrelations and correlations between these established theories, research can not only begin to drive our understanding of transactive memory in general, but also inform better methodological design and measurements.

Of the theories, frameworks and concepts discussed above, the one that may be the most immediately applicable is the idea of situation awareness (Endsley, 1995). In his seminal paper, Wegner (1987) described transactive memory as an interpersonal awareness of the knowledge possessed by others. Additionally, in two of the dimensions of transactive memory, specialization and accuracy, awareness is discussed as playing a key role in their formation (Austin, 2003). This may imply that a specialized situation awareness mechanism drives the formation of transactive memory, in which awareness focuses on the actions and knowledge of others, rather than the environment. During interactions, the awareness of others would be implicit transactions of knowledge and behavior, which can then be fused with explicit communication, to build and maintain transactive memory systems. Situation awareness also becomes an excellent starting point for this research due to its applicability to multiple domains (e.g., Bardram, Hansen, & Soegaard, 2006; Blandford & Wong, 2004; Salmon, Stanton, Walker, & Green, 2006), competing theoretical perspectives (Bedny & Meister, 1999; Endsley, 1995; Smith & Hancock, 1995), and rich measurement techniques (Salmon, et al., 2006). Similar to situation awareness, team mental models also have a rich history (Mohammed, Ferzandi, & Hamilton, 2010), in multiple complex domains and contexts (e.g., Cannon-Bowers, Salas, & Converse, 1990; Cannon-Bowers, et al., 2001; Rouse, Cannon-Bowers, & Salas, 1992) and include numerous measurement techniques (e.g., Langan-Fox, Code, & Langfield-Smith, 2000; Mohammed & Dumville, 2001) that could be useful in furthering our understanding of transactive memory. Unlike situation awareness, team mental models may not be as useful as understanding the formation, but rather the content and structure. Measurement tools that enable studying task-work and team-work team mental models, may further inform the structure and content of T-E-P units (Brandon & Hollingshead, 2004), which could be used to drive theory and design. While only a few theories were discussed here, numerous others exist within inter- and uni-disciplinary fields, which may enable us to further our understanding of transactive memory formation, maintenance and utilization.

Research Direction 5: Ubiquitous Computing

Research should form an understanding how mobile, ubiquitous technologies will impact how transactive memory is formed, maintained and utilized. These results should inform the design of these systems so they can further enable not only distributed, but face-to-face collaborations.

In much of the research discussed above, many of the assumed interactions, whether they are face-to-face or distributed were synchronous collaborations. Even in Moreland & Myaskovsky (2000), where they were trained and unaware of their teammates, their ultimate collaboration occurred in real-time. In all of the technological research presented above, collaborators were interacting with each other in real-time via some sort of shared workspace (e.g., Adibhatla, et al., 2009; Keel, 2007; Schreiber & Engelmann, 2010). Though, it must be assumed that in many of the organizational studies, the teams or groups were not working together at the same time, as is often the case with open source software teams (X. Chen & Dietrich, 2009), the temporality of their collaboration was not discussed in relation to transactive memory. While this concept was briefly touched upon in the discussion of transactive memory updating in relation to the social web, ubiquitous computing technologies make this issue even more important.

Transactive memory, when first conceived, the notion of a constant connection to your workplace, team, and collaborators meant never leaving work. With ubiquitous technologies such as smart phones and wearable computers, support for information gathering, knowledge transfer and social interactions can be supported anywhere at any time (Gay, 2009). Though transactive memory has not been explicitly explored in regards to ubiquity, a similar concept of social capital has been investigated within the context of mobile computing (e.g., Ali-Hassan, Nevo, & Nevo, 2010; Campbell & Kwak, 2010; S. Yang, Kurnia, & Smith, 2011). Similar to transactive memory, social capital researchers identify the area as equal parts social, organizational and technological.

Though the most prevalent concept in current research, mobile computing is only the tip of the iceberg for ubiquitous computing. Wearable computers that are context and content aware are becoming available in the commercial market. The goal of these systems is to require minimal user interaction, while being able to provide relative information about the users location, emotions, and needs in real-time (Davies, Siewiorek, & Sukthankar, 2008).

In Research Direction 2, it was implied, based on an article by Sparrow (2011), that knowing how to access or find knowledge, may be just as valuable as possessing the knowledge. While this is a perfectly valid discussion for transactive memory research today and most likely for the next several years, as ubiquitous computing becomes more context aware, there may no longer be a necessity to encode transactive information. If a computer can identify what your information needs are, and point you to the appropriate person or location for help, the computer will offload transactive memory from the human. This idea of offloading would be similar to the skill sheets discussed in (Moreland & Myaskovsky, 2000), but aware of your needs, and ever updating to represent the current status of the individual. While this now may seem like a purely technical problem of how do you gather, store and represent data in a usable form, the cognitive and social/organizational effects of the technology in relation to transactive memory are of equal importance. With the cognitive load of gathering and storing specific information about other people offloaded from the user, the question of what other interpersonal information will they store, and how will that enable collaboration and improve performance becomes important. Additionally this presents an interesting methodological perspective of how we can start to research these concepts now. Finally, this would beg the question of whether this would even transcend transactive memory, and become a new socio-cognitive theory in itself.

Research Direction 6: Human-Robot Interaction

Research should examine the role of transactive memory systems in the collaborative processes of human-robot and human-agent teams and re-examine the definition of "the group mind'

As discussed previously, the traditional perspective of transactive memory exists- in some fashion- between a small group (Hollingshead, 1998a; Wegner, et al., 1991; Wegner, et al., 1985), and we expanded on this idea by presenting the idea of a transactive memory in the cloud. Another technological phenomenon that we must begin to address is the inclusion of robots, or intelligent agents, in our everyday life. If you consider this new research domain, of Human-Robot/Agent Interaction, the question of how to approach transactive memory theory becomes apparent. In their 1987 article, Wellens & McNeese (1987) were two of the first researchers to propose an interdisciplinary connection between social psychology and intelligent machines. This research served as a call to the community to understand not only the design of agents themselves, but also the impact they have on and interplay with human cognition, emotion and behavior. Since then, research has begun to explore the idea of shared cognition between humans and robots, looking at shared mental models (Fan & Yen, 2011), collaborative learning (Magnisalis, Demetriadis, & Karakostas, 2011) and even anecdotally discussing the idea of transactive memory systems (Liu & Hinds, 2009). While contributions towards the development of intelligent technology and algorithms this research does not address the cognitive and social implications of these interactions.

Compared to the other research areas discussed in this section, this remains the most unexplored. While there is little research in this area, the idea of intelligent machines interacting with humans has been a question in academia since the 1950s. In his paper *Computing Machinery and Intelligence* Alan Turing (1950) proposed the question "Are there imaginable digital computers which would do well in the imitation game?" This question itself gave birth to the now famous *Turing Test*, and eventually became an essential concept within the field of Artificial Intelligence. What many people do not realize is that they interact with artificial intelligence agents every day, when they use search engines such as Google, or intelligent recommendation systems like provided on Amazon. These types of interactions, or “background agent” interactions, are becoming more and more common in our everyday lives. Additionally, agents are slowly moving to the foreground with the inclusion on interface agents, automation systems, intelligent tutors, and eventually humanoid robots. The integration of intelligent robots and agents into the workplace and our everyday lives offer numerous advantages, such as quickly storing, accessing, and manipulating large amounts of data (e.g., Cao, Gorodetsky, & Mitkas, 2009), dynamic decision making (Fan, et al., 2010), completing routine tasks (Jameson, 2009), and reducing human errors (Charissis & Papanastasiou, 2010). With these advantages come many questions that must be answered, specifically about the social, organization, and cultural effects of human-robot interaction (Fiore, et al., 2011; Wellens & McNeese, 1987).

This emerging research area raises three intertwined theoretical discussions, specifically transactive memory for human to robot interactions, robot to human interactions, and robot-to-robot interactions. From a broad perspective, each of these discussions will require research to push the bounds of what is capable of participating in the group mind. Robot to robot interactions creates is a purely technical question that may not be as interesting to interdisciplinary researchers. The other discussion points though raise interesting questions about how we encode this information to access robots knowledge, and the interactive process that robots or agents use to access our knowledge. How do humans store T-E-P units (Brandon & Hollingshead, 2004) in relation to interactive agents or robots, and likewise from the other perspective, how do your technologically store T-E-P units within an intelligent system. How does the traditional concept of the makeup of a transactive memory system hold true when interacting with a robot or agent, in terms of coordination, creditability and specialization (Moreland, 1999). Trust in human-robot interaction is already accepted to be a major factor in enable their collaboration (Fiore, et al., 2011; Hancock, et al., 2011; Wellens & McNeese, 1987; Wellens & McNeese, 1999), and since specialization is assumed, the importance of credibility is magnified. Research may focus on how robots or agents can be explicitly designed (from a visual, industrial and technical perspective), to foster trust for the purposes of transactive memory system. Similar to the discussion at the end of Research Direction 5, research may want to focus on using experimental methods such as wizard-of-oz (e.g., Rosenthal, Veloso, & Dey, 2012; Saulnier, Sharlin, & Greenberg, 2010), scenario based design (e.g., Parlitz, Baum, Reiser, & Hägele, 2007) and knowledge elicitation. These would allow researchers to understand the emotional, social, and cognitive outcomes of human-robot/interaction in terms of transactive memory formation, maintenance, and utilization without necessarily having a fully intelligent system.

Conclusion

Transactive memory is just as important in enabling team collaboration today as it was when Wegner first conceived it in 1985. In this chapter, I have presented a comprehensive literature review of previous work in transactive memory and several proposed directions for future interdisciplinary research. From the literature review three main perspectives on transactive memory were identified, the cognitive, social/organizational and finally the technological. The cognitive perspective focuses on how we construct transactive memory systems in our heads and their performance outcomes. The social/organizational perspective focuses on how to best support transactive memory within organizations and large social structures, as well as the social and organizational aspects of the systems. Finally, the technological perspective is working towards developing systems that can best enable transactive memory in distributed interactions. While each research area in itself has been valuable in furthering our understanding of not only transactive memory, but also socio-collaborative interactions, researcher must begin to push the boundaries set up by their individual disciplines. To change our fundamentals understanding of transactive memory it must be approached from a realistic context that takes into account multiple perspectives.

To achieve this, I have proposed that rather focusing research efforts within single discipline, it must begin to move towards an interdisciplinary approach that takes into account information, technology and people. Based on what the research in transactive memory and the current ecology of interdisciplinary research six interesting research directions that are not only interesting, but also necessary are identified. Future interdisciplinary research in these directions and transactive memory as a whole must not only focus on the development of technology, but also aim to understand the social, organizational and cognitive effects of its integration in our lives, and use this as a basis for evolving our understanding and perspective of transactive memory formation, maintenance and utilization. While many of the cornerstones of the theory will still hold true today, it is important that we account for the ever-changing technological, social and organization landscapes that are fundamentally changing how humans think, behave and interact with one another. The set of research directions presented and discussed in this chapter are nowhere near exhaustive, but serve as a catalyst to encourage a discussion about how transactive memory has changed from our fundamental understanding.

Chapter 3

team*NETS*: A Human-in-the-Loop Simulation to Study Transactive Memory in Distributed Cyber Teams

Since the propositions discussed in the previous chapter present a large problem space, which cannot be addressed by a single study. This dissertation focuses on three of the research directions: (1) understanding the impact of transactive memory on team cognition (Research Direction 4), (2) designing online collaboration tools to support transactive memory (Research Direction 1), and (3) the role of transactive memory in a highly complex and dynamic environment (Research Direction 3).

While this interplay between technology, theory and the environment creates a desirable and interesting environment for researchers, gaining access and gathering rich data can be very difficult. In order to address this challenge, researchers must rely on new methodologies that allow them to not only gain firsthand accounts, but also simulate the environments in laboratories. One such method, referred to as the living lab approach (McNeese, et al., 2000) allows researchers to blend qualitative fieldwork within lab simulations to drive the development of theory and technology for these types of environments. While the fieldwork involved in the living lab is integral to its success, it is just as important that researchers have realistic, flexible, and useful simulations so they can hone in on the various aspects of the task. This chapter presents a scaled world simulation designed to address the three Research Directions discussed above. Based on an understanding of the environment, theory and previous research in simulations, the *teamNETS* simulation supports research on interdisciplinary issues in not only transactive memory, but also team cognition and collaboration.

Simulations in Research

A good simulation can be an invaluable resource for not only academic research but also organizational training. From a researcher's point of view, a simulation can be valuable in better understanding how humans behave, interact and make decisions in a controlled setting. From an organizational point of view, a simulation is a tool to better support training initiatives that prepare employees to work in these environments. In order to best support these goals, it is important that simulations be designed based on an understanding of the environment, the training or research objectives. One particular type of simulations, scaled worlds, are effective utilities in academic, organization and military settings.

Scaled world simulations are simulated task environments which allow researchers to preserve certain aspects of the original context, while controlling for others (Ehret, Gray, & Kirschenbaum, 2000; Gray, 2002). The goal of scaled worlds is to reduce the complexities and confounds of an actual environment for research while maintaining other aspects related to the research or training goals. Scaled worlds play an important role in research regarding the role of technology and humans situated within Command, Control, Communication, Computers and Intelligence (C^4I) environments. Because of the unpredictability and inaccessibility of these environments, simulation research has allowed researchers and practitioners to understand the requirements of user-interfaces as well as the roles humans play within these environments.

Research into C^4I systems and simulations applies to numerous contexts-- such as military, homeland defense and emergency response. However, little research has focused on adopting these methods to the cyber domain (e.g., Chase, 2009; Malik, Mahboob, Khan, & Zubairi, 2011). In today's geo-political landscape, Cyber-attacks coupled with traditional warfare methods can result in high impact outcomes. A 2011 statistic published in the Huffington Post, Douglas Birch[1] reported that midway through 2011, cyber-attacks were already up over 100% from 2010. Additionally, Homeland Security Department warns that cyber security issues are not just a matter of protecting

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[1] http://www.huffingtonpost.com/2011/09/30/cyberattacks-rise-2011_n_988573.html

computers and information, as our utilities and infrastructures are also vulnerable. Hence, it is important to understand this environment to enable human-centered support within it.

The following section presents a modification to the *NETS* architecture (Mancuso, et al., 2012) aimed at studying transactive memory systems within the context of distributed cyber teams. The design incorporates multiple domains of cyber security within a team-based human-in-the-loop scaled world simulation. This simulation will aid researchers and practitioners in understanding critical elements of the decision-making processes and interpersonal interactions that occur within a cyber-security environment. In the following section, an overview of previous research in scaled world simulations are presented, as well as a brief assessment of the cyber domain and transactive memory research to extract requirements used to inform the design of team*NETS*.

NeoCITIES Experimental Task Simulator

History

The *NeoCITIES Experimental Task Simulator* (*NETS*) is the newest iteration of the *NeoCITIES* simulation, which is as a test bed for research at The Pennsylvania State University, College of Information Sciences and Technology MINDS Group (Hamilton, et al., 2010; Hellar & McNeese, 2010; McNeese, Bains, et al., 2005). The original *NeoCITIES* simulations were developed based on an ethnographic study and knowledge elicitation of emergency 911 dispatchers (Terrell, et al., 2004). Using the data and knowledge gained from these studies, the first iteration, *NeoCITIES* 1.0 was designed. In addition to furthering the understanding of team decision making in the context of emergency response, *NeoCITIES* 1.0 served as a platform to study intelligent group interfaces, information overload, and team communications. Based on the experiences with the first iteration, *NeoCITIES 2.0* was developed with a focus on geo-collaborative and their impact on team collaboration (Balakrishnan, Pfaff, McNeese, & Adibhatla, 2009).

The newest iteration of *NeoCITIES* (3.0) was built using Web 2.0 technologies and was designed as a more flexible research tool than the previous versions (Hellar & Hall, 2009). The initial research using *NeoCITIES 3.0* was focused on how Information Overload affects team performance and how interface artifacts can mitigate its effects (Hellar & McNeese, 2010). This version of *NeoCITIES* was later modified (to *NeoCITIES* 3.1*)* to study the effects of storytelling and reflexivity on situation awareness and team mental models (Hamilton, et al., 2010; Mancuso, Parr, et al., 2011). Of all the previous versions, *NeoCITIES* 3.1 was the most widely used, with over 500 participants in its 3-year timeframe.

While there have been several iterations of *NeoCITIES* throughout the years, it has for the most part remained the same. In *NeoCITIES*, teams consist of three players, representing Fire, Police and HazMat dispatch officers. Each player has a set of unique resources with different abilities, and are responsible for identifying events, and allocating appropriate resources to solve the events (McNeese, Bains, et al., 2005). While this platform has served as an excellent test-bed for numerous research projects, its overall simplicity limits our abilities to use it to answer questions about more complex collaborations and environments.

Table 7 presents an overview of all four versions of the NeoCITIES simulations, a description of each simulation, their main research foci, and relevant references.

Table 7: Description of previous NeoCITIES versions

Version	Description	Research Focus	References
1.0	First version of NeoCITIES. Informed by original CITIES Simulation and ethnographic study of emergency management officials	Intelligent Group Interfaces Fuzzy Cognitive Maps Stress and Mood	(Jones, McNeese, Connors, Jefferson, & Hall, 2004; McNeese, Bains, et al., 2005; McNeese, et al., 2006)
2.0	Updated version of 1.0 that was redesigned using newer technologies and with a greater emphasis on Geographic Information Systems	Geo-Collaboration	(Balakrishnan, et al., 2009)
3.0	Brand new version designed with Web 2.0 technologies. Simplified simulation to only three roles and removed geographic displays	Information Overload Situation Awareness	(Hellar & McNeese, 2010)
3.1	Updated version of 3.0 with greater emphasis on mechanisms to study information sharing, team mental models and situation awareness	Situation Awareness Information Sharing Team Mental Models Storytelling	(Hamilton, et al., 2010; Mancuso, Hamilton, et al., 2011; Mancuso, Parr, et al., 2011)

Overview of NETS

Similar to the development of the original *NeoCITIES,* the *NETS* platform[2] was designed based on interviews and observations of cyber security experts (Tyworth, et al., 2012). The overall architecture of *NETS* is built upon the same general principles of *NeoCITIES,* resource allocation and situation assessment, but has been expanded to better support more complex decision making and richer scenario definitions. Similar to the most current version of *NeoCITIES,* the *NETS* platform is a standard client – server web application deployed as an Apache Tomcat web server developed using three technologies: Sun JAVA, Adobe BlazeDS and Adobe Flex 4.5. This system architecture, as seen in Figure 3, allows NETS simulations to be easily and rapidly deployed.

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[2] The NETS platform was developed as a part of a collaboration of researchers in the MINDS Group at The Pennsylvania state University with the support of U.S. Army Research Office (ARO) MURI Grant "Computer Aided Human Centric Cyber Situation Awareness" W911-NF-09-1-0525.

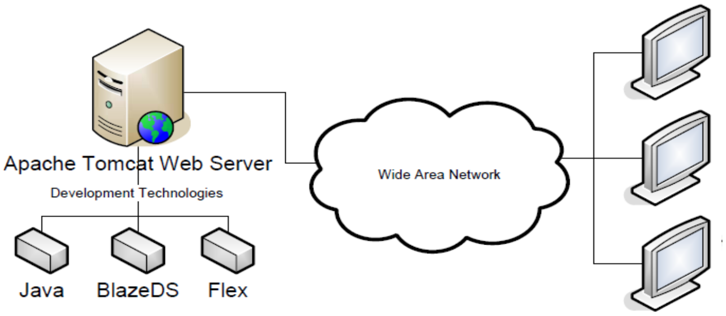


Figure 3: *NETS* System Architecture Diagram

In order for the users and researchers to interact with the system, two Flex front ends are required: the client user interface, and the administrator's server console. The client user interface allows the game player to interact with the scaled world which is maintained by the server. The administrator's console provides the controls for the researcher to manipulate the server settings, monitor player's actions, and save data for statistical interpretation.

Within the *NETS* platform, there are two primary components, the scaled world definition, and the simulation engine.

Simulation Structure

Based on field work and understanding of both simulation research and the cyber environment, a new structure to better represent the complexities and nature of the context was developed. To best support this environment, the system would have to be flexible enough that it applies to the numerous domains of cyber security while being concrete enough to support rapid deployment in multiple research programs. The current working architecture is rich enough to provide a deep decision making task for experimentation, but also general enough, that it can be applied to multiple domains.

The four main components of the Scaled-World Definition for an *NETS* simulation are resources, events, locations and information. Each of these concepts are described in more detail below:

- Resources – Answers that are applied to an event. These could take the form of a specific person (i.e. Send IT Help Desk Technician to manually restart computer), or a categorization of a problem (i.e. Categorize problem on server 192.168.1.27 as Denial of Service attack). Unlike previous versions, the *NETS* platform allows researchers to attach additional meta-data to each resource to require more in depth problem solving by the user
- Events – Problems that occur within the scaled environment. Users have to use other information in the environment to identify and events in order to solve them.
- Locations – A physical entity that exists somewhere in the scaled environment. This could be a workstation, server, firewall, etc. All events that occur in a simulation occur at a location.
- Information – Hard and soft data that may or may not inform the users about events that are currently happening at a location. Like in a real cyber environment, where problems are not visible, the information provided by the simulation is the users only window into potentially harmful events that are occurring in the simulated environment

Each of these elements are loaded into the simulation engine at runtime by the researcher using two XML files, one representing the environment (including Locations and Resources), and one representing the scenario (including Events and Information). Other information which is loaded using the XML files is the dispatch time of information and events, answers to events, and the overall time length of the scenario.

NETS Simulation Engine

The second component of the *NETS* platform is the Simulation Engine. The simulation engine is primarily responsible for interpreting the scaled world-definitions into a simulated environment, running the simulation, and responding to user interaction. Within the system, a Java application interprets the scaled-world definitions, and runs the

Game Engine to maintain the state of the scaled-world. The BlazeDS middleware is responsible for handling user interactions that affect the scaled world.

The backbone of the simulation engine is the Human Performance Scoring model (HPSM; Wellens & Ergener, 1988). The HPSM is responsible for interpreting user interactions into measurable actions against events that are occurring in the simulated world based on the accuracy and reaction time of the actions. The initial implementation of the HPSM, scores are calculated by comparing the current severity of an event versus the number of resources applied. Unlike its initial incarnation, the *NETS* platform allows the player to attach additional metadata to each resource. Depending on the accuracy of the resource, and the metadata attached, a set number of resources will be applied to the event. For example, in the first simulation build off the *NETS* platform, *idsNETS*, resources took the form of broad categorizations of the type of intrusion. In addition to the categorization, the user prioritized the event based on its severity. Depending on the accuracy of the prioritization, the user would then receive positive or negative points towards solving the event.

Studying Cyber Teams in NETS – The Development of teamNETS

The first simulation built upon the *NETS* platform, *idsNETS*, was developed to study situation awareness of individual intrusion detection analysts. While this simulation provided a useful starting point, in order to understand the nature of cyber security decision making situated within a larger team or organization, there were numerous changes made. Before development began, there was a careful investigation of the cyber environment and transactive memory (see Chapter 2**)**, and simulation requirements were extracted.

The Cyber Environment

When developing the initial *NETS* platform, there was careful consideration to maintain contextual and ecological validity with the cyber environment. We considered numerous complexities and interdependencies of the cyber environment during the initial development of the *NETS* platform. For example, in the cyber world there is an absence of more ecological and contextual anchors which are an integral part of our decision making process in the physical world (McNeese, 2004). In the physical world, an analyst can use these anchors to be certain in the fact that an event has actually happened, whereas cyber threats are only visible through an interpretation of data within the cognitive mind of an individual or team. This disconnect is further confounded as the cyber world is rarely tied to physical anchors, and the only connection an analyst has with the environment is through a computer's interpretation of the environment. Other complexities that need to be considered for adaptation to the cyber environment are the massive amounts of data that analysts are responsible for (Fink, North, Endert, & Rose, 2009), burdensomely long sequences of activities (Eilertson, Ertoz, Kumar, & Long, 2004), and a ever-changing dynamic environment (S. J. Yang, Holsopple, & Sudit, 2006).

While the general nature of the environment created numerous requirements for the larger platform, during the development of *teamNETS*, there was consideration of the teams within the cyber environment. Many of the issues discussed above have an inherent impact on team collaboration. Since there is no physical world in which events, data, and communications are happening, there is more of a possibility for mental model divergence. It is possible that different cyber analysts have different perceptions of the cyber world, thus impeding their ability to form a common understanding and collaboration. Adding to the possibility for mental model divergence is a natural distribution of work across multiple functional domains in cyber security. In Tyworth et al. (2012), the authors conducted 23 semi-structured interviews of cyber-security professionals across multiple organizations, as well as an ethnographic observation of a military cyber-defense exercise. One of their main findings was that within Cyber Security professionals, the "big picture," or complete cyber situation awareness is distributed across multiple individuals operating in different functional domains. From their observations, they identified at least four distinct functional domains, tactical/intrusion detection, operational/system administration, threat landscape analysis, and management/policy. Their findings suggested that the amount of overlap in domains is a function of how much their goals overlap. This meant that it was common that operators operating within one functional domain focused on their own goals that they are unaware of the complete picture and what information analysts operating in another domain required. This lack of common ground caused analysts to file reports that were lacking necessary mission-salient and contextual information, causing wasted and overlapping effort to occur on a regular basis.

Simulation Requirements

Based on an assessment of team collaboration in the cyber domain, previous research in designing simulations for cyber security (Mancuso, et al., 2012; Reifers, 2010), and the review of transactive memory literature presented in Chapter 2, a set of 4 broad simulation requirements were extracted.

From the research conducted by Tyworth et al. (2012), we know that roles must be carefully created to represent each of the distinct functional domains in cyber security. While each of these roles may be working towards the same general goal, it is important that the system can support the different sub goals, methods and datasets across different roles. In many of the functional domains described, one of the biggest issues is lack of a common language developed by significantly different jobs. For example, in intrusion/threat analysis, the majority of the data they work with are intrusion detection, while people in system administrators may monitor computer process logs, and reports from humans. Finally, while there is a greater, often invisible, collaboration occurring in cyber security teams, the majority of the work is at the individual level. Collaboration within the cyber domain is more a product of transferring reports between the functional domains, with little intertwined collaboration.

From the transactive memory perspective, there are several requirements that are required. First, in order to assess a depth of knowledge, resources must be developed with the higher, lower-order knowledge paradigm in mind (Wegner, 1987). This would mean, rather than a resource representing a complete answer, as was the case in the original *NeoCITIES* simulations, resources should have multiple levels of lower order knowledge associated with them to solve events. This will allow players to develop a depth of knowledge in a specific area. Finally, to design a better transactive memory assessment tool, there must be some way of explicitly sharing information that is representative of transactive memory utilization. This will avoid any problems of invisible work, and allow researchers to better assess a team's transactive memory utilization.

For an overview of the extracted simulation, requirements see Table 8.

Table 8: Simulation Requirements for *teamNETS*

Requirement	**Description**
Multiple functional domains	Roles must be developed to represent the different functional domains of cyber security. Each with different goals, methods, and types of data they work with.
Loosely Coupled Collaboration	Rather than a tight collaboration with teammates, roles should be tasked with primarily individual work that is situated within a larger team task.
Higher/Lower Order Knowledge	Resources must be developed to represent higher order knowledge, each with multiple pieces of lower order knowledge associated with them so certain roles can develop specialization of depth in one area.
Explicit Information Sharing	The system must have explicit methods for sharing information across the distributed boundaries. This will minimize invisible work, and allow quicker and easier post-task assessment of transactive memory utilization.

These were then extracted and converted to functional aspects of the simulation and/or experimental structures. The following section will present an overview of the *teamNETS* simulation, and demonstrate the implementation of these requirements.

The teamNETS Simulation

Functional Domains in teamNETS

To best represent a division of labor within *teamNETS*, the functional domains had to be interpreted into distinct areas within the simulation Since the primary source of participants for the simulation is going to be undergraduate students, many of whom were enrolled in general education courses, the four domains discussed in the previous section were translated into more simplified terms. Additionally, since the main purpose of this system would be for reactive cyber security and be situated in a decision making task, threat landscape analysis was excluded from the final design.

The three remaining functional domains, tactical/intrusion detection, operational/system administration, and management/policy, for the purposes of this simulation are interpreted as, Intrusion Detection, Malicious Software, and Improper usage. Table 9 describes each of these functional domains, their interpretations within *teamNETS* and a brief description.

Table 9: Functional Domains from Tyworth, et al. (2012) within teamNETS

Functional Domain	teamNETS Interpretation	Description
Intrusion/Threat Analysis	Intrusion	Assessing and mitigating issues where an unauthorized human from an outside computer connects to a machine within the network for inappropriate or malicious purposes
Operational/System Administration	Malicious Software	Assessing and mitigating issues where software running on a computer is causing damage, stealing information, or other unacceptable behaviors.
Management/Policy	Improper Usage	Assessing and mitigating issues where humans inside the network violate policy by exhibiting inappropriate, malicious or unacceptable behaviors.

Solving Events in teamNETS

To support the transactive memory research questions, rather than having simple resources, users are tasked to fill out and submit action reports in order to solve events within the simulated network environment. Each Action Report consists of one piece of higher order information, and three pieces of low-order information.

The higher order information takes the form of three higher order or main, categories, which correspond to the three functional domains of cyber security described in the previous section. Beneath each main category, there are three pieces of lower order information, or meta-data, a user can attach to an action report, Sub-category, Priority level, and Mitigation Code.

The subcategories represent a more specific assessment of the problem from the higher order main category. For malicious software, the user can classify the event as the result of a Virus, Worm, or Phishing attempt. For intrusions, the user can classify the issue is the result of a Script Runner, Vandal, or Black-Hat Hacker. Finally, for Improper Usage, the user can classify the violation as inadvertent, an active policy violation or malicious behavior. Depending on the details provided in the incident report, the user can figure out the subcategory for the report. For an overview of subcategories for the different higher-order categories in teamNETS see Table 10.

Table 10: Subcategory Definitions by Higher Order Category

Higher Order Category	**Subcategory**	**Code**	**Description**
Malicious Software	Virus	MS-SC-VRS	Malicious software which a user inadvertently installs or downloads onto the system
	Worm	MS-SC-WRM	Malicious software which tunnels onto a system without a user downloading or installing
	Phisher	MS-SC-PHI	Malicious software which is storing or stealing personal information
Intrusion	Script-Runner	IN-SC-SRN	Amateur hacker who uses premade tools and doing it only for credit
	Vandal	IN-SC-VND	Hacker with the sole purpose of spreading a message or damaging an image
	Black Hat Hacker	IN-SC-BHH	Hacker with the purpose of making money
Improper Usage	Inadvertent	IU-SC-INV	Improper usage that was probably an accident
	Active Policy Violation	IU-SC-APV	When a user knowingly and intentionally violates a policy
	Malicious Behavior	IU-SC-MAL	When improper usage results in major damage or theft

Across all of the higher order categories, there are three levels of prioritization -- low, medium and high. However, their definitions differ between higher order categories. For malicious software, the priority is associated with the total damage on the infected machine. For intrusions, the priority is associated with the frequency of the attacks. Finally for improper usage, the priority is associated to the amount of harm is being caused to the network. Depending on the details provided in the incident report, the user should be able to identify and select the priority for the report. For an overview of the prioritizations for each higher order category, see Table 11.

Table 11: Prioritization Definitions by Higher Order Category

Higher Order Category	Priority	Description
Malicious Software	Low	Malicious software is present but not causing any harm
	Medium	Malicious software has infected at least one software application and causing some harm
	High	Malicious software has infected multiple important pieces of software and causing substantial harm
Intrusion	Low	Intrusion only happened once or twice, result of recreational hacking
	Medium	Intrusion occurred more frequently, no malicious behavior, but some suspicious activity
	High	Intrusion occurring several times at consistent rate. Purpose of intrusion to cause harm or damage to system or network
Improper Usage	Low	Improper usage that does not cause any harm to network and does not affect university
	Medium	Improper usage that violate university policy, but is not a cause for concern.
	High	Improper usage that violates numerous university policies and causes harm to network or university

Finally, similarly to priorities, there are three mitigation levels, I, II, and III, for each higher order category. For malicious software, the mitigation level corresponds to whether or not the organization knows about the software and if they know how to fix it. For intrusions, the mitigation level corresponds to whether or not the organization knows about the intrusion method and if they know how to stop it. For improper usage, the mitigation level refers to whether or not the user has had violations in the past. To assign mitigation levels for each higher order category, the user must consult the process log for malicious software, IDS log for intrusions and the User ID for improper usage. These are included in the Incident Report. For an overview of the mitigation levels for each higher order category, see Table 12.

Table 12: Mitigation Levels by Higher Order Category

Category	**Data Used**	**Mitigation**	**Description**
Malicious Software	Process Log	MS-MIT-1	Malicious software is known by the organization and there are organizational guidelines in place for successful removal.
		MS-MIT-2	Malicious Software is known by the organization but there is currently no consistent method for successful removal
		MS-MIT-3	Software which has not been identified by the organization and no known method of removal exists.
Intrusion	IDS Log	IN-MIT-1	Amateur hacker who uses premade tools and doing it only for credit
		IN-MIT-2	Hacker with the sole purpose of spreading a message or damaging an image
		IN-MIT-3	Hacker with the purpose of making money
Improper Usage	User ID	IU-MIT-1	User has no previous improper usage violation
		IU-MIT-2	User has one or more improper usage violation in the past year, none of which are major
		IU-MIT-3	User has had one or more major improper usage violation, or is on the organization watch list based on other information obtained about the individual

For a player to receive the highest score in the game, they have to correctly identify an events higher order category and attach three correct pieces of lower order meta-data to the report (subcategory, priority and mitigation). If the user leaves a piece of meta-data blank, they receive no penalty. If they assign an incorrect piece, they will receive a penalty to their final score for that event. For a complete overview of the attributes of all the higher-order categories and the lower-order meta-data see Appendix B.

TeamNETS Interface

The final aspect of the teamNETS simulation is the simulation user interface. Based on previous research of the design of simulation user interfaces (Mancuso, Hamilton, et al., 2011) and an assessment of freely available cyber security tools, a simple user interface was designed (Figure 4).

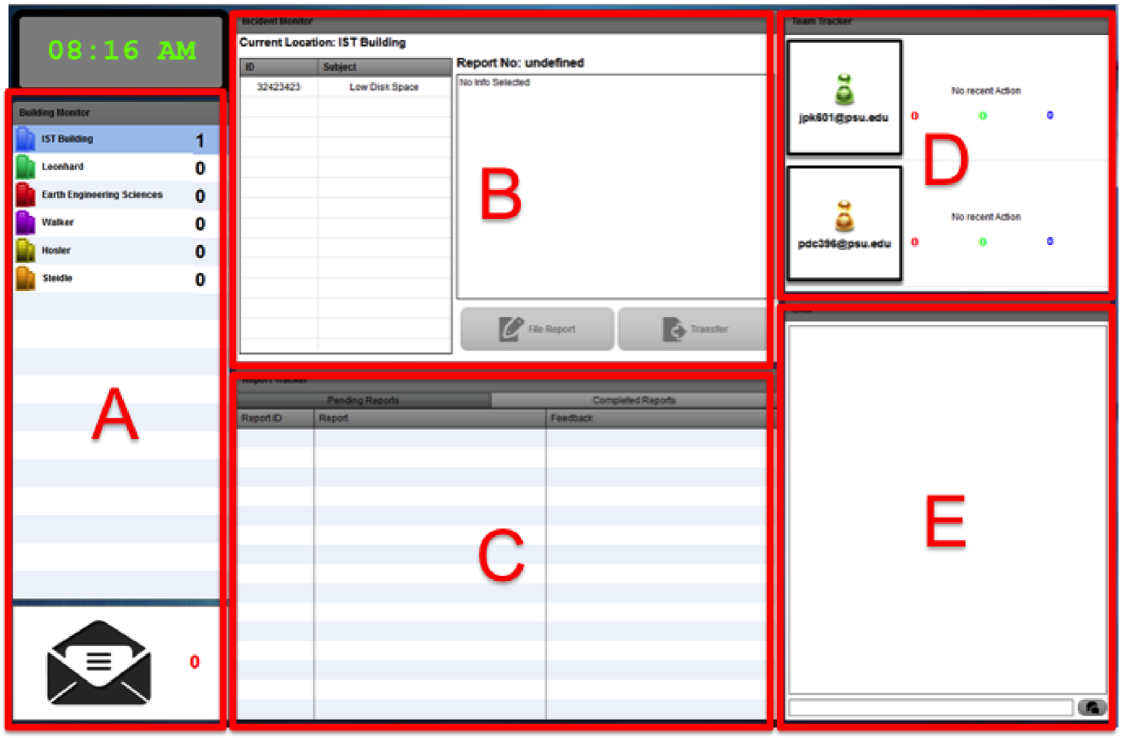
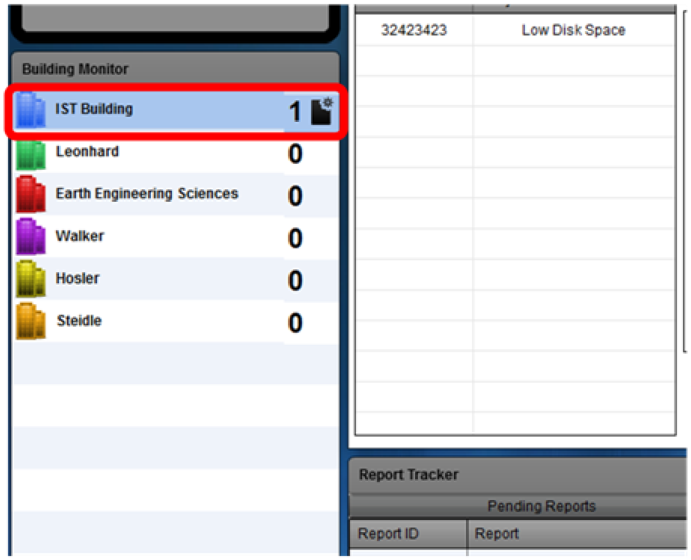

Current Location: IST Building
Report No: undefined

Figure 4: teamNETS Simulation User Interface

The simulation user interface is an integral part of the system because it is the main component that the participants will interact with, and is their only window into the state of the scaled world. The main teamNETS interface is made up of 5 components, the Location Tracker (A), Incident Report Monitor (B), Action Report Monitor (C), Team Monitor (D) and Chat (E). In addition to these components, there are pop-up windows to allow users to transfer information and file action reports. This interface allows users to monitor different locations on the simulated network, investigate or transfer emerging events, file action reports, and monitor individual and team progress in the simulation.

The Location Tracker (A) is a list of the buildings that the analyst is responsible to monitor. For each building, there is a unique icon, an indication of how many active events are occurring at this location, and an icon signaling whether or not there is an unread report. As shown in Figure 5, the “IST Building” has 1 active event occurring at that location, and since there is an icon to the right of it, the current user has yet to read that report.



Building Monitor

IST Building	1
Leonhard	0
Earth Engineering Sciences	0
Walker	0
Hosler	0
Steidle	0

32423423	Low Disk Space

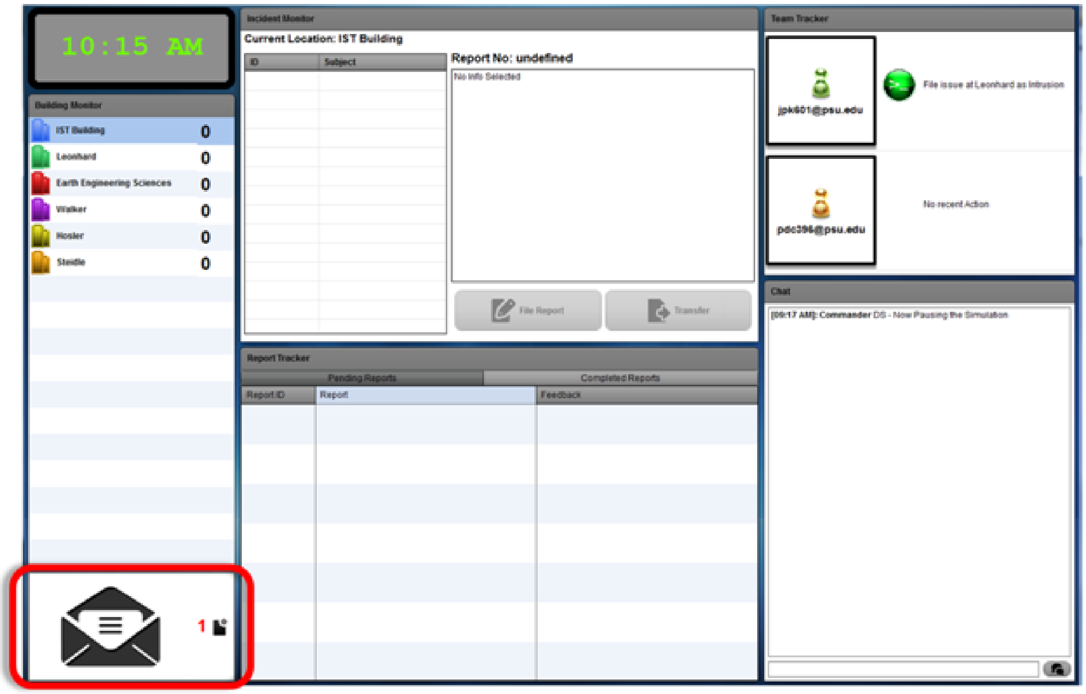
Report Tracker

Pending Reports

Report ID	Report

Figure 5: Location Tracker (A) with unread report

Additionally, below the location tracker is the active user’s Inbox, which acts the same as the location tracker, but contains events that another user transferred (Figure 6).



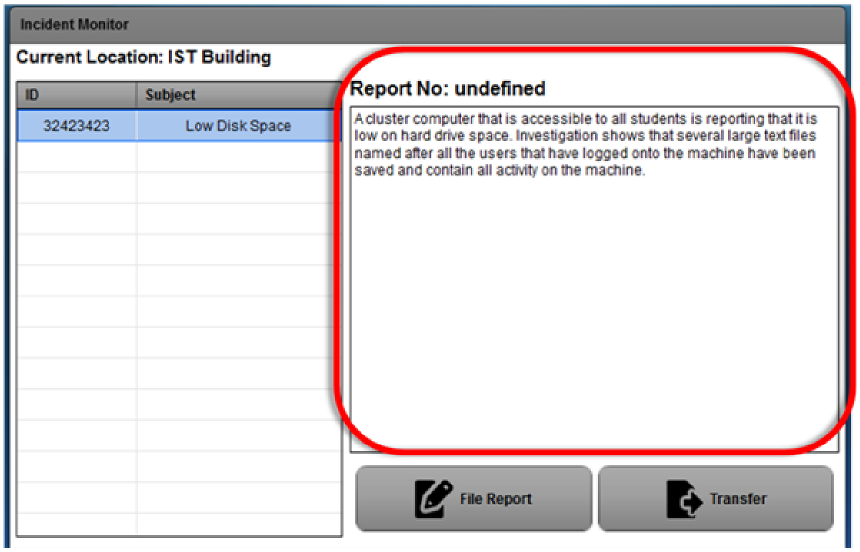
IST Building	0
Leonhard	0
Earth Engineering Sciences	0
Walker	0
Hosler	0
Steidle	0

File issue at Leonhard as Intrusion

[09:17 AM]: Commander DS - Now Pausing the Simulation

Figure 6: Inbox Located Below Location Tracker (A)

Whenever the user selects a location in the building monitor or the inbox, the Incident Report Monitor (B) updates to show a list of the active events that are occurring at the selected location. When the user clicks an incident in the list on the left side, they can view detailed information about the event in the Report Window (Figure 7).

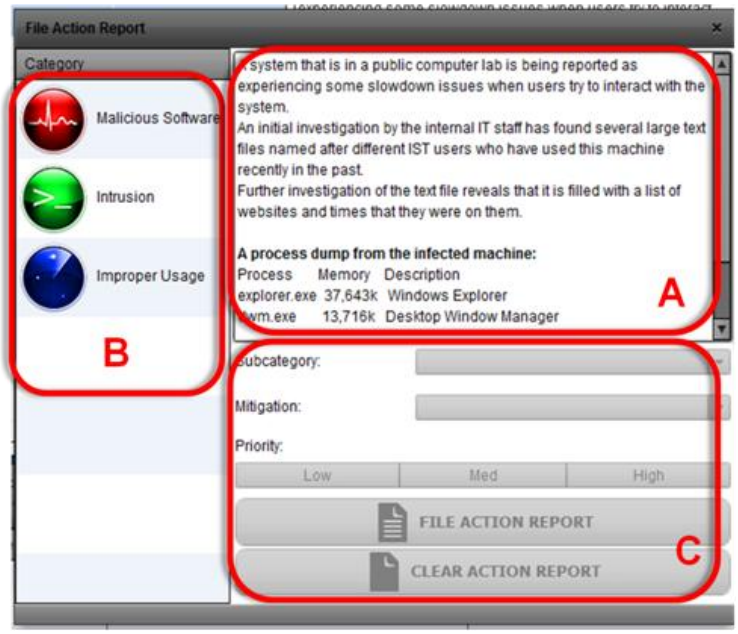


ID	Subject
32423423	Low Disk Space

A cluster computer that is accessible to all students is reporting that it is low on hard drive space. Investigation shows that several large text files named after all the users that have logged onto the machine have been saved and contain all activity on the machine.

Figure 7: Incident Report Monitor (B)

After reading an event, the user has two options, they can choose to file a report to fix the event, or transfer it to another user. If the user wishes to solve the event, they can click file report and then use the action report window (Figure 8).



A system that is in a public computer lab is being reported as experiencing some slowdown issues when users try to interact with the system.
An initial investigation by the internal IT staff has found several large text files named after different IST users who have used this machine recently in the past.
Further investigation of the text file reveals that it is filled with a list of websites and times that they were on them.

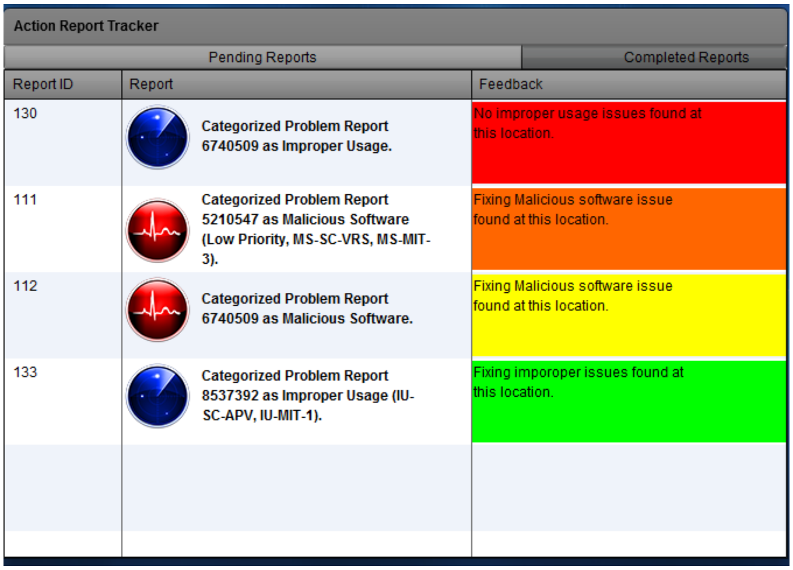
A process dump from the infected machine:

```
Process      Memory   Description
explorer.exe 37,643k  Windows Explorer
dwm.exe      13,716k  Desktop Window Manager
```

Figure 8: File Action Report Window

In the File Action Report window, users are able to review the report once again(A), select a main category (B) and fill in relevant and meta-data such as subcategory, mitigation strategy and priority (C). Depending on which main category the user selects, they will receive different options in subcategory and mitigation. The system will allow users to submit Action reports without any meta-data attached, but they will receive a lower score on that particular event then if they assigned the correct subcategory, mitigation strategy and priority.

After the user files a report, they can monitor its progress in the Action Report Tracker. If the user assigns the incorrect higher order category, they are informed their report was incorrect and the event is returned to the assigned location (or inbox). If they get the correct higher order category, the feedback informs them that the problem is being fixed, and is provided with feedback assessing the accuracy of their attached meta-data in the form of text, and color indicator (Figure 9).

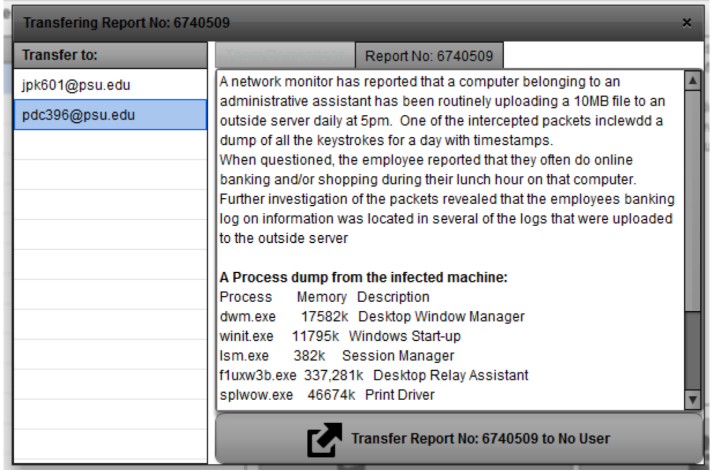


Report ID	Report	Feedback
130	Categorized Problem Report 6740509 as Improper Usage.	No improper usage issues found at this location.
111	Categorized Problem Report 5210547 as Malicious Software (Low Priority, MS-SC-VRS, MS-MIT-3).	Fixing Malicious software issue found at this location.
112	Categorized Problem Report 6740509 as Malicious Software.	Fixing Malicious software issue found at this location.
133	Categorized Problem Report 8537392 as Improper Usage (IU-SC-APV, IU-MIT-1).	Fixing imporoper issues found at this location.

Figure 9: Action Report Tracker (C) with feedback (Green = Best, Red = Worse)

When the user assigns the incorrect higher order category, they receive a red color grade, informing them that there were no issues of that type at the location. If the user gets the correct higher order category, and correctly assigns all three pieces of meta-data, they receive positive feedback and a green color grade. If the user does not get all of the meta-data correct (but still gets the higher order category correct), they will receive positive feedback, and a color grade somewhere between dark orange and yellow.

On the other hand, if the user does not know how to solve the event, they can click the transfer button, to open the Transfer Report window (Figure 10), where they can send the incident report to another user.



A network monitor has reported that a computer belonging to an administrative assistant has been routinely uploading a 10MB file to an outside server daily at 5pm. One of the intercepted packets inclewdd a dump of all the keystrokes for a day with timestamps.
When questioned, the employee reported that they often do online banking and/or shopping during their lunch hour on that computer.
Further investigation of the packets revealed that the employees banking log on information was located in several of the logs that were uploaded to the outside server

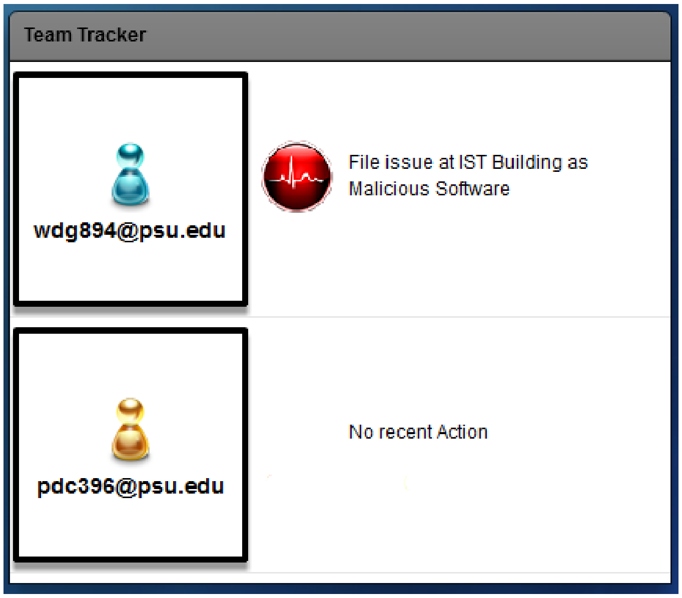
A Process dump from the infected machine:

```
Process      Memory   Description
dwm.exe       17582k  Desktop Window Manager
winit.exe    11795k  Windows Start-up
lsm.exe       382k    Session Manager
f1uxw3b.exe  337,281k  Desktop Relay Assistant
splwow.exe    46674k  Print Driver
```

Figure 10: Transfer Report Window

Using the transfer report window, the user can review the report and select a user to transfer to. Once the user clicks the Transfer Report button, the receiving user will receive the action report in their Inbox. The transferring of a report serves as an explicit mechanism of transactive memory utilization

The final interface component that supports team collaboration is the Team Monitor. Using the team monitor, players are able to see the avatars of their teammates, as well as the most recent report that they filed (Figure 11).



File issue at IST Building as Malicious Software

No recent Action

Figure 11: Team Tracker

The team tracker serves as a window into the behaviors and actions of the others in the environment, and allows team members to coordinate their actions. Additionally the team monitor can serve as a component for experimental manipulation.

Running Experiments with teamNETS

While the majority of the design choices made during the development of *teamNETS* focused on enabling the study of transactive memory in distributed cyber teams, its flexibility and rich data collection mechanisms provide numerous opportunities for research. The following sections describe metrics that can be collected within the simulation, as well as potential manipulations for different research questions.

In-Simulation Metrics

Within the *teamNETS* simulation, collected metrics allow researchers to study both individual and team cognition. Currently, there are nine separate sources of data that are generated, representing both individual and team behavior. At the conclusion of a scenario, the researcher is able to save an output file that is comprised of nine different data types, each with numerous imbedded metrics.

Using this data, researchers can implement metrics to study transactive memory, decision making, situation awareness as well as team collaboration and processes --to name a few. For transactive memory, the information history serves as an explicit measure of transactive memory utilization within the simulation. In order to successfully transfer an event to another player, one must be able to form a full T-E-P unit (Brandon & Hollingshead, 2004) by recognizing the event (T), what specialty is needed to complete that event (E) and who possesses that specialty (P). For team collaboration and processes, both quantitative and qualitative data is captured. The quantitative data collected from the chat histories (team and individual) as well as the information transfer provide insight into the explicit collaborations that occur during a scenario. For more insight, researchers can use the chat transcript to understand team processes, leadership, and other emerging collaborative tendencies that may occur. Finally, *teamNETS* has built-in mechanisms for studying both behavioral and actual situation awareness. The performance metrics generated by the team and individual score, as well as the action and event histories, which provide behavioral measures of situation assessment through the HPSM, reaction time, and accuracy metrics. Additionally, the question history can be used to collect data using freeze-probe metrics such as SAGAT (Endsley, Aircraft, & Hawthorne, 1988).

For a complete overview of all the data collected within *teamNETS*, see Table 13

Table 13: Data Collected by *teamNETS* Simulation

Data Source	**Measurements:**	**Description**
Team Score	Normal Score, Raw score, Events Solved %, Info Transferred	Overall team performance across all events, including the raw and normal scores, percentage of events completed, and how many information transfers
Individual Score	Normal Score, Raw score, Events Solved %, Info Transferred	Same as team score, calculated at the individual level
Action History	Accuracy, Reaction Time	Logs every user interaction with the scaled world, registering which event they are working on, the accuracy of their report, and their response time in responding to the event
Information History	Reaction Time, Accuracy	Logs every time a user transfers information to another user, the reaction time, and whether or not the receiving user was capable of solving the event
Event History	Status, Responding vs Assigned user, Normal Score, Raw Score	Final status of every event in the scenario including the normal and raw scores, whether the event completed or failed, and which user responded to it
Question History	Response, Accuracy, Reaction time	Response of questions in freeze probe survey, whether the answer was correct or not, and their reaction time in answering the question
Chat Transcript	Chat	Full transcript of chat during scenario
Team Chat	Utterances, Words, Characters	Quantitative information about the chat behaviors of entire team
Individual Chat	Utterances, Words, Characters	Same as team chat but calculated for at the individual level

In addition to the metrics, each data source includes meta-data about the session, including the team id, which researcher is running the study, the session time, division, current scenario and experimental condition. This makes the transition between data collection and analysis much easier.

Potential Manipulations

Similar to its predecessors, *teamNETS* is a lightweight tool to allow researchers to add manipulations to approach multiple research questions. Because of its flexibility, researchers can easily manipulate several different independent variables within and outside of the simulation.

Within the simulation, researchers can manipulate the environment, scenario and interface to study numerous research questions. By modifying the environment, researchers can address questions about the use of geographic and perceptual anchors by manipulating the names and types of locations in the location tracker, the division of labor by modifying the roles within the simulation, and expand the number of functional domains covered. By changing the scenario, the most obvious manipulation would be task load, but also could look at human/collaborative information fusion, different data types, and fuzzy decision-making. Finally, by manipulating the interface, researchers can evaluate the effects, usability and utility of cognitive aids in improving individual and team performance, as well as the overall collaboration, the effects of different modalities of communication, and the utility of workspace awareness mechanisms.

Outside of the simulation, *teamNETS* offers even more potential for answering rich research questions. In addition to adding cognitive aids within the simulation, more complex systems can be coupled with the data outside of the system to study the varying effects and designs of complex data visualizations (i.e., Reifers, 2010), decision aids, fusion systems. Another area for manipulations is the task and higher/lower knowledge trainings. For the task training, researchers can study the cognitive effects and utilities of varying training methods, explicit vs. no leadership roles, varying communication training, or training interventions (i.e., Mancuso, Parr, et al., 2011). Additionally, higher and lower order knowledge can be distributed in different ways across the team to study different transactive memory structures.

For an overview of independent variables and manipulations, that can be investigated using the *teamNETS* simulation see Table 14.

Table 14: Potential Independent Variables and Manipulations within *teamNETS*

Type	**Independent Variable**	**Manipulations**
Within Simulation	Environment	Geographic/perceptual anchors, division of labor, role definitions, functional domains
	Scenario	Task load, division of events, data types, fuzzy vs concrete decision making
	Interface	Cognitive and collaborative aids, communication type, workspace awareness mechanisms
Outside Simulation	External System	Information Visualizations, decision aids, fusion systems
	Task Training	Training style, leadership roles, communication training, training interventions
	Knowledge Training	Transactive memory structures, knowledge differentiation

This is not an exhaustive list of the potential manipulations and independent variables possible in *teamNETS*, but serves as a set of examples to show its flexibility in approaching multiple research questions.

In addition to manipulations, researchers can add numerous surveys and metrics at the beginning and end of the simulation to study individual differences, team compositions, and various theories out of psychology, human-computer interaction, computer supported cooperative work, and social informatics, to name a few.

Pilot Testing

In order to ensure that the *teamNETS* platform could be used effectively in human subject experiments and to assess transactive memory in distributed cyber teams, two rounds of pilot testing were conducted. The first round of pilot testing, referred to as the 'paper pilot,' focused on improving the utility of the higher and lower order training materials and making sure the event descriptions were solvable and aligned properly with the pre-determined answers. The second round of pilots focused on assessing the training materials, user interface, scenario pacing and task-load, and survey instruments.

Pilot 1

After development of the simulation and training materials, over 100 different events using the higher order and lower order paradigms described in the previous section were constructed. To develop the events, relevant cyber-security news stories, and research papers were consulted. After all events were written and assigned higher and lower order answers, they were checked for consistency, spelling, and grammar.

Following the completion of the events, the first round of pilot testing evaluated the content of the events, and the utility of the training in helping solve them. For this study, four members of the research team, who were familiar with simulation research (but not the specifics of the *teamNETS* simulation), and cyber security were recruited. Each participant received 12 handouts, three that described each higher order category and 9 slides for each of the lower order meta-data. Events were printed on slips of paper and divided equally amongst the research team. Each participant used the handouts to assign a higher order category, and all three lower order meta-data pieces (subcategory, priority and mitigation). Additionally, participants underlined portions of the event that were confusing, or poorly written.

During the task, participant's observations helped approximate how long it took to solve an event, which events took the longest, and how often they consulted various pieces of the training. Following completion, each event was entered into a spreadsheet and responses were classified based on their correctness. From the 114 events, there were 39 events which were answered correctly (meaning correct higher-order category and all three pieces of lower order meta-data). The remaining 75 events had at least one problem. The results showed that the mitigation was the easiest, with over 80% of the responses being correct, while the prioritization was the most difficult with only 57% of the responses being correct. Across the three functional areas, both Intrusions and Improper usage had a similar success rate (~28%) while Malicious Software was significantly easier (44.7% success rate). For a full break down of the results of the paper pilot, see Appendix E.

Following the analysis, the researcher went through all the events, and assessed whether the incorrect responses were a result of the event description, the training material, or errors made by the respondent. For further clarification of some of the answers, members of the research team were consulted to better understand their responses. From this, over 80 changes were made to the events, which included changing answers to be more representative of the events, wording clarifications, adding new material to aid in decision making for lower order meta data, and removed confusing wording. Additionally, the training material was modified to represent these changes, and avoid confusion across higher and lower order handouts. Finally, measures were taken to ensure that the task load across roles was equal.

Pilot 2

Following the paper pilot, four separate *teamNETS* scenarios were developed--two intended for training and two intended for performance. Based on the results from the previous pilot, events were organized based on their difficulty, and paced according to the observed response times. Once the scenario XML files were constructed and tested, a second pilot assessed the events and training materials, determine adequate pacing for the events, assess the interface and prepare for the full study.

For the second pilot 50 undergraduate students (73.5% Male) from a general education class were recruited and divided into 16 three-person teams and one two-person team. The sample was distributed across academic standing, with the majority of the students being either freshman (32%) or sophomores (34%). Seniors made up for the least amount of the sample (10%) and juniors fell in the middle (22%). Of the 50 participants, only 12% reported having absolutely no experience in cyber security, with the majority (69%) claiming to have taken at least one cyber security related class.

Each session of this pilot lasted approximately 2 hours, and involved two rounds of training, each including training slides and a training material, 2 performance scenarios, and 4 surveys. The overall procedure was similar to the one described in Chapter 3. This pilot was an iterative process and the training material, scenarios, and higher/lower order knowledge would often change between sessions. After the first few sessions, events were removed due to low scores, and the event dispatch interval was increased so participants would have more time to assess events before new ones appeared.

To ensure that there was an equal workload across the three roles, a one-way analysis of variance (ANOVA) was conducted on the individual scores. The results showed no significant differences between roles. Additionally, descriptive statistics collected helped identify events with unusually low means and upper bound confidence levels and that needed editing.

From the surveys, data collected ensured the task was at an appropriate level of difficulty. Overall, 48% found the task neutral in terms of difficulty. Only 14% found the task easy, while 38% found it difficult (32% reported difficult, while 6% reported very difficult). Additionally, from the sample 52% of the participants agreed their team was able to complete the simulation, and 62% felt there was adequate time to complete tasks.

In addition to the changes made to individual events, and the event pacing's, other changes were made to the training materials, procedures, and survey metrics.

Conclusion

This chapter provides an overview of a new-scaled world simulation, *teamNETS*. This simulation allows researchers to study various aspects of team cognition set within the context of cyber security. While a low fidelity data and decision-making, the collaborative processes maintain ecological and environmental validity. A basic user interface supports the necessary collaborations, as well as provides an immersive experience for the participants. Additionally, the flexibility of the simulation allows for numerous interdependent and dependent variables allow research in team cognition.

To assess the research design and tool, there were two separate pilot tests. The first pilot test assessed the event design and training materials. This pilot, conducted with members of the research team informed numerous changes before having to invest time and resources into a full experiment run through. The second pilot assessed the design of the interface and the pacing of the simulations. This pilot used real subjects, and replicated a full *teamNETS* experiment session. The results of this pilot informed further changes before deploying the simulation in full experiment.

In the following chapters, the *teamNETS* simulation is a platform to study transactive memory in distributed teams. By manipulating the training materials and the user-interface, the following research study investigates the role of transactive memory structures and shared virtual feedback on distributed teams.

Chapter 4

Evaluating Transactive Memory in Distributed Cyber Teams: Methods and Materials

In Chapter 2, six potential interdisciplinary research directions for furthering our understanding of transactive memory were introduced. In this chapter, an experiment is described, that was conducted to approach three of these directions, *Research Direction 1: Online Collaboration Systems*, *Research Direction 3: Interdisciplinary Domains,* and *Research Direction 4: Integration with Theory*. Specifically this experiment design aims to answer three main research questions:

> *RQ1: What are the effects of a shared virtual feedback mechanism on a distributed cyber team's transactive memory system and performance in a simulated task?*
>
> *RQ2: When working in a distributed cyber team, is it better to have a differentiated or integrated transactive memory structure?*
>
> *RQ3: What are the correlational, and mediating effects of situation awareness on transactive memory systems in distributed cyber teams?*

To test each of these research questions the *teamNETS* human-in-the-loop cyber security simulation, as described in Chapter 3, was used as a basis for evaluation. The following section will outline the research methodology, development of hypotheses, manipulations and measures, participants, equipment, and procedures.

Methodology

Research Design

To best approach the three main research questions, this experiment utilized a 2x2 factorial design with between subject testing for the independent variables of transactive memory structure and presence of shared virtual feedback. With a fully crossed design, there are four distinct conditions. Table 15 shows the possible conditions.

Table 15: Experiment Design

	Shared Virtual Feedback	No Shared Virtual Feedback
Differentiated TMS	A1	A2
Integrated TMS	B1	B2

Listed separately the three conditions are:

- A1: Differentiated TMS Profile with Shared Virtual Feedback
- A2: Differentiated TMS Profile with No Shared Virtual Feedback
- B1: Integrated TMS Profile with Shared Virtual Feedback
- B2: Integrated TMS Profile with No Shared Virtual Feedback

Since the facilities allowed for only two teams per session and to minimize coordination problems, both teams in one session would participate in the same conditions. Additionally, to minimize set up time and reduce probability for errors, the presence of shared virtual feedback was manipulated between sessions and transactive memory structure was manipulated between days. A maximum of two experimental sessions were held per day, meaning no more than four teams per day went through the experiment.

Manipulations and Measures

The two independent variables (IVs) that were manipulated in this experiment were the type transactive memory structure (differentiated vs. integrated) and the presence of shared virtual feedback via the Augmented Transactive Memory Interface (ATM vs. NOATM). For dependent variables, the data collected represented task performance, transactive memory, and situation awareness.

Independent Variables

Transactive Memory Structure

Transactive memory structure was manipulated during each experiment through the training material provided at the beginning of each session. Across all participants, there was 12 pieces of training handouts related to answering events, three higher-order category handouts and nine lower-order training handouts. Regardless of condition, each participant received all pieces of higher-order category handouts describing how to identify each category of problem. This training was integrated into the PowerPoint, as well as hung on the wall to the right of the participants. Depending on their condition, participants then received a set of three lower-order training handouts. In the differentiated condition, participants received all three lower-order training handouts from the same higher order category, while in the integrated condition each participant received one lower order training hand-out from each higher order category. Table 16 provides a breakdown of the division of knowledge for one participant across conditions.

Table 16: Training Materials per Higher Order category by condition (for one participant)

	Differentiated Structure	*Integrated Structure*
Malicious Software	3	1
Intrusions	0	1
Improper Usage	0	1
Total	3	3

For a complete set of training materials and their organization across participants and conditions, please see Appendix B.

Participants would receive their lower order handouts during the first round of training immediately after learning each higher-order category. Participants were unaware of their experimental condition. However, in each condition it was suggested that their teammates might have received different training.

Shared Virtual Feedback

The second independent variable was a manipulation of two of the components in the *teamNETS* interface, the team monitor and the information transfer window. The ATM is a shared virtual feedback system that provides team members up to the minute information of their collaborators performance and abilities. In the shared virtual feedback condition, participants would receive extra information in each window that provided them with a real time evaluation of their team member’s performance within each functional domain. Additionally, within the information transfer window, users could compare each team member’s performance against their own, and the average of the team. Figure 12 shows the additions to each interface component as a part of the manipulation.

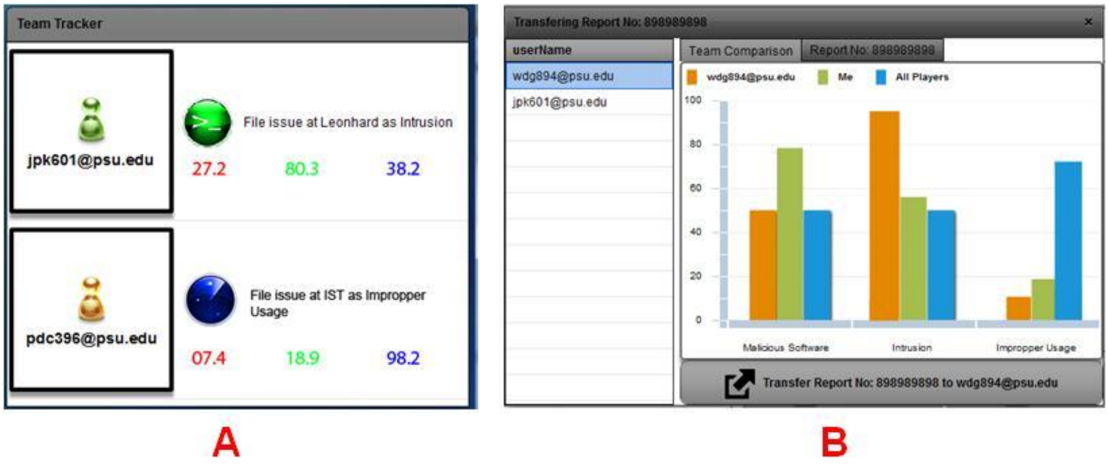


Figure 12: Team Tracker and Information Transfer with ATM Enabled

In the team tracker (Figure 12-A), the three numbers located below the previous action indicator are only present in the shared feedback condition. Each number represents that players rating in each functional domain, with red corresponding to malicious software, green - intrusion, and blue - improper usage. In the example above the user, jpk601@psu.edu is best at intrusion events, and worst at malicious software. In the information transfer window (Figure 12-B) whenever you select a user on the left, it shows each category, and their rating (orange), the active users score (green) and the team average (blue). To prepare participants in the shared feedback condition, following the end of the second training, they received a brief three-slide overview of the ATM.

For a complete overview of the design rational, process and implementation of the ATM within the *teamNETS* interface, see Appendix F.

Dependent Variables

Task Behaviors

Within the *teamNETS* simulation, there are multiple measurements that can be collected to represent team and individual task behavior:

- Overall Performance – based on the Human performance scoring model (Hellar & Hall, 2009; Wellens & Ergener, 1988), a raw and normalized score will be provided for all events in each scenario.
- Reaction Time – average amount of time it takes an individual to recognize an event is occurring and successfully file an action report
- Report Completeness – Percentage score representing how many correct lower order information pieces in an action report. If the main category is incorrect than this ratio is automatically 0.
- Errors – Number of times the team filed a report with an incorrect higher-order category
- Communication – Variables representing the total number of words, utterances and characters during each scenario

Each of these metrics are calculated at the team and individual level. These scores are used as a basis for assessing the effects of transactive memory, transactive memory structure and shared virtual feedback on group performance.

Transactive Memory

To measure transactive memory, three main variables were collected that represent their perceptions of their transactive memory systems, transitive memory utilization, and their specialization index.

- Perceived TMS – Lewis (2003) scale for measure perceived transactive memory, including metrics for coordination, specialization and credibility.
- Transactive Memory Utilization – Percentage score representing total number of transferred information pieces that lead to solving of an event divided by the total number of information transfers.

- Specialization Index – Measurement of transactive memory system structure and content that is calculated by adding unique recalled items for each functional domain. The higher the number, the more diverging the specialties Method derived by combining Wegner (1987) recall task, and the Transactive Memory Index proposed by Moreland & Myaskovsky (2000).
    - Individual Specialization Index – Standard deviations of the sums of correct items recalled for each higher order category
    - Team Specialization Index – Sum of individual specialization indexes

Since the first item, perceived TMS, is the only validated metric, it serves as the main dependent variable when looking at performance differences.

Situation Awareness

To assess the interplay between transactive memory, performance and situation awareness, there are two scales to assess the individuals and teams SA.

- SART – Subjective rating technique developed by Taylor (1990). Relies on ten dimensions of situation awareness each using 7-point likert scale. Delivered after each scenario.
- MARS – Subjective rating technique developed by Mathews & Beal (2002). Five questions using a 4-point scale. Delivered after each scenario

In addition to these metrics, the Human Performance Scoring model has also been shown to be a behavioral metric of situation awareness (Hellar & McNeese, 2010; Reifers, 2010). These measures are calculated at the team level, and will be used to better understand the interplay between transactive memory systems and team performance.

Development of Hypothesis

The overall goal of this study is to understand the interplay between transactive memory perception, content and utilization on team performance in a simulated cyber security task. More specifically, it is to understand the effects of *shared virtual feedback*, *structure of transactive memory system*, and *situation awareness* on transactive memory systems. In addition to the three main research questions, another goal of this experiment is to assess the viability of the two proposed metrics for transactive memory utilization and content proposed in the previous section. Using the metrics described, and the research questions outlined at the beginning of this chapter, a set of 7 hypotheses and one open-ended question were developed for this experiment. The following section describes the development of each hypothesis and relevant literature supporting them.

Shared Virtual Feedback

There is agreement amongst researchers that feedback that is shared amongst a team can be more valuable in improving performance than individual feedback (Jarvenpaa & Leidner, 1999; Rasker, Post, & Schraagen, 2000; Van der Vegt, de Jong, Bunderson, & Molleman, 2010). When dealing with virtual teams, these effects increase as team members lose the ability to monitor each other’s actions, and objectively assess their performance for themselves. Some studies have tried to understand effects on performance, but due to the inclusion of other confounds and moderators, it is difficult to interpret their findings (M. Chen, Liou, Wang, Fan, & Chi, 2007; Geister, Konradt, & Hertel, 2006; Jang, Steinfield, & Pfaff, 2002). Studies which have focused explicitly on shared virtual feedback has been discussed in depth in the HCI and CSCW community, but much of the research focuses on the broader concept of improving awareness, rather than performance (Nacenta, Gutwin, Aliakseyeu, & Subramanian, 2009; Stuckel & Gutwin, 2008; Tee, Greenberg, & Gutwin, 2009).

Though not focused on improving performance, awareness is one of the cornerstones of transactive memory theory. In some of the earliest studies, information regarding team member’s expertise or specialty has been shown to be positively linked to transactive memory formation. In Wegner’s (1985) first study of transactive memory, he showed that when unfamiliar team members were informed about each other’s specialty, their transactive memory system was comparable to teams with long term interpersonal relationships. Possibly providing more evidence was from the study conducted by Moreland & Myaskovsky (2000), where rather than training teams together, they provided participants with feedback evaluation of the skills their team members acquired during training. To the author’s knowledge, there has been no research conducted on how explicit shared virtual feedback mechanisms improve a team’s transactive memory system. Though focused on shared workspaces rather than feedback, Schreiber & Engelmann (2010) evaluated the effects of shared visual concept maps on the completion of a hidden knowledge profile task. Rather than providing explicit shared feedback, they shared team member’s knowledge maps in the experimental condition, and allowed no sharing in the control condition. The authors found that teams who were able to receive feedback of their collaborators knowledge map improved team performance, and developed a shared agreement on the location of knowledge within the group, though there were no mediating effects of the transactive memory systems on performance. Additionally, Keel (2007) & Adibhatla (2009) proposed similar systems using more explicit feedback mechanisms, though no formal assessment was conducted.

Even though previous research did not formally evaluate the independent effects of shared virtual feedback on team performance, their results and anecdotal evidence suggests that teams will be able to better coordinate their actions and have higher levels of team awareness thus improving their performance and transactive memory systems with such a mechanism. Additionally, since much of this research focused on the completion of fuzzy tasks (such as document authoring, or subjective decision making), it can be hypothesized that when coupled with a more direct and clear task the performance increases will be magnified. Finally, even though not based in virtual or distributed team, the findings out of the early transactive memory literature imply that when team members are able to maintain an awareness of each other’s skills and performance they develop effective transactive memory systems. Based on these patterns in the literature, we can expect that:

> ***Hypothesis 1:*** *Teams who receive shared virtual feedback via the ATM interface will perform better in the simulated task than teams in the control condition (i.e., no shared virtual feedback, ATM).*
>
> ***Hypothesis 2:*** *Teams who receive shared virtual feedback via the ATM interface will have higher scores on transactive memory metrics than teams in the control condition.*

Transactive Memory Structure

The majority of conceptual and empirical evidence agree that teams who have more of a divergent transactive memory structure will outperform teams with integrated structures. This divergence is often referred to as specialization vs. generalization (Moreland, 1999). In the expanded dimensions of transactive memory, Austin (2003) describes transactive memory as when each member has a deeper knowledge base in a specific area of expertise. He suggests that teams who have stronger specializations, or a more divergent transactive memory system, are able to perform better in complex tasks. As another example, in early transactive memory literature Wegner (1987) suggested that when a team has a more differentiated structure, there will be more of an agreement within the group of who possesses what knowledge, and a team can complete a variety of tasks at different levels. Additionally, Lewis (2004) suggests that individuals in a team believe that others possess different knowledge, they are more likely to learn more about their own specialty, thus naturally forming a more divergent structure.

The majority of empirical studies on transactive memory structures also show strong support for divergent structures. In a study of clerical staff members, Littlepage et al. (2008) found that whenever there were more divergent specialties found in a group, teams were able to allocate their resources more effectively and improve their groups performance. Similarly, Michinov & Michinov (2009) showed that student teams who had more diverging structure were able to produce higher quality work than teams with more integrated structures. Though in some transactive memory field studies, researcher has shown that divergence may not always be preferable and may sometimes even be detrimental. Gupta & Hollingshead (2010) studied the concept in relation to a collaborative test and found that teams with integrated structures out-performed teams with a differentiated structure as they were more helpful within their team, helped correct errors, and had a more tightly coupled collaboration. Similarly Chen & Dietrich (2009) and van Ginkel et al. (2010) found that teams with purely divergent structures had negative performance since there was a lack of understanding and coordination between team members.

Even though there is some evidence that claims divergent structures may not be preferable, since the manipulations provides some overlap in specialties, the issues found in (X. Chen & Dietrich, 2009; Gupta & Hollingshead, 2010; van Ginkel, et al., 2010) should be avoided. Additionally, with the strong support of divergent structures from other previous research, we can expect that:

> ***Hypothesis 3:*** *Teams with diverging transactive memory structure will perform better in the simulated task than teams with integrated transactive memory structure.*
>
> ***Hypothesis 4:*** *Teams with diverging specialty will have higher scores on transactive memory metrics than teams with integrated transactive memory structures.*

Situation Awareness

In a study of World of Warcraft players, Richter & Lechner (2009) conceptually showed the linkage between teams shared situation awareness and transactive memory systems. Even though not directly acknowledged from its inception, transactive memory has been described as an *interpersonal awareness* of the knowledge possessed by others (Wegner, 1987). Additionally, in the dimensions of transactive memory as described by Austin (2003), awareness plays a key role in the formation of specialization of knowledge and accuracy of knowledge sources. Other than this one study and these conceptual acknowledgements, research in linking situation awareness and transactive memory is rare.

Generally speaking, an individual's situation awareness (SA) is described as "the perception of elements in the environment with a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1995). SA can also be described at the team level as "the sharing of a common perspective between two or more individuals regarding current environmental events, their meaning, and their projected future status" (Wellens, 1993). The formation of accurate SA has been shown to be an important factor in numerous domains, such as emergency response (Blandford & Wong, 2004; McGrath & McGrath, 2005), C4i systems (French & Hutchinson, 2002; Salmon, et al., 2006), surgical teams (Bardram, et al., 2006; Hazlehurst, et al., 2007), and cyber security (Cone, Irvine, Thompson, & Nguyen, 2007; Ma, 2006; Tyworth, et al., 2012).

In the collective learning task experiments (Hollingshead, 1998b; D. W. Liang, et al., 1995; Moreland & Myaskovsky, 2000), teams were instructed to assemble a simple radio after a period of either individual or team training. In conditions where the participants were trained as a team, they were able to not only talk and share information, but were able to observe each other as they practiced different aspects of the task. These observations allowed team members to form an understanding of each other's strengths and weaknesses based on performance. By merging the information from explicit transactions (i.e. information sharing, talking, etc.), and the implicit transactions (i.e. observations of others succeeding or struggling with a task), teams were able form and utilize effective transactive memory systems that helped improve their performance.

Though not explicitly discussed, in these studies, the awareness of team members' behaviors, actions and knowledge, helped improve the team's transactive memory. This may imply that in addition to the traditional environmental cues, part of an individual's SA focuses on the formation and utilization of transactive memory. Even though there is little support from the literature, we can assume that the interpersonal awareness that aids in transactive memory formation is a part of one's "complete situation awareness." This would imply that when an individual has a strong awareness of the environment, it is more likely that they also have a strong awareness of the knowledge possessed by others. This effect would be magnified in contexts in which there is a strong interplay between the human-computer and human-information interactions, but also a strong emphasis on human-human interactions.

Based on this, we can expect that:

> ***Hypothesis 5:*** *Perceived situation awareness ratings will be an accurate predictor of transactive memory metrics.*

Assessment of Metrics

Previous methods of measuring transactive memory can be partitioned three distinct categories, actual, behavioral and perceived measurements (Lewis, 2003). The actual, transactive memory measurements assess the actual content of the team's transactive memory. This method was utilized in the collective recall experiments (Hollingshead, 1998b, 2000, 2001; Wegner, et al., 1985). In these experiments, team transactive memory, and performance measurements are calculated by comparing the number of unique items recalled by a team, compared to the number of overlapping items. While there is a question of how well this metric would scale to a more complex task, this is the only metric, which can present a clear representation of a team's transactive memory structure and content. Other studies have assessed transactive memory based on behavioral metrics such as the transactive memory index (Moreland & Myaskovsky, 2000) and anticipation ratios (Sarcevic, et al., 2008). These metrics assess explicit knowledge or information transactions that represent the presence of a transactive memory structure. They rely on subject matter expert observations of memory differentiations, coordination, and perceived trust for the transactive memory index, and a ratio of communications providing information vs. communications requesting information. While these are both very strong and rich methods, the overhead of subject matter observations makes it difficult to implement, plus, since much of the work in distributed collaborations is invisible, they may not be practical in their current form. Finally, there are numerous perceived scales, but many of them require subject matter experts to develop or deploy (e.g., Austin, 2003; X. Chen & Dietrich, 2009), creating a financial and temporal burden on the researcher. Because of this constraint the Lewis (2003) field measure scale is the most widely used.

In addition to the field measure, there are other behavioral and content measures explicitly designed for this experiment. Within the task, the action of transferring an event to somebody who is able to complete it is an explicit indication of utilization of a transactive memory system. Additionally, the team specialty index, which is based off of the transactive memory index and group recall task, shows a team's depth at different specialties. Since these metrics were carefully designed with previous literature and metrics in mind, we can expect that:

> ***Hypothesis 6:*** *Transactive memory utilization scores will be an accurate predictor of perceived transactive memory.*
>
> ***Hypothesis 7:*** *Team Specialty Index will be an accurate predictor of perceived transactive memory.*

The final proposed exploration from this experiment is of an open-ended question rather than a hypothesis. While in previous literature, the specialization of expertise has the largest effect on transactive memory systems and performance (e.g., DeChurch & Mesmer-Magnus, 2010; Littlepage, et al., 2008; E. Michinov, et al., 2009), further exploration should be made to account for the context and the distributed nature of the task. As discussed in a previous chapter, it has been shown that trust plays a major role in distributed teams performances (Coppola, et al., 2004), it is possible that credibility may be a more defining factor. On the other hand, Austin (2003), discussed that even with a strong specialization differentiation, teams without strong communication and coordination processes cannot utilize them. This problem may magnify with the lack of face-to-face interactions in distributed collaborations. With these multiple theoretical perspectives, we cannot provide an anticipation of results, but can ask the question:

> ***Open Ended Question:*** *Which dimension of transactive memory (specialization, coordination, and credibility) best predicts transactive memory and performance in distributed interactions?*

Participants

For this study, 198 undergraduate participants (66 three-person teams) were recruited from 17 different undergraduate classes at the Pennsylvania State University. Even though the majority of the participants were unlikely to have a strong understanding of cyber security, or the environment, many of the classes had a strong emphasis on group work, which supports the macrocognitive goals of this study.

In each class, student volunteers received a pre-determined amount of extra credit to be added towards their final grade. Participation was not mandatory, and an alternate assignment was offered to those who did not want to or could not participate in this study due to their schedule or participating in another class. Another similar study was conducted in parallel to this study, and careful consideration was taken to ensure that students only participated in one of the studies in order to minimize learning effects.

Equipment

In order to support two simultaneous teams of three, the User Science and Engineering Lab (IST 314A) at the Pennsylvania State University, College of Information Sciences and Technology was used to run all experiments (Figure 13). This lab has facilitated multiple Human-In-The-Loop experiments using NeoCITIES Simulation (e.g., Connors, 2006; Hellar & McNeese, 2010; Mancuso, Parr, et al., 2011; McNeese, et al., 2006; Pfaff, 2008).

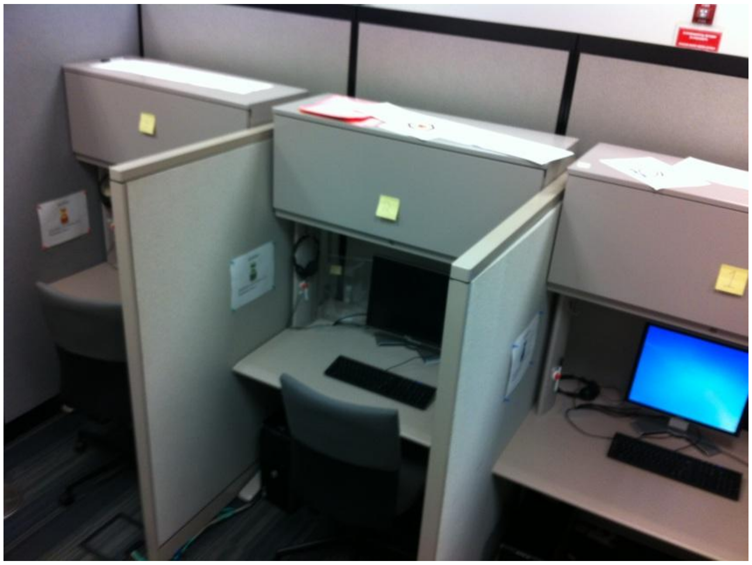


Figure 13: User Science & Engineering Simulated Distributed Team Research Facility

Within the facility, six separate computers are isolated from each other to create the experience of a distributed team. At each station a monitor, mouse and keyboard to allows participants to navigate the training material, complete surveys and play the simulation (Figure 14).

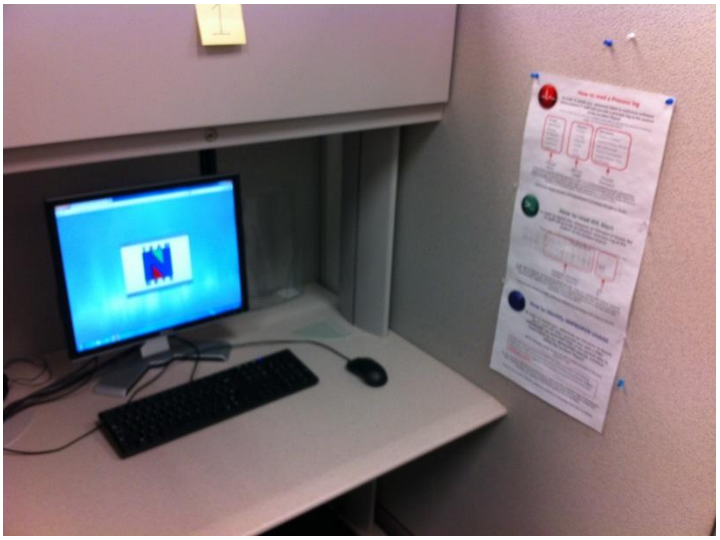


Figure 14: Participant Workstation

At each station, information posted on the walls included the username and password of the player at that station, and an overview of the three higher-order categories. These remained visible for the entirety of the study. Finally on the desk at every station were the three handouts of lower order information. At the beginning of the study, there were placed face down and stacked, but after the participants were introduced to them, they were free to organize them as they see fit.

Task & Procedure

Each experimental session took approximately 2 hours. The experiment consisted of two rounds of training, each with a set of self-paced power-point slides and a *teamNETS* practice scenario. During the first training, each participant were presented with three handouts, which corresponded to the lower-order information they were assigned. Following the training, the participants played two performance scenarios that included equal number of events from each main category. Finally, the participants completed an online survey. For a full breakdown of the procedure, see Table 17.

Table 17: Experiment Procedure with Estimated Durations

Number	Task	Duration
1	Sign consent form	2 min
2	Survey 1	5-10 min
3	Basic *teamNETS* training	5-10 min
4	Practice Scenario 1	7 min
5	Complex *teamNETS* training	10-15 min
6	Practice Scenario 2	9 min
7	Survey 2	5-10 min
8	Performance Scenario 1	16 min
9	Survey 3	10-15 min
10	Performance Scenario 2	16 min
11	Survey 4	15-20 min
	Total:	~120 min

After the participants arrived, they were divided into teams and assigned to a computer terminal. Once participants were at their computer, they were presented with consent forms and explained the nature and directions of the task. Following the consent form, participants were then instructed to complete an introductory survey comprised of questions regarding their demographics, ability to multitask, team experience, and previous simulation experience.

Following the completion of the introductory survey, the participants were instructed to begin the first set of training slides. The first round of training focused on how to interact with the interface, and how to solve events within the game. It was during this time the participants were presented with the higher-order categories and the lower-order training depending on their role and condition. When players finished the training they were instructed to wait for further instruction but were free to go back and review any material.

Once all participants on both teams were finished with training 1 they played their first *teamNETS* training scenario. This scenario was comprised of 12 events, 4 for each player. Since the purpose of this scenario was to introduce players to the interface and game, players only received events from one higher-order category and were not permitted to transfer information. At the end of training scenario 1 the participants were presented with their score, and permitted to take their time to review their performance. For this scenario, the participants were presented with the answers for each event they were assigned.

After completion of the first training scenario, participants were then instructed to begin the second set of training slides that consisted of the collaborative aspects of the simulation, including the team monitor, chat window and information transfer. At the end of these training, participants in the shared virtual feedback condition received a brief training introducing them to the updates to the interface and how to use the new components. When players finished the training, they were instructed to wait for further instruction but were free to go back and review any material from training 1 or 2.

Once all participants on both teams were finished with training 2 they played the second *teamNETS* training scenario. This scenario was comprised of 18 events, 6 for each player. Since the purpose of this scenario was to introduce players to the collaborative aspect of the game players received the majority of events from the higher order category they answered in training 1 (4 events), but one event from each of the other categories. Additionally participants were able to transfer information during this scenario. At the end of training scenario 2, participants were presented with their score, and permitted to take their time to review their performance. Following this scenario, the participants took a short survey about their perception of the game and their self-efficacy.

Following the second survey participants played their first performance scenario. Prior to starting this scenario the researcher informed participants that this scenario would be longer, and it is important they try their best. This scenario was comprised of 27 events, with each player receiving 3 from each higher order category (totaling 9 per player). At the end of this scenario, participants were presented with their score, and permitted to take their time to review their performance. After assessing their score, participants took a survey with items to assess their transactive memory, situation awareness and team dynamics. Following this the participants participated in their final performance scenario which was comprised of 36 events, with each player receiving 4 from each higher order category (totaling 12 per player).

Finally, participants were instructed to complete survey 4. This survey was comprised of the same questions as survey 3, but also included metrics to assess the content of their transactive memory system (used to calculate the specialization index), as well as their opinions on their team and self-efficacy and assessment of the user interface. After all players completed the survey they were debriefed about the purpose of the study, and thanked for their time.

For a complete overview of the events from each scenario and the list of measures collected in each survey, see Appendix C and Appendix D.

Chapter 5

Evaluating Transactive Memory in Distributed Cyber Teams: Results

Participants

One hundred and ninety-eight undergraduate students (70.7% Male) enrolled in 17 courses participated in the study. The majority of the students were lower to middle classmen, with freshmen and sophomores accounting for 62.1% of the sample, resulting in a relatively young average age (M=20.21, SD=3.26). Since the recruiting focused on General Education classes, there was a wide distribution of majors represented in the study, with 22 majors accounted for, though the majority of students associated themselves as IST/SRA (51%).

These one hundred and ninety-eight students, divided into 66 three-person teams[3], and evenly distributed across all four conditions. The vast majority had never participated in simulation research before (i.e., NeoCITIES), with only 20 participants (10.1%) reporting previous experience. On the other hand, around half of the participants (57%) reported some cyber security experience, mainly from introductory classes (44%). Of the participants, only 6 participants reported high level of cyber security knowledge (i.e., holding cyber security job or professional certifications). Most of the participants reported working in 3 or more teams (89.9%), but the majority of students worked in 2 or fewer distributed teams (66.2%). Even with the lack of experience, most of the students reported being moderately to extremely comfortable working in virtual/distributed teams (66.7%).

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[3] Following conclusion of the data collection, 11 teams were dropped due to technical and procedural errors or invalid data.

Preliminary Analysis

Normality and Comparison of Outcome Variables across Time

Since the outcome variables for performance and transactive memory represent two separate performance scenarios, descriptive statistics and one-way t-tests ensured normality and assess difference across time. Table 19 presents an overview of the results of these tests.

The skewness and kurtosis levels all had absolute values less than 2 and 3 respectively, so the assumptions of normality were not violated by any of the outcome variables (Hildebrand, 1986). Of all the variables only transactive memory specialization differed across time, as it was reported significantly higher after Performance 2 ($M=4.04$, $SD=0.51$) than Performance 1 ($M=3.91$, $SD=0.51$), $t(56)=-2.37$, $p < .05$. Since specialization has been shown to increase as teams work together longer (Hollingshead, 2000, 2001; Wittenbaum, et al., 1996; Wittenbaum, et al., 1998), this is not considered out of the ordinary. Due to the lack of difference across time, all future analyses reflect Performance 2 scores and reactions.

Factor Analysis

To ensure that the metrics for the Lewis (2003) transactive memory scale properly loaded on the correct dimensions, an exploratory factor analysis using a principal axis extraction method with a Promax rotation was utilized. As expected 3 factors emerged, representing coordination ($\lambda=7.47$, 49.77% of variance), specialization ($\lambda=2.57$, 17.15% of variance) and credibility ($\lambda=1.50$, 9.98% of variance). This solution accounted for 76.90% of the variance of the item responses. All scales showed high levels of reliability (Coordination, $\alpha = 0.93$; Specialization, $\alpha = 0.84$; Credibility, $\alpha = 0.87$). Table 18 shows a full breakdown of each factor and the questions that loaded onto it.

Table 18: Exploratory Factor Analysis for Perceived Transactive Memory Scale

Variables	*Factor Loadings*		
	Coordination	Specialization	Credibility
1. Our team worked together in a well coordinated fashion	**0.93**	0.17	0.05
2. We accomplished the task smoothly and efficiently	**0.91**	-0.03	-0.07
3. Our team had very few misunderstandings about what to do	**0.88**	0.21	-0.03
4. There was much confusion about how we would accomplish the task	**0.76**	0.31	0.25
5. Our team needed to backtrack and start over a lot	**0.75**	0.31	0.32
6. I know which team members have expertise in specific areas	0.61	**0.57**	0.27
7. The specialized knowledge of several different team members was needed to complete the task	0.05	**0.89**	0.13
8. Each team member has specialized knowledge of some aspect in our task	0.22	**0.82**	0.28
9. I have knowledge about an aspect of the task that no other team member has	0.22	**0.82**	0.15
10. Different team members are responsible for expertise in different areas	0.30	**0.77**	0.31
11. I was confident relying on the information that other team members brought to the discussions	0.11	0.23	**0.85**
12. I was comfortable accepting procedural knowledge from other team members	-0.06	0.10	**0.82**
13. When other team members gave me information, I wanted to double check it for myself	0.00	0.15	**0.74**
14. I trusted that other team members' knowledge about the task was credible	0.36	0.32	**0.73**
15. I did not have much faith in other members "expertise"	0.57	0.29	**0.60**

All items loaded perfectly onto their expected factor except item number 6, which was supposed to load onto specialization but had an equally high factor loading for coordination. Since the scale is already established, and removal of the item from the specialization factor caused a decrease in reliability (0.84 to 0.80) and addition to the coordination factor caused no increase in reliability (0.93 to 0.93), the item remained as a part of the specialization subscale for subsequent analyses.

Correlations

Bivariate correlations of the independent and dependent variables at the team level examined in the study were calculated for performance 2. As shown in Table 20, teams who received the shared virtual feedback were coded 1, while teams without were coded 2. Similarly, teams in the differentiated transactive memory structure condition were coded 1 while integrated teams were coded 2.

Table 19: Distribution of Outcome Variables and Difference Across Time

Outcome Variable	Performance 1: Descriptives						Performance 2: Descriptives						Mean Diff.	
	Mean	SD	Skewness	Kurtosis	Min	Max	Mean	SD	Skewness	Kurtosis	Min	Max	t-value	p
Transactive Memory														
Specialty	3.91	0.51	-0.46	-0.20	2.67	4.67	4.04	0.51	-0.46	-0.55	3.00	5.00	-0.57	0.57
Credibility	3.49	0.43	-0.14	0.10	2.33	4.33	3.47	0.53	-0.24	-0.75	2.33	4.33	0.33	0.75
Coordination	3.15	0.73	-0.21	-0.90	1.67	4.67	3.18	0.69	-0.06	-0.78	1.67	4.33	-2.37	0.02
Full Scale	3.39	0.44	-0.53	-0.38	2.33	4.00	3.43	0.45	-0.39	-0.98	2.67	4.00	-0.91	0.37
Performance	38.90	15.29	0.25	-0.63	6.32	68.94	37.42	15.32	0.08	-0.75	9.46	70.44	-2.37	0.31

Table 20: Descriptive Statistics and Correlations at Team Level for Performance 2

	Mean	SD	1	2	3	4	5	6	7	8	9	10
Independent Variables												
1. Presence of Shared Virtual Feedback	1.49	.50										
2. Transactive Memory Structure	1.51	.50	-.02									
Measured Variables												
Perceived Transactive Memory												
3. Specialization	4.04	.51	-0.02	-0.44**								
4. Credibility	3.47	.53	0.01	0.02	0.43**							
5. Coordination	3.18	.69	0.12	-0.60**	0.55**	0.32						
6. Full Scale	3.43	.45	0.07	-0.39	0.72	0.66	0.80**					
Measured Transactive Memory												
7. Transactive Memory Utilization	0.58	0.30	-0.12	-0.41**	0.35**	0.00	0.42**	0.35**				
8. Specialization Index	6.60	4.59	-0.09	-0.63**	0.23	0.18	0.60**	0.41**	0.32*			
Situation Awareness												
9. SART	2.96	.37	0.05	-0.21	0.40**	0.24	0.45**	0.41**	-0.03	0.03		
10. MARS	2.35	.40	0.20	-0.43**	0.40**	0.08	0.64**	0.49**	0.51**	0.35**	0.25	
Performance												
11. Team Score	37.42	15.32	0.13	0.02	0.02	-0.20	0.02	-0.07	0.43**	-0.04	-0.22	0.39**

Note: N=57 three person teams. * p < .05, ** p < .

No correlations were found between the presence of shared virtual feedback and any of the collected metrics, including performance, situation awareness, and all of the transactive memory structures. On the other hand, the training condition was correlated with multiple transactive memory conditions, including perceived transactive memory specialization ($r=-0.44$, $p < .01$) and coordination ($r=-0.60$, $p < .01$), as well as the full perceived transactive memory scale ($r=-0.39$, $p < .01$), transactive memory utilization ($r=-0.41$, $p < .01$), and specialization index ($r=-0.63$, $p < .01$). Since all correlations are negative, this implies that teams in the differentiated condition reported and scored higher on the transactive memory metrics than teams in the integrated conditions.

Additionally, there was a consistent pattern across many of the transactive memory measurements of positive relationships. These correlations were found between transactive memory utilization and perception ($r=0.42$, $p < .01$; additionally correlations were found at all three dimensions) and the specialization index ($r=0.32$, $p < .51$). Both situation awareness metrics had positive correlations with most transactive memory metrics, with the exception of SART not correlated with Specialization Index or transactive memory utilization. Finally, the team score was only correlated with two variables on the matrix, transactive memory utilization ($r=0.43$, $p <.01$) and MARS ($r=0.39$, $p < .01$).

Hypothesis Testing

The first two hypotheses determined whether the inclusion of shared virtual feedback improved a team’s ability to perform the distributed cyber task and/or their perceptions of their transactive memory. Since the first set of hypotheses were looking across only two groups, independent samples t-tests were conducted to compare the team normalized score, and the teams overall perceived transactive memory across each of the independent variables.

Contrary to Hypothesis 1, the first independent sample t-test revealed no significant difference between teams score in the shared virtual feedback (M=35.47, SD = 14.92) and no shared virtual feedback (M=39.43, SD=15.73) conditions. Similarly for hypothesis 2, an independent sample t-test revealed no significant difference between teams perceived transactive memory in the shared virtual feedback (M=3.40, SD = .42) and no shared virtual feedback (M=3.46, SD=.47) conditions.

Next, Hypotheses 3 and 4 evaluated whether the integration of a team's transactive memory system had an impact on their performance and/or their perceptions of their transactive memory system. Once again to evaluate these Hypotheses, two independent samples t-tests were conducted to compare the team normalized score, and the teams overall perceived transactive memory across the Differentiated and Integrated transactive memory structure conditions. Contrary to Hypothesis 3, the independent sample t-test revealed no significant difference between teams in the divergent (M=37.16, SD=13.77) and integrated (M=37.66, SD=16.92) transactive memory structure conditions. On the other hand, consistent with Hypothesis 4, the independent sample t-test revealed that teams in the differentiated transactive memory structure condition reported significantly higher perceived transactive memory (M=3.61, SD=.37) than teams in the Integrated condition (M=3.26, SD=.45), t(55)=3.12, $p < .01$.

The next sets of hypotheses determined accurate predictors of perceived transactive memory. A hierarchical linear regression tested each of these hypotheses. The analyses were conducted such that the control variables were entered on the first step of the model (i.e., Shared Virtual Feedback-Divergent Structure, No Shared Virtual Feedback-Integrated Structure, etc.), as well as other pertinent controls such as simulation and cyber security experience. On the second step of the model were the dependent variables for each hypothesis, such as situation awareness, transactive memory utilization and transactive memory content and structure.

Hypothesis 5 predicted that a team's perceived transactive memory would be predicted by their perceived levels of post-task situation awareness. Two situation awareness measurements were consulted, SART and MARS. As shown in Table 21, the two situation awareness measures were entered into step 2 of the regression analysis.

Table 21: Regression Analysis of the Relationships between Situation Awareness and Perceived Transactive Memory System

	R^2	F	ΔR^2	F_{inc}	β	t
Step 1	0.08	2.00				
SVF-DS					0.30	1.80*
SVF - IS					-0.09	-0.56
NSVF-DS					0.31	1.94**
Simulation Experience					-0.09	-0.65
Cyber Security Experience					0.30	0.23
Step 2	0.27	3.91	0.20	7.44**		
SART Perceived SA					0.30	2.39**
MARS Perceived SA					0.32	2.39**

Note: N = 57 teams, * $p < .10$, ** $p < .05$; SVF = Shared Virtual Feedback, NSVF = No Shared Virtual Feedback, DS = Differentiated Structure, IS = Integrated Structure

From the table, you can see that both SART (β = 0.30, $p < .05$) and MARS (β = 0.32, $p < 2.39$) significantly predicted team perceived transactive memory, supporting Hypothesis 5. Additionally, both SART and MARS explain incremental variance beyond the control variables ($\Delta R^2 = .20$, $F(2,49) = 7.44$, $p < .01$), which become non-significant once they are entered into the model.

Hypothesis 6 and 7 predicted that teams that had higher transactive memory utilization and content would report higher levels of perceived transactive memory. The second hierarchical linear regression had transactive memory utilization scores and the specialization entered into step 2 of the regression analysis (Table 22).

Table 22: Regression Analysis of the Relationships between Transactive Memory Utilization and Content and Perceived Transactive Memory

	R^2	F	ΔR^2	F_{inc}	β	t
Step 1	0.08	2.00				
SVF-DS					0.29	1.80*
SVF - IS					-0.09	-0.56
NSVF-DS					0.31	1.94
Simulation Experience					-0.09	-0.65
Cyber Security Experience					0.03	0.23
Step 2	0.16	2.57	0.11	3.51**		
Transactive Memory Utilization					0.28	1.93**
Specialization Index					0.30	1.76*

Note: N = 57 teams, * p < .10, ** p < .05; SVF = Shared Virtual Feedback, NSVF = No Shared Virtual Feedback, DS = Differentiated Structure, IS = Integrated Structure, SA = Situation Awareness

From the table you can see that both Transactive Memory Utilization (β = 0.28, p < .05) and the Specialization Index (β = 0.90, p < .1) significantly predicted team perceived transactive memory, supporting both hypothesis 6 and 7. Additionally, both metrics explained incremental variance beyond the control variables ($\Delta R^2 = .11$, F(2,49) = 3.51, p < .05), which become non-significant once they are entered into the model.

The final open-ended question was aimed at understanding which dimension of transactive memory, specialization, coordination and credibility, was the best predictor of team performance. To assess this question, the hierarchical linear regression with team's performance added to Step 1 of the model was conducted. To understand how the dimensions influence performance, all three metrics were added to step 2 of the regression analysis. As shown in Table 23 the variables entered into step 2 of the regression analysis did not explain incremental variance in the model ($\Delta R^2 = .01$, F(2,49) = 7.30, p > .1).

Table 23: Regression Analysis of the Relationship between Transactive Memory Dimensions and Team Performance

	R^2	F	ΔR^2	F_{inc}	β	t
Step 1	0.58	11.45				
SVF-DS					-0.01	-0.11
SVF - IS					0.04	0.31
NSVF-DS					0.00	-0.08
Simulation Experience					0.08	0.82
Cyber Security Experience					0.14	1.55
Perf 1 Team Score					0.77	7.95
Step 2	0.58	7.30	0.01	0.16		
Credibility					-0.17	0.87
Coordination					-0.20	0.84
Specialization					0.67	0.50

Note: N = 57 teams, * p < .10, ** p < .05; SVF = Shared Virtual Feedback, NSVF = No Shared Virtual Feedback, DS = Differentiated Structure, IS = Integrated Structure

While not significant, it should be noted that of the three dimensions, specialization of expertise had a lower p-value compared to the other two dimensions.

Summary of Results

These results represent 7 hypothesis and one open ended question. The first four hypotheses focused on the experimental manipulations, and their impact on team performance and transactive memory. The final three hypotheses looked to understand predictor variables of a team's perceived transactive memory. The overall conclusions found support for four of the hypotheses, and the rejection of the other three. Due to lack of significance, the open-ended question was inconclusive. Table 24 provides a full summary of the results.

Table 24: Experiment Hypotheses Results Summary

ID	Hypothesis	Dependent Variable	Conclusion
H1	Teams who receive shared virtual feedback via the ATM interface will perform better in the simulated task than teams in the control condition	Perf 2 Team Score	Reject
H2	Teams who receive shared virtual feedback via the ATM interface will have higher scores on transactive memory metrics than teams in the control condition.	Perceived TM	Reject
H3	Teams with diverging transactive memory structure will perform better in the simulated task than teams with integrated transactive memory structure.	Perf 2 Team Score	Reject
H4	Teams with diverging specialty will have higher scores on transactive memory metrics than teams with integrated transactive memory structures.	Perceived TM	Support
H5	Perceived situation awareness ratings will be an accurate predictor of transactive memory metrics.	Perceived TM	Support
H6	Transactive memory utilization scores will be an accurate predictor of perceived transactive memory.	Perceived TM	Support
H7	Team Specialty Index with be an accurate predictor of perceived transactive memory.	Perceived TM	Support
OE	Which dimension of transactive memory (specialization, coordination, and credibility) best predicts team performance in distributed interactions?	Perf 2 Team Score	Inconclusive

Based on the initial tests of hypothesis, numerous questions became apparent about the effects of shared virtual feedback, the teams Transactive Memory structure, and the utility of the proposed transactive memory measurements. An ancillary analysis addressed each of these questions.

Ancillary Analysis

Interaction Effects between Shared Virtual Feedback and TM Structure

To understand the effects of Shared Virtual Feedback and Transactive Memory structure on team performance and transactive memory systems the first follow up analysis looked at interactions between the conditions.

Team Performance

To assess the team performance in the task (via the normalized score), a 2 (Presence of Shared Virtual Feedback) x 2 (Transactive Memory Structure) factorial ANOVA was conducted to assess difference across conditions. Not surprisingly, this analysis revealed no main effects for either Interface Type (F(1,53) = .942, p = .336, partial η2 = .02) or Division of Knowledge conditions (F(1,63)=.016, p = .9, partial η2 = .00). Additionally further analysis revealed no significant interaction effects (F(1,53) = .30, p = .59, partial η2 = .01). Table 25 shows the means associated with this interaction and the results are visualized in Figure 15.

Table 25: Team Performance: Presence of Shared Virtual Feedback (SVF) x Transactive Memory Structure

		Team Performance	
		Integrated	Differentiated
SVF	*M*	36.82	34.03
	SE	4.02	4.16
No SVF	*M*	38.56	40.30
	SE	4.16	4.16

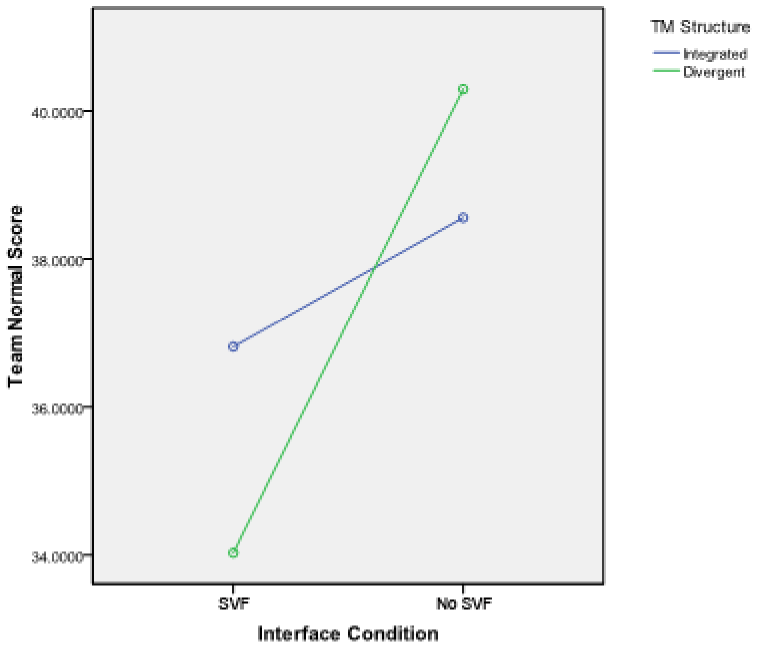

Figure 15: Estimated Marginal Means of Team Performance (Presence of Shared Virtual Feedback x TM Structure)

Since no effects were found for team performance using the normalized score metric, other metrics generated by *teamNETS* simulation were consulted, specifically the communication patterns, report completeness, errors, and reaction times. Since these variables are all related and factor into the calculation of the team score, a 2 (Presence of Shared Virtual Feedback) x 2 (Transactive Memory Structure) multivariate analysis of variance (MANOVA) was conducted to examine teams average reaction time, report completeness and communication patterns (in the form of word count) across conditions.

This analysis revealed a significant multivariate main effects for both transactive memory structure (Wilks' Λ = 0.37, F(4,50) = 21.37, p < .01, partial η2 = .63), and Presence of Shared Virtual Feedback (Wilks' Λ = 0.82, F(4,50) = 2.69, p < .05, partial η2 = .17). There were no multivariate interaction effects found.

The univariate analysis for communication patterns revealed a main effect for transactive memory structure (F(1,53) = 13.93, p < .01, partial η2

= .21), with teams in the integrated condition having significantly higher word count (M=193.17, SE=30.39) than teams in the differentiated condition (M=31.43, SE=30.91). While not significant using a standard alpha level of 0.05, it was found that teams who did not receive the shared virtual feedback had a higher word count (M=146,178, SE=30.91) than teams who received the shared virtual feedback (M=77.82, SE=30.39), F(1,53) = 2.53, p = .11, partial η2 = 0.05. Table 26 shows the means associated with this interaction and the results are visualized in Figure 16**.**

Table 26: Word Count: Presence of Shared Virtual Feedback (SVF) x Transactive Memory Structure

		Word Count	
		Integrated	Differentiated
SVF	*M*	136.13	19.50
	SE	42.23	43.71
No SVF	*M*	250.21	43.36
	SE	43.71	43.71

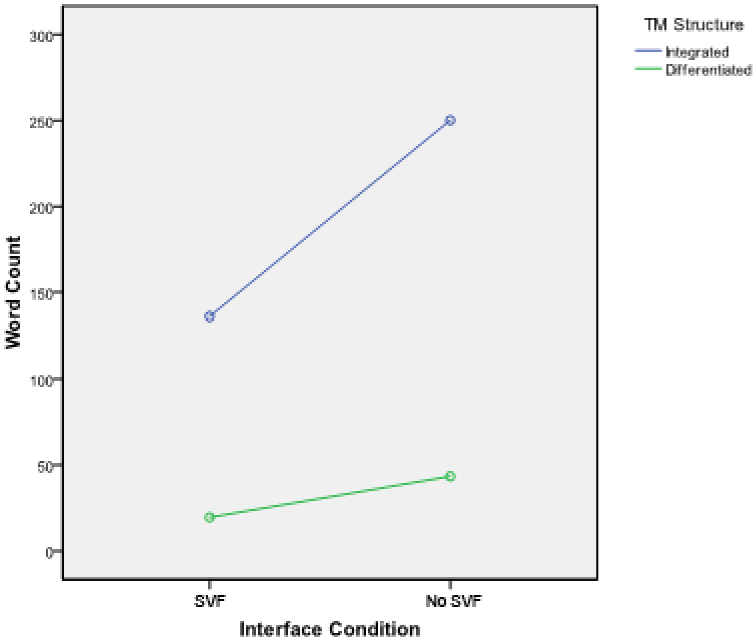

Figure 16: Estimated Marginal Means of Word Count (Presence of Shared Virtual Feedback x TM Structure)

The second univariate analysis for report completeness, revealed main effects for both transactive memory structure (F(1,53) = 74.61, p < .01, partial η2 = .59), and the presence of shared virtual feedback (F(1,53) = 4.77, p < .05, partial η2 = .08). For transactive memory structure it was found that teams in the divergent condition had significantly higher report completeness (M=.69, SE=0.01) than teams in the integrated condition (M=0.52, SE=0.01). Unlike previous results where the shared virtual feedback was detrimental to performance, it was found that teams who received the shared virtual feedback had significantly higher report completeness (M=.62, SE=0.01) than teams who did not receive the interface (M=.58, SE=.01). Table 27 shows the means associated with this interaction and the results are visualized in Figure 17**.**

Table 27: Report Completeness: Presence of Shared Virtual Feedback (SVF) x Transactive Memory Structure

		Report Completeness	
		Integrated	Differentiated
SVF	*M*	0.54	0.70
	SE	0.02	0.02
No SVF	*M*	0.51	0.65
	SE	0.02	0.02

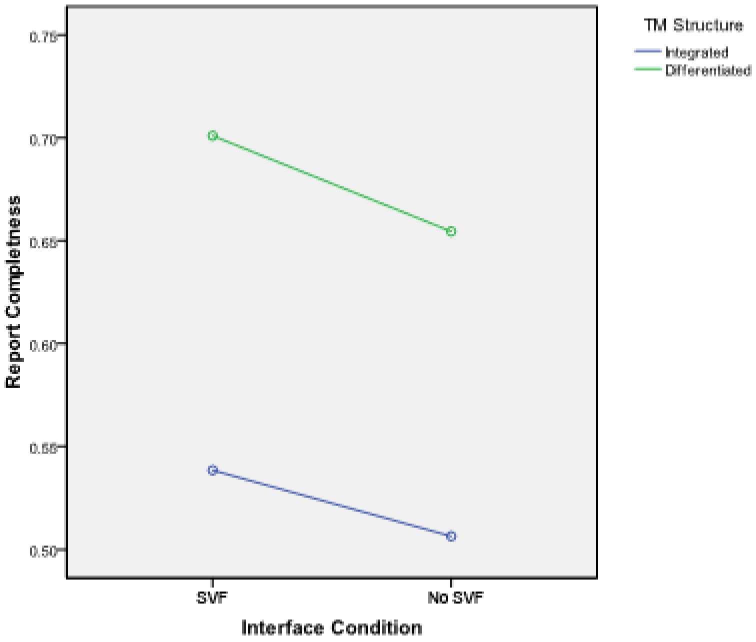

Figure 17: Estimated Marginal Means for Report Completeness (Presence of Shared Virtual Feedback x TM Structure)

The third univariate analysis for errors revealed a main effect for transactive memory structure (F(1,53) = 7.57, p < .01, partial η2 = .13), with teams in the integrated condition making significantly more errors (M=8.41, SE=0.91) than teams in the differentiated condition (M=4.86, SE=0.91). While not significant using a standard alpha level of 0.05, it was found that teams who did not receive the shared virtual feedback made fewer errors (M=5.71, SE=0.92) than teams who received the shared virtual feedback (M=7.55, SE=0.91), F(1,53) = 2.03, p = .16, partial η2 = 0.04. Table 28 shows the means associated with this interaction and the results are visualized in Figure 18**.**

Table 28: Errors: Presence of Shared Virtual Feedback (SVF) x Transactive Memory Structure

		Errors	
		Integrated	Differentiated
SVF	*M*	9.53	5.57
	SE	1.26	1.30
No SVF	*M*	7.29	4.14
	SE	1.30	1.30

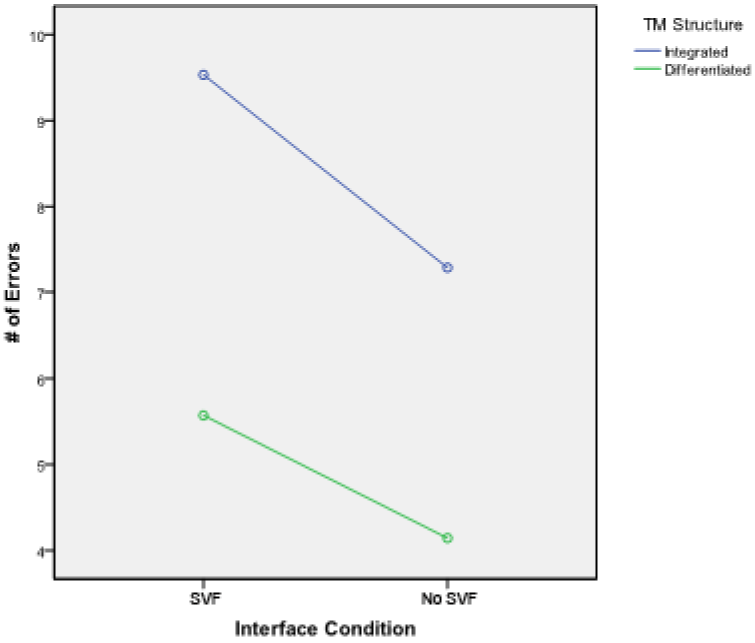

Figure 18: Estimated Marginal Means of Errors (Presence of Shared Virtual Feedback x TM Structure)

No univariate main effects for either Presence of Shared Virtual Feedback (F(1,53) = .57, p =.46, partial η2 = .01) or transactive memory structure (F(1,53) = .76, p = .39, partial η2 = .01) were found for reaction times. Table 28 shows the means associated with this interaction and the results are visualized in Figure 18**.**

Table 29: Reaction Times (s): Presence of Shared Virtual Feedback (SVF) x Transactive Memory Structure

		Reaction Time (s)	
		Integrated	Differentiated
SVF	*M*	32.26	35.18
	SE	2.25	2.33
No SVF	*M*	31.42	32.54
	SE	2.33	2.33

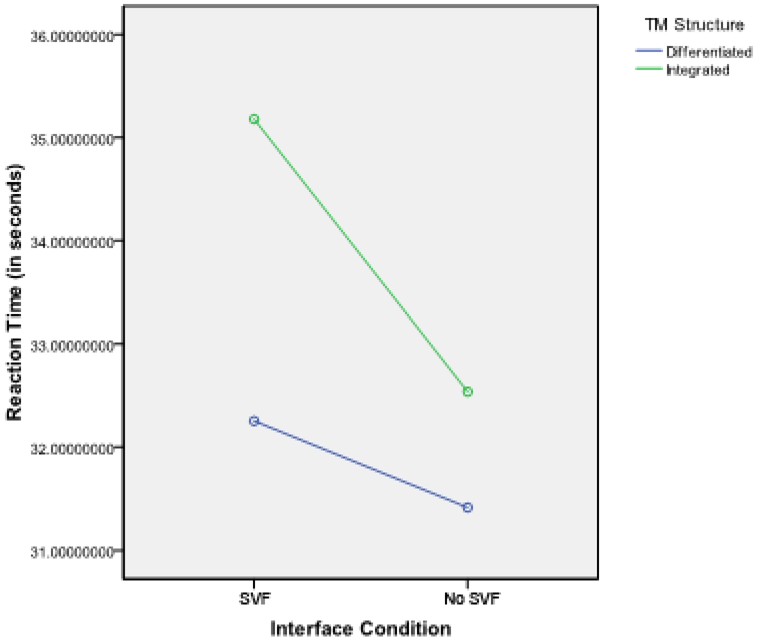

Figure 19: Estimated Marginal Means for Reaction Time in seconds (Presence of Shared Virtual Feedback x TM Structure)

Finally no interaction effects between the two conditions were found for any of the variables.

Transactive Memory

To assess the teams perceived transactive memory via the Lewis (2003) scale a second 2 (Presence of Shared Virtual Feedback) x 2 (Transactive Memory Structure) factorial ANOVAs was conducted. Consistent with the initial analysis, a main effect was found for transactive memory structure (F(1,53) = 9.38, p < .01, partial η2 = .15), with teams with divergent structures having higher reported transactive memory (M=3.61, SE=0.08) than teams with integrated structures (M=3.27, SE=0.08). On the other hand no main effect was found for interface type (F(1,53) = .25, p = .62, partial η2 = .01). Additionally, further analysis revealed no significant interaction effects (F(1,53) = .08, p = .78, partial η2 = .02). Table 30 shows the means associated with this interaction and the results are visualized in Figure 20.

Table 30: Perceived Transactive Memory: Presence of Shared Virtual Feedback (SVF) x Transactive Memory Structure

		Perceived TM	
		Integrated	Differentiated
SVF	*M*	3.22	3.60
	SE	0.11	0.11
No SVF	*M*	3.31	3.62
	SE	0.11	0.11

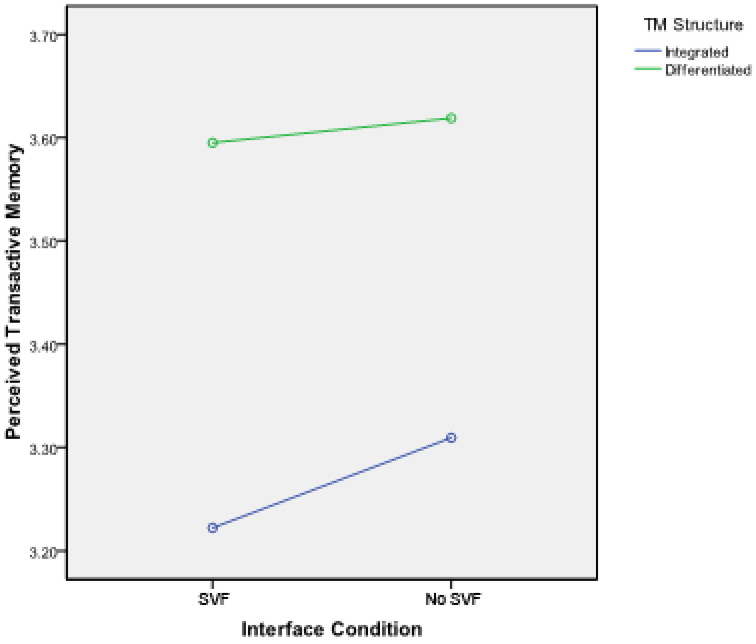

Figure 20: Estimated Marginal Means of Perceived Transactive Memory (Presence of Shared Virtual Feedback x TM Structure)

Since the Lewis (2003) scale only measure perceived transactive memory, a follow up analysis was conducted to see if there were any differences across conditions for transactive memory content and utilization. A 2 (Presence of Shared Virtual Feedback) x 2 (Transactive Memory Structure) MANOVA was conducted to examine teams transactive memory utilization scores and specialization index. This analysis revealed a significant multivariate main effects for only transactive memory structure (Wilks' Λ = 0.54, F(2,52) = 22.04, p < .01, partial η2 = .46). No effects were found for Presence of Shared Virtual Feedback (Wilks' Λ = 0.97, F(2,52) = .91, p = .41, partial η2 = .03). However, the multivariate effect for transactive memory structure should be interpreted in light of a significant multivariate interaction effect for Transactive Memory Structure x Presence of Shared Virtual Feedback (Wilks' Λ = 0.90, F(2,52) = 2.60, p < .10, partial η2 = .09).

The first univariate analysis, for specialization index revealed a main effect for transactive memory content (F(1,53) = 35.21, p < .01, partial η2 = .40), with teams in the differentiated condition having significantly higher specialization index (M=9.50, SE=0.69) than teams in the integrated condition (M=3.77, SE=0.68). No main effect was found for Presence of Shared Virtual Feedback (F(1,53) = 0.83, p = .37, partial η2 = .02), as there was no significant difference in specialization index for teams in the shared virtual feedback (M=7.07, SE = 0.68) and no shared virtual feedback (M=6.20, SE=0.69) conditions. Additionally, there was no interaction effect found between conditions. Table 31 shows the means associated with this interaction and the results are visualized in Figure 21.

Table 31: Specialization Index: Presence of Shared Virtual Feedback (SVF) x Transactive Memory Structure

		Specialization Index	
		Integrated	Differentiated
SVF	*M*	4.37	9.78
	SE	0.94	0.97
No SVF	*M*	3.17	9.21
	SE	0.97	.097

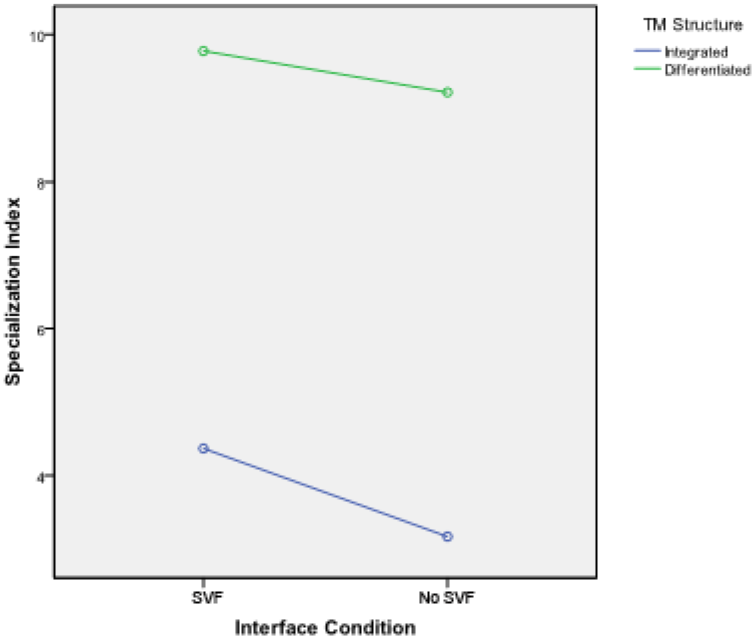

Figure 21: Estimated Marginal Means of Specialization Index (Presence of Shared Virtual Feedback x TM Structure)

The second univariate analysis, for transactive memory utilization revealed a main effect for transactive memory structure (F(1,53) = 12.17, p < .01, partial η2 = .19), with teams in the differentiated condition having significantly higher transactive memory utilization (M=.70, SE=0.05) than teams in the integrated condition (M=0.45, SE=0.05). No main effect was found for Presence of Shared Virtual Feedback (F(1,53) = 0.83, p = .37, partial η2 = .02), as there was no significant difference in utilization for teams in the shared virtual feedback (M=0.79, SE = 0.05) and no shared virtual feedback (M=0.54, SE=0.05) conditions. However, the main effect for transactive memory structure should be interpreted in light of a transactive memory structure x Presence of Shared Virtual Feedback interaction that was also obtained (F(1,53) =5.29, p < .05, partial η2 = .09). Table 32 shows the means associated with this interaction and the results are visualized in Figure 22.

Table 32: Transactive Memory Utilization: Presence of Shared Virtual Feedback (SVF) x Transactive Memory Structure

		Transactive Memory Utilization	
		Integrated	Differentiated
SVF	*M*	0.57	0.66
	SE	0.07	0.07
No SVF	*M*	0.34	0.74
	SE	0.07	0.07

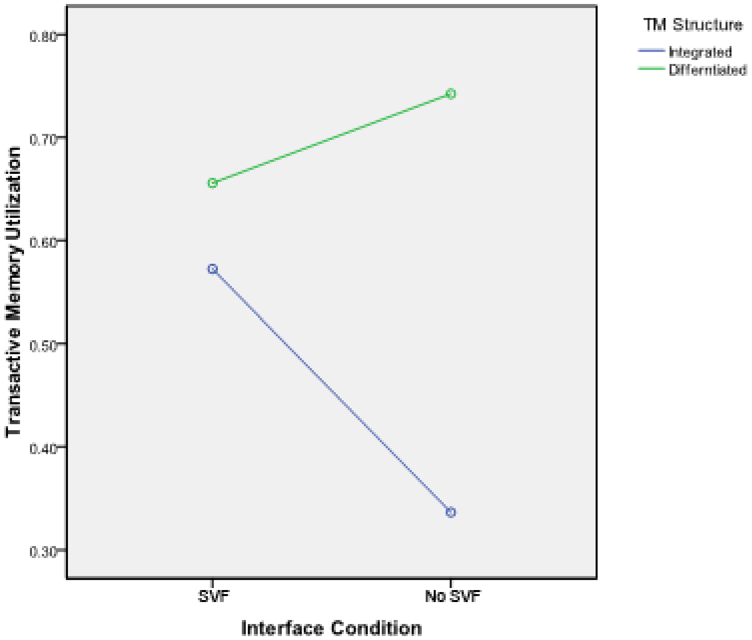

Figure 22: Estimated Marginal Means of Transactive Memory Utilization (Presence of Shared Virtual Feedback x TM Structure)

This interaction shows that the shared virtual feedback improved transactive memory utilization for teams with integrated structures. On the other hand, for teams with differentiated structures, the shared virtual feedback was detrimental to their ability to utilize their transactive memory system. However, it should be noted, that since the Transactive Memory Utilization was calculated as a percentage, this interaction may be a result of *fewer* information transfers for teams with integrated structures. A follow up independent sample t-test that teams with differentiated structures transferred significantly more incident reports (M = 25.14, SD = 3.9) than teams with integrated structures (M=15.38, SD=9.80).

Team Perceptions

A final set of analyses assessed more intangible outcomes of the manipulations on the teams. Specifically, this analysis looked at how a team's perceptions of their integration and processes. Within the survey, team processes were measured based on a team's perception of their ability to share correct information, adjust strategies, keep track of each other's actions, request assistance, identify and correct mistakes, coordinate and synchronize actions, develop confidence in each other, and encourage each other to do their best. Team integration was measured based on a team's perception of their ability to work closely with each other, communicate frequently, work collectively rather than independently, and transfer information.

To assess if there were any effects as a result of the manipulations on team processes and integration, a 2 (Presence of Shared Virtual Feedback) x 2 (Transactive Memory Structure) MANOVA was conducted. This analysis revealed a significant multivariate main effects for transactive memory structure (Wilks' $\Lambda = 0.77$, $F(2,52) = 7.96$, $p < .01$, partial $\eta2 = .23$), but no effects for Presence of Shared Virtual Feedback (Wilks' $\Lambda = 1.0$, $F(2,5) = 0.04$, $p = 0.96$, partial $\eta2 = .002$) or interactions.

No univariate main effects for either Presence of Shared Virtual Feedback (F(1,53) = .57, p =.46, partial η2 = .01) or transactive memory structure (F(1,53) = .76, p = .39, partial η2 = .01) were found for perceived team processes. Table 33 shows the means associated with this interaction and the results are visualized in Figure 23**.**

Table 33: Perceived Team Processes: Presence of Shared Virtual Feedback (SVF) x Transactive Memory Structure

		Team Processes	
		Integrated	Differentiated
SVF	*M*	2.53	2.36
	SE	0.12	0.13
No SVF	*M*	2.31	2.50
	SE	0.13	0.13

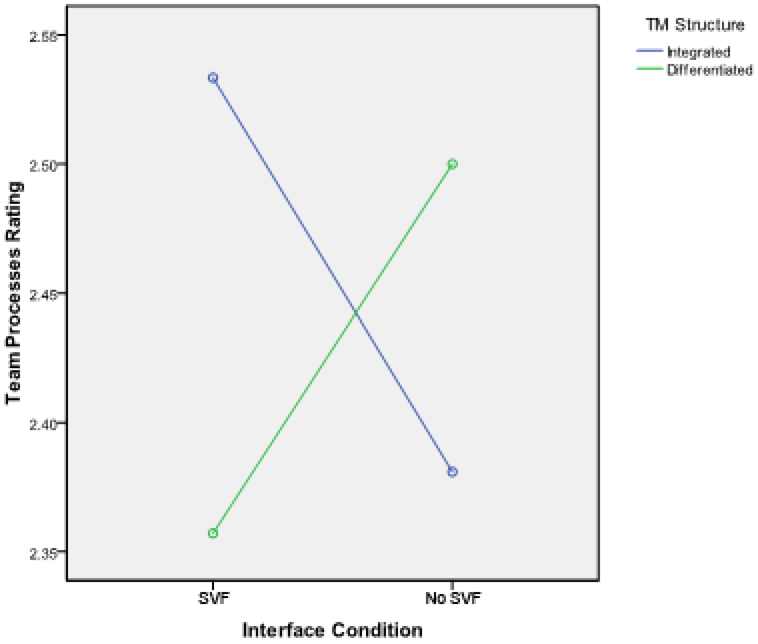

Figure 23: Estimated Marginal Means of Team Processes Ratings (Presence of Shared Virtual Feedback x TM Structure)

The second univariate analysis, for team integration revealed a main effect for transactive memory structure (F(1,53) = 12.93, p < .04, partial η2 = .20), with teams in the integrated condition having significantly higher team integration (M=3.10, SE=0.09) than teams in the differentiated condition (M=2.67, SE=0.09). Similarly, no main effect was found for Presence of Shared Virtual Feedback (F(1,53) = 0.07, p = .80, partial η2 = .001), as there was no significant difference in specialization index for teams in the shared virtual feedback (M=2.90, SE = 0.09) and no shared feedback (M=2.87, SE=0.09) conditions. Additionally there were no interaction effects found. Table 34 shows the means associated with this interaction and the results are visualized in Figure 24.

Table 34: Perceived Team Integration: Presence of Shared Virtual Feedback x Transactive Memory Structure

		Team Integration	
		Integrated	Differentiated
SVF	*M*	3.11	2.69
	SE	0.12	0.12
No SVF	*M*	3.10	2.64
	SE	0.12	0.12

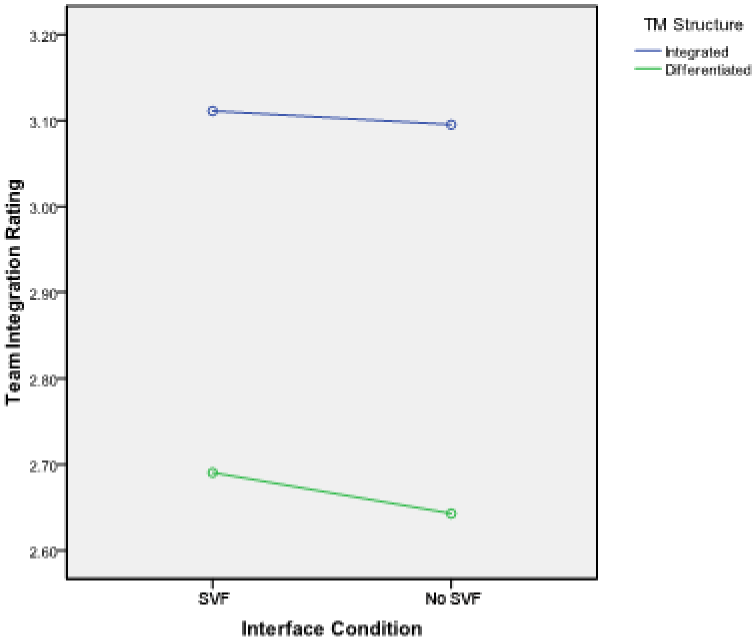

Figure 24: Estimated Marginal Means of Team Integration Ratings (Presence of Shared Virtual Feedback x TM Structure)

Since the teams perceived transactive memory system did not have any effects on team performance (as measured by the normal score), follow up analysis looked at the impact of a team's transactive memory system on more intangible outcomes. To assess these, two separate hierarchical regression analysis was used, with the outcome variables (integration, processes and self-efficacy) as the dependent variables (DV). The analyses were conducted such that the control variables were entered on the first step of the model (i.e., Shared Virtual Feedback-Divergent Structure, Shared Virtual Feedback-Integrated Structure, etc.), as well as other pertinent controls that might affect their perceptions of team work (i.e. previous team experience, comfort and preference). Finally, on the second step of the model was the teams perceived transactive memory rating.

The first regression analysis looked at how perceived transactive memory (on Step 2) predicted perceived team processes. As Table 35 shows, the team process rating was set as the DV for the regression analysis.

Table 35: Regression Analysis of the Relationships between Perceived Transactive Memory System and Team Processes

	R^2	F	ΔR^2	F_{inc}	β	t
Step 1	0.03	0.78				
SVF-DS					-0.08	-0.45
SVF - IS					0.13	0.78
NSVF-DS					0.07	0.42
Team Experience					0.11	0.67
Distributed Team Experience					-0.31	-1.93^t
Distributed Team Comfort					0.11	0.77
Team Preferences					0.03	0.18
Step 2	0.18	2.52	0.20	13.34*		
Perceived Transactive Memory					0.50	3.65**

Note: N = 57 teams, ^{t} p < .1 * p < .05, ** p < .01; SVF = Shared Virtual Feedback, NSVF = No Shared Virtual Feedback, DS = Differentiated Structure, IS = Integrated Structure

From the table you can see that a team's perceived transactive memory ($\beta = 0.50$, $p < .01$) positively predicts their perception of their team processes. Additionally, perceived transactive memory explains incremental variance beyond the control variables (Δ R^2 = .19, F(1,50) = 2.52, p < .01), which become non-significant once they are entered into the model.

The second regression analysis looked at how perceived transactive memory (on Step 2) predicted perceived team integration. As Table 36 shows, the team integration rating was set as the DV for the regression analysis.

Table 36: Regression Analysis of the Relationships between Perceived Transactive Memory System and Team Integration

	R^2	F	ΔR^2	F_{inc}	β	t
Step 1	0.15	2.45				
SVF-DS					-0.36	-2.32*
SVF - IS					0.00	-0.02
NSVF-DS					-0.41	-2.71**
Team Experience					0.08	0.56
Distributed Team Experience					-0.15	-1.04
Distributed Team Comfort					0.00	-0.02
Team Preferences					0.24	1.75^t
Step 2	0.15	3.76	0.13	9.85*		
Perceived Transactive Memory					0.40	3.14**

Note: N = 57 teams, ^{t} p < .1 * p < .05, ** p < .01; SVF = Shared Virtual Feedback, NSVF = No Shared Virtual Feedback, DS = Differentiated Structure, IS = Integrated Structure

From the table you can see that a team's perceived transactive memory (β = 0.40, p < .01) positively predicts their perception of their team processes. Although the addition of perceived transactive memory explains incremental variance beyond the control variables (Δ R^2 = .15, F(1,48) = 2.52, p < .05), some of the control variables, including SVF-DS and NSVF-DS conditions and team preferences remain significant at Step 2 of the model.

Summary

The ancillary analysis revealed several interesting findings that better helps us understand the impact of shared virtual feedback and transactive memory structure on various team outcomes. Since there are no observable effects for the overall team performance scales, ancillary analyses were conducted on other behavioral measures such as report completeness, reaction time, errors, and communication. For transactive memory, further analysis was conducted to investigate any interaction effects between the two IVs as well as further analysis on the team's transactive memory structure and content. Finally, since transactive memory did not directly influence performance, its effects on other intangible variables such as team processes and integration were investigated. Table 37 presents a summary of the analyses and findings from the ancillary analysis.

Table 37: Summary of Ancillary Findings

ID	Analysis Question	Finding(s)
1	What are the interaction effects between transactive memory structure and Presence of Shared Virtual Feedback on team performance?	• No significant effects
2	What are the interaction effects between transactive memory structure and Presence of Shared Virtual Feedback on team communication?	• Teams in differentiated conditions communicated less than teams in integrated • Teams who did not receive shared virtual feedback communicated slightly more than teams who received the interface
3	What are the interaction effects between transactive memory structure and Presence of Shared Virtual Feedback on report completeness?	• Teams in differentiated condition had significantly higher scores for report completeness • Teams who received shared virtual feedback had significantly higher report completeness
4	What are the interaction effects between transactive memory structure and Presence of Shared Virtual Feedback on errors made?	• Teams in the differentiated condition made significantly fewer errors • Teams who received shared virtual feedback made slightly more errors than teams who did not
5	What are the interaction effects between transactive memory structure and Presence of Shared Virtual Feedback on reaction time?	• No significant effects
6	What are the interaction effects between transactive memory structure and Presence of Shared Virtual Feedback on perceived transactive memory?	• Teams in the differentiated condition reported higher levels of transactive memory
7	What are the interaction effects between transactive memory structure and Presence of Shared Virtual Feedback on transactive memory content?	• Teams in the differentiated condition had higher scores on specialization index
8	What are the interaction effects between transactive memory structure and Presence of Shared Virtual Feedback on transactive memory utilization?	• Teams in differentiated condition had higher scores on transactive memory utilization metrics • Significant interaction showing shared virtual feedback was detrimental to teams in differentiated condition while beneficial to teams in the integrated condition
9	What are the interaction effects between transactive memory structure and Presence of Shared Virtual Feedback on team processes?	• No Significant Effects
10	What are the interaction effects between transactive memory structure and Presence of Shared Virtual Feedback on team integration?	• Teams with integrated structure reported higher team integration
11	How does the perception of transactive memory impact team processes?	• Teams transactive memory positively predicted high team processes ratings • Teams transactive memory positively predicted high team integration ratings

Chapter 6

Evaluating Transactive Memory in Distributed Cyber Teams: Discussion

Experiment Analysis

Shared Virtual Feedback

One of the main goals of this study was to understand how a shared virtual feedback interface could help augment transactive memory for distributed teams. There is an emerging consensus that transactive memory is formed through an interpersonal awareness of the knowledge of others (Wegner, et al., 1985). In previous research, transactive memory is typically formed through interactions such as collective learning (Hollingshead, 1998a), collaborative training (Hollingshead, 1998b), or long term social or professional interactions (Hollingshead, 2000; Jackson & Moreland, 2009; Littlepage, et al., 2008; Moreland, et al., 2010). While not fully operationalized, it was assumed that the transactive memory system was built through explicit (i.e., telling somebody you know something), and implicit (i.e., observing somebody utilizing knowledge to complete a task) knowledge transactions that occurred during the study or from previous interactions. While these transactions occur naturally in face-to-face interactions, many of the affordances, like explicit communication, or body language, are lost in the virtual context. This not only causes a lack of transactive memory formation, but also an overall decrease in performance.

Since there was very little research on supporting transactive memory in distributed teams, research from shared workspaces and groupware informed the development of the ATM interface. From this research, the ATM shared virtual feedback interface provided an up-to-the-minute assessment of each team member’s performance across the different functional domains. Contrary to expectations, the shared virtual feedback, for the most part, showed little to no increases in performance, and in some cases was actually detrimental. The first two hypotheses projected that the shared virtual feedback would improve teams overall performance (via the normal score) and cause an increase in their perceived transactive memory system. While there was no significance found, it is interesting to note that on average, teams who did not receive shared virtual feedback had higher team scores and perceived transactive memory.

Based on the initial hypothesis, several follow up analyses investigated the effects of shared virtual feedback on other behavioral outcomes and transactive memory metrics, as well as any interaction effects with the transactive memory structure. Of the remaining behavioral outcomes, shared virtual feedback only had a positive effect on improving report completeness. Teams who did not have shared virtual feedback communicated *slightly* more and made *slightly* fewer errors. There were no significant effects found for reaction time. However, on average teams who received shared virtual feedback responded slower to reports than teams who did not receive the feedback. For transactive memory, there were metrics to measure the team's transactive memory content (specialization index) and utilization. For content, there was no significance found. However, teams in the shared virtual feedback conditions had on average, a higher rating. While there were no significant main effects, the results showed an interesting interaction effect. The shared virtual feedback improved transactive memory utilization in teams with integrated transactive memory structures, but was severely detrimental to teams with differentiated structures. This finding showed that while shared virtual feedback was beneficial in improving transactive memory formation in teams with integrated structures, it impeded formation for teams with differentiated structures.

While much of the literature from CSCW and HCI have made claims that if designed correctly, collaborators can maintain awareness of each other's actions in a shared workspace, there has been little attempt to tie their findings specifically to transactive memory. While we hypothesized in the other direction, these results further support previous transactive memory literature that implied face-to-face interaction is required (i.e., Hollingshead, 1998b). While the lack of performance outcomes contradicted our hypotheses, the detriment caused by the shared virtual feedback in other behavioral measures was even more surprising. Although teams in the shared virtual feedback condition had higher overall report completeness, they were on average slower, more error prone, and less communicative. Based on results from Moreland & Myaskovsky (2000), it was thought that by providing team members performance grades on various knowledge areas would help avoid mistakes and improve communication between relevant parties. After closer examination, the current implementation of the ATM interface has several inherent differences from the expertise review sheets used by Moreland & Myaskovsky. One major difference between the two mechanisms was that the expertise review sheets were static from the beginning of the study to the end, while the ATM was a dynamic measure. Additionally, each team member's rating across the functional domains reset to zero at the beginning of each scenario. Because of this lack of consistency across scenarios, the scores were susceptible to individual events skewing the score and providing ratings that may not be representative of a person’s actual knowledge or skills. This causes a conflict between the information reported on the ATM and the individual’s transactive memory system. If one person they previously thought was good at solving one type of event but had a relatively low rating reported in the ATM, their decision making process could be slowed down and their internal cognitive processes interrupted.

Another possible reason for these differences was the lack of training for the interface. In order to keep training times similar in conditions where the ATM was present on the interface, teams only received 7 extra slides, four of which provided insight on how to use the interface. Additionally, in these training slides, participants were told “When looking to TRANSFER REPORTS or identify who can provide advice in a specific area, make sure to utilize the ATM-I” and “if used properly, the ATM-I should help improve team performance.” This may have caused teams who received the ATM to lean on it as a replacement for communication, rather than a supplementary tool that integrates into their collaboration. This may be further confounded due to the modality of the communication mechanism. It has been shown that text based chat does not afford effective information sharing (McNeese, et al., 2006), and when combined with a “replacement tool,” users may be even less prone to sharing. This could have caused participants to rely on the ATM to provide information about each other rather than obtaining it through interpersonal communications and interactions via the chat window. It is possible that if participants were properly trained to use the ATM as a supplementary tool to improve their communications and collaborations, that they would see a score increase.

The result discussed is the interaction effect found between the shared virtual feedback and transactive memory structure on transactive memory utilization. This interaction showed that in conditions where the teams had differentiated structures the presence of shared virtual feedback had a negative effect on their transactive memory utilization, but when the team had an integrated structure, they saw a significant increase in their utilization scores. This finding is consistent with the effects found in Wegner et al. (1985). In their study, when dyads that had an established transactive memory structure were given an explicit structure their performance decreased. On the other hand, dyads that were unfamiliar with each other saw a performance increase with the introduction of an explicit structure. In the case of this study, the teams with differentiated structures had a very clear division of labor based on their training and the ATM may have conflicted with their predetermined system. Because teams in the integrated condition had no predetermined agreement of who was good at what, the ATM interface allowed them to form natural specialties in the different functional domains based purely on their performance. In this situation, the ATM interface tried to force an explicit transactive memory structure upon the team, which acted as interference with the team member's mental models.

While these negative effects were not significant, the results may magnify if the task required more close collaboration. In this simulation, the task relied on individual work, situated within a collaborative system. If the task would required more interdependent work (e.g., more information sharing, collaborative decision-making, etc.), it is possible that the ATM interface, as it is currently presented (in both implementation and training), would become even more detrimental to team performance.

Table 38 shows a summative analysis of the impact of shared virtual feedback on various perceptual and behavioral outcomes in the simulation.

Table 38: Summative Analysis for Shared Virtual Feedback

Outcome	Impact of ATM	Significant
Team performance	Negative	No
Team communication	Negative	Yes (slight)
Report Completeness	Positive	Yes
Errors	Negative	Yes (slight)
Reaction Time	Negative	No
Perceived Transactive Memory	Negative	No
Transactive Memory Content	Positive	No
Transactive Memory Utilization	Positive	No
TM Utilization x TM Structure	Positive (Integrated Structure) Negative (Differentiated Structure)	Yes

Transactive Memory Structure

The second focus of this study was on understanding the difference in transactive memory structures on distributed team performance. Most research agrees that teams with more diverging knowledge (or more specialization) are preferable over teams with more similar knowledge (i.e., Austin, 2003; Lewis, 2003; Littlepage, et al., 2008; N. Michinov & Michinov, 2009; Moreland, 1999; Wegner, 1987). On the other hand, several researchers have shown that the nature of the task should dictate the type of structure necessary to complete it (i.e., X. Chen & Dietrich, 2009; Gupta & Hollingshead, 2010; van Ginkel, et al., 2010).

While there was some evidence against it, due to the nature of the task, and a previous understanding of the cyber environment (Tyworth, et al., 2012), it was hypothesized that teams who had divergent transactive memory structures would outperform and have higher reported levels of transactive memory than teams in the integrated condition. From the results, there is support for only one of these hypotheses. There was no significant difference in performance between teams in either condition (though teams in the integrated condition performed *slightly* better on average).

Consistent with the initial hypothesis, teams with differentiated structures reported higher levels of transactive memory than teams with integrated structures. To follow up on these results from the initial hypotheses, a follow-up analysis on other behavioral measures, transactive memory content and utilization were conducted. For the other behavioral measures, there was a split between which type of transactive memory structure was preferable in improving group behaviors. Overall teams with diverging transactive memory structure made significantly fewer errors and had significantly better report completeness than teams with integrated structures. On the other hand, teams with integrated structures communicated significantly more during the simulation. For the other transactive memory metrics, teams with differentiated structures had significantly higher scores on both transactive memory utilization, and transactive memory content (specialization index).

These results were *esp*ecially interesting because of the finding from the open-ended question showing that transactive memory had no significant effects on performance within the simulation. Therefore, while the teams in the differentiated condition had higher levels of transactive memory (perception, content and utilization) it had no effect on their performance. For the Lewis (2003) study, this is to be expected as perceived team cognition metrics do not account for the structure or actual knowledge possessed within the team and may not result in performance outcomes (DeChurch & Mesmer-Magnus, 2010; Mohammed, Tesler, & Hamilton, 2011). The results for transactive memory content and utilization are consistent with the findings of Jackson & Moreland (2009). They showed that even when teams had previously formed transactive memory systems from face-to-face interactions, they were not able to utilize these in distributed settings to improve their performance. This implies that the issue with distributed interactions may not be one of transactive memory *formation* or *maintenance* but rather an issue of *utilization*. Adding to their results, our findings show that teams with a divergent transactive memory structure communicated significantly less, and relied too heavily on the division of labor defined by their specialties. For these teams, the transactive memory system may have actually hurt them, as it made them assume they did not need to communicate, which is required in the distributed context. This resulted in a more loose collaboration, in which teams relied more heavily on *individual* work and simply coordinated their actions. On the other hand, teams with integrated structures, communicated more so they could form a more complete picture of each functional area.

This difference in teamwork is described by Dillenbourg (1995) as the distinction between collaboration and cooperation. In his research, he defined cooperation as work that is "…accomplished by the division of labor among participants, as an activity where each person is responsible for a portion of the problem solving…" while collaborative work is defined as "…mutual engagement of participants in a coordinated effort to solve the problem together." These two concepts map directly to the results presented above. Teams in the integrated condition, due to their incomplete knowledge, had to rely on communication in order to form a complete understanding of each functional domain. Using the chat, teams with integrated knowledge structures took part in collaborative work, where the team worked together and took collective responsibility of the problem solving. Interestingly, in the differentiated condition, teams relied very little on communication. Rather than discussing individual reports, these teams choose to create a division of labor across functional domains, and work independently. Because of this, teams with integrated structures were able to make up for their incomplete knowledge through communication and tight collaborative processes in order to achieve a similar performance to teams in the differentiated structure condition.

Finally, in a subsequent analysis, the results show that teams in the integrated structure, because of their tighter collaborative processes had significantly higher levels of perceived team integration. Since research has shown that teams will naturally form specialties (i.e, Hollingshead, 2000, 2001; Wittenbaum, et al., 1996; Wittenbaum, et al., 1998), over a longer period, it is possible that these intangible aspects of teamwork that were formed early in their interaction would enable them to improve their performance more so than other teams. Since teams have more similar information, they could form a stronger sense of common ground which would be even more beneficial in the long haul (Clark & Brennan, 1991). Because they had incomplete information, they had to share information in order to learn each functional domain, creating a collective learning effect, which is beneficial in improving team performance (i.e., Hollingshead, 1998b; D. W. Liang, et al., 1995; Moreland & Myaskovsky, 2000). Based on all of these factors, over a longitudinal period, it is possible that teams who started with integrated structure will begin to outperform teams with differentiated structures.

It is possible that if teams in the differentiated structure would have communicated more and had a tighter collaboration, they will have been able to increase their score and perceived team integration, thus separating themselves from teams with integrated structures in the short and long term. In the training, there was little emphasis on communication, other than a general implication that you should do it. This caused teams to form their own agreement on how much was necessary. Since teams with differentiated structures were able to achieve satisfactory performance with little communication, they felt it was unnecessary and did not rely on it for their task. If trained in better communicative practices, it is possible that they would experience a collective induction effect, which would improve team synergy, develop a shared understanding of the problem space, and improve team performance.

A summative analysis of the impact of the transactive memory structure on various perceptual and behavioral outcomes in the simulation is shown in Table 39.

Table 39: Summative Analysis for Transactive Memory Structure

Outcome	Preferred Structure	Significant
Team performance	Integrated	No
Team communication	Integrated	Yes
Report Completeness	Differentiated	Yes
Errors	Differentiated	Yes
Reaction Time	Differentiated	No
Perceived Transactive Memory	Differentiated	Yes
Transactive Memory Content	Differentiated	Yes
Transactive Memory Utilization	Differentiated	Yes
Team Integration	Differentiated	Yes

Measuring Transactive Memory in Distributed Teams

One of the first challenges that needed overcome when starting this work was to develop new ways to measure transactive memory in distributed collaborations. While some previous research had looked at transactive memory in distributed teams (e.g., Adibhatla, et al., 2009; Keel, 2007; Schreiber & Engelmann, 2010) they focused primarily on technological design and didn't add much in terms of potential measurement tools. Since the Lewis (2003) scale was already validated and shown to be an accurate measure for perceived transactive memory, focus was placed on developing measures to assess transactive memory utilization and content. From our findings, both of the metrics, transactive memory utilization and specialization index, were accurate predictors of a team's perceived transactive memory.

The transactive memory utilization measured tangible behaviors that indicated the presence of a strong transactive memory system. The real benefit of this metric is that it made the utilization of transactive memory visible and measurable, even in the distributed context. The downside to the current implementation of transactive memory utilization in the *teamNETS* simulation was that there were opportunities for teams to operate outside of the metric. For example-- rather than explicitly transferring information, players could ask each other using the chat how to solve a specific event. This would be a behavioral indication of the presence of a transactive memory system, but not represented in the current metric. The second metric for transactive memory content, the specialization index, was also successful at predicting perceived transactive memory. The specialization index showed that the recall metric used by many early studies (i.e., Hollingshead, 1998a; Wegner, et al., 1991; Wegner, et al., 1985) was scalable to a more complex task. Rather than focusing on remembering words in different categories, participants recalled aspects of the training and organized them into their functional domains. Additionally, through the integration of the transactive memory index, the metric was able to get at the structure of the system by representing the overall division of actual knowledge shared amongst the team and across the different functional domains.

While successfully deployed in this study, further examination of the metrics will be necessary to see if they are generalizable and scalable to other tasks and contexts. For transactive memory utilization, the metric was effective because the overall task and goal was clear. In more interactions that have fuzzy or unclear goals, teasing out transactive memory utilization may not be as simple as in this study. The other metric, the specialization index, while effective, may have scalability issues when translating to a more complex or realistic task. Being a scaled-world simulation, the experimental design controls the total amount of knowledge and knowledge categories, which made the recall task manageable within the context of the experiment. In a more realistic task, relevant knowledge is dynamic and susceptible to changing several times based on the current situation and needs. Future implementations of this metric may have to use more complex knowledge elicitation methods, such as concept mapping (Thordsen, 1991), card sorting (Cordingley, 1989), repertory grid analysis (Kelly, 1992), or ladder grid (Geiwitz, Kornell, & McCloskey, 1990), to name a few. While this would add a significant amount from the researcher’s point of view, it would provide richer data, and more insight into not only the transactive memory content, but also the structure.

Role of Transactive Memory in Distributed Teams

The research that has looked at transactive memory in distributed teams focused on technological (i.e., Adibhatla, et al., 2009; Keel, 2007; Schreiber & Engelmann, 2010) or organizational (i.e., Choi, 2010; Moreland, et al., 2010) outcomes with limited contributions to understanding how the construct has changed or evolved. Going into this study, there was a strong research base that predicted the formation and utilization of transactive memory in distributed teams was not possible (i.e., Hollingshead, 1998a; Jackson & Moreland, 2009). Using the Lewis (2003) transactive memory field measure, which has been utilized in numerous studies to provide evidence of transactive memory (i.e., Jackson & Moreland, 2009; Lewis, 2004; Littlepage, et al., 2008; N. Michinov & Michinov, 2009), there was some evidence to support the presence of transactive memory systems. While we can make some claims to the fact that teams were able to form some level of transactive memory system, there was little evidence to support the presence of effective transactive memory utilization.

Though there is little research on the role of transactive memory in distributed teams, researchers agree that having an effective transactive memory system is a positive predictor of team performance. More specifically, of the three dimensions of transactive memory, specialization of expertise has the largest effect on team performance (i.e., DeChurch & Mesmer-Magnus, 2010; Littlepage, et al., 2008; E. Michinov, et al., 2009). While this may be the case, since trust plays a major role in distributed collaborations, the impact of credibility on performance would increase. Unfortunately, our results showed no relationship between any of the dimensions of transactive memory and performance. Additionally, the complete transactive memory scale had no relationship with team performance. Rather than directly influence a complex outcome like team performance, follow up analyses looked at whether or not transactive memory had an impact on other mediating variables. Specifically, the intangible teamwork aspects such as team integration and processes were assessed. While there was no support for transactive memory improving team processes, teams who had high transactive memory were more likely to have higher team integration.

As discussed earlier, these results are consistent with the findings of Jackson & Moreland (2009), where even if teams had formed a transactive memory system, they were not able to utilize it in a distributed context. In their research Jackson & Moreland (2009), explain that the internal functions that enable transactive memory utilization are triggered by face to face interactions, thus the performance drop off in distributed interactions. Contrary to this, via the transactive memory utilization scale, our results show some evidence of transactive memory utilization, but it was not effective enough to improve team performance. Another possible explanation is in the nature and length of the task. Since the performance scenarios were only 15 minutes in length, and part of a 2-hour experiment, the teams may have not had the chance to fully develop their transactive memory systems and understand how to utilize them to improve performance. While many of the early studies in transactive memory involved similar periods, they also allowed more face-to-face and social interactions, which allowed teams to see the benefits of an effective transactive memory system in a shorter amount of time. Since the task did not require tightly coupled collaboration, the effects of the transactive memory system may have been minimal. If teams were required to collaborate to fill out action reports, rather than individually complete them, there may have been an increase of the effect of the transactive memory system on performance.

Situation Awareness and Transactive Memory

As discussed earlier, transactive memory forms through awareness of the others in the environment and the knowledge and skills they possess. While the literature is very persistent of this fact, little work has gone into understanding exactly what that awareness is. To address this one of the hypotheses attempts to understand the interplay between situation awareness and transactive memory. Even though the apparent overlap, the two constructs have only been anecdotally tied to each other (Richter & Lechner, 2009). From our results, we found that two separate measures of perceived situation awareness, SART and MARS, were significant predictors of transactive memory. This showed that when teams reported having higher levels of situation awareness, they were more likely to report having high levels of transactive memory.

This finding has major implication for not only transactive memory research, but also research in distributed collaborations and situation awareness as well. The positive relationship between the two constructs implies that transactive memory formation may occur through a specialized type of team situation awareness, where rather than aspects of the environment, awareness situates in the behaviors, actions, and knowledge of others. In this context, the situation awareness would act as a social cognitive process in which an individual's awareness would act as implicit transactions. This mechanism, when coupled with explicit communication and information sharing, would help form and maintain transactive memory systems. Looking back at models of situation awareness, several connections are established. Within the context of the Endsley (1995) three level model, one would have perception of knowledge or skills possessed by another, comprehension the significance and utility of those skills, and make predictions of what other similar skills they may have and the utility of those skills. This is not to say that one would have either transactive or situation awareness, but rather this awareness would be part of one's "complete situation awareness."

On the other hand, rather than transactive memory being a functional aspect of situation awareness, it is possible that a team or group SA resides within a larger transactive memory system. In Stanton et al. (2006), the authors explain the concept of distributed situation awareness as a system in which the complete SA is divided amongst people and technology present in the environment. This interpretation would imply that the situation awareness divides amongst the group, based on their specializations and roles. Team members would use a coordinated retrieval function (Wegner, 1995), to process who is responsible for a portion of the awareness and then leverage their knowledge to complete a task.

While the results presented in this dissertation do not represent a full understanding of the interaction between transactive memory and situation awareness, the positive relationship found opens the door for future research. In addition, since situation awareness has a long and rich history, the previous research may be informative in the design and interpretation of future transactive memory studies.

Cyber Security Teams

In the design of the simulation, there was careful consideration to replicate the collaborative nature of cyber security analysts. While the task itself and data representations do not have the same complexities in the real world, the results from this study still have numerous applications and implications for cyber security teams. The current set of findings, as well as the qualitative findings from Tyworth et al. (2012), show compelling evidence that the lack of collaboration within cyber security teams is still a major gap that needs to be addressed by research.

In this study, teams with differentiated structures were most similar to the cyber security collaborations and teams described in Tyworth et al. (2012). These teams communicated with each other very little, and shared information with each other only when it was necessary. Consistent with their results, teams with differentiated knowledge (or knowledge of one functional domain) focused solely on their own job, and did little in regards of information sharing, or trying to understand other functional domains, which caused teams to have lower team integration. When they did share information, because of their divergent knowledge, it is possible that they had difficulty translating and understanding each other.

These results may imply the lack of communication and effective information sharing is a product of the transactive memory or knowledge structures within the team and not necessarily unique to the cyber context. Though it should be noted that there are other confounds associated with cyber security which may magnify these effects--such as analysts being reluctant to share information between each other (Hui, et al., 2010), and some organizations policies (Majchrzak & Jarvenpaa, 2004). In Tyworth et al. (2012) the authors suggest that through the design and implementation of effective boundary objects the collaborations across functional domains may be improved. Contrary to this, in our study the shared virtual feedback, which served as a boundary object across roles, caused further detriment to team communication and collaboration. Since there was very little emphasis placed on training for cross-domain communication and collaboration, teams resorted to the least amount of effort necessary to complete the task. This implies that the issue is not a purely technological one, and even a properly designed artifact may further confound the issue. Rather emphasis may focus on training individuals to not only use the artifact or boundary object (Star & Griesemer, 1989), but also in general communication and collaboration processes that can improve performance.

Another particular research domain which these results may be applicable to is furthering the understanding of a team cyber situation awareness (Jajodia, Liu, & Swarup, 2009). While much of the research in cyber situation awareness (Cyber SA) focuses on software, network and computational technologies, also the human component is important. Cyber SA has been proposed as being a two-step process, focused on the interactions between the human analyst and the technology within the environment (Mancuso, et al., 2012). This interaction requires the technology to accurately mine, fuse and present data, while the analyst must detect, extract and leverage the information for decision-making. The results found in this study show that while this may remain true for individual analysts, when considering a team of analysts, the awareness may also be tied to knowledge transactions in the system. This implies that Team Cyber SA, may be a three stage process, tied to not only interactions between the technology and the individual analysts, but also the team(s) of analysts that are present in the environment.

Contributions

The research presented in this dissertation offers five main contributions: (1) the development and delivery of the scaled world simulation, *teamNETS*, (2) the theoretical organization of the literature in transactive memory and propositions for future interdisciplinary research, (3) an experimental evaluation of cyber teams, (4) the experimental design, construction of scenarios, roles, and manipulations, and (5) the analytical investigation of transactive memory in distributed cyber teams.

teamNETS Simulation

The main technological contribution of this study was the development of the new team research platform, *teamNETS*. *TeamNETS*, a simulation based on NeoCITIES, was informed by research that has taken place at the College of Information Sciences and Technology at the Pennsylvania State University for the better part of a decade. Overall the development of the initial *NETS* platform, and the *teamNETS* branch took place over 6 months, consisting of a complete revamp of both the simulation user interface (front end) and the simulation engine (back end).

As a research tool for studying distributed teams, *teamNETS* offers a significant upgrade over previous simulations developed by the MINDS Group[4] (i.e., NeoCITIES 1.0, 2.0, 3.x). With the new higher/lower order knowledge paradigm, *teamNETS* requires

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[4] The MINDS (Multidisciplinary Initiatives in Naturalistic Decision Making) Group is a research ensemble within the User Science & Engineering Lab that studies the role of cognitive technologies within team performance

more complex decision-making, which was not present in previous simulations. Additionally, by coupling a primarily individual task, within a larger more collaborative system, the simulation better represents tasks that a real world analyst (cyber or otherwise) may participate in. These upgrades will allow future students to ask more complex research questions and collect richer data, which may have not been possible before.

The *teamNETS* simulation serves as a major step forward in team research in the MINDS Group. Most previous research situates in the context of distributed emergency response dispatchers. While this domain served its purpose, the move to cyber security has allowed us to investigate a new and dynamic domain, as well as update our research to reflect the current interest in interdisciplinary fields such as Human Factors, Human-Computer Interaction, and Naturalistic Decision Making. This study serves as the first time in the MINDS Group that a team based simulation within the context of cyber security was successfully deployed.

Overall, *teamNETS* has served as a major upgrade from previous versions and ensures a reliable, valid, and easily extendable research tool for the next several years. As displayed in this study, *teamNETS* is a viable platform for investigating team performance, decision-making and cognition within the context of not only cyber security, but also other similar command and control environments.

Interdisciplinary Research Directions for Transactive Memory

The most important theoretical contribution of this study was the interdisciplinary assessment of the previous work in transactive memory. Traditionally, transactive memory research takes a cognitive or socio-organizational perspective and more recently, the technological perspective. While each of these perspectives has added to our overall understanding of the construct, there has been little, if any, cross-disciplinary research on transactive memory. This gap is *esp*ecially surprising considering the impact that transactive memory has in enabling group work.

Based on an understanding of interdisciplinary research domains, and transactive memory, several prospective research opportunities and their potential contributions are discussed. These directions can serve as a basis for furthering our understanding of how transactive memory has changed or evolved within the context of information technology and people. For each of these perspectives there are numerous opportunities to not only to update our understanding of transactive memory, but to validate and build upon previous research from the cognitive, organizational and technological perspectives.

The study presented in this dissertation aims to address some of these research directions. This study looks at transactive memory in a new and complex domain (cyber security) and integrates the use of online collaboration tools. Additionally, the interplay between transactive memory, situation awareness and team dynamics was investigated. This study serves as an important first step in moving transactive memory research out of the individual perspectives and to a more interdisciplinary approach.

Experiment Construction and Design

In order to make this study happen, the overall experimental design was rebuilt from the ground up. Being the first team based simulation on cyber security; significant effort was placed on redeveloping the roles, resources, team processes, in-game metrics, and survey measurement tools. While some of the work was informed by previous qualitative (Tyworth, et al., 2012) and simulation research (Mancuso, et al., 2012), a significant amount of development work had to be done. To support the higher/lower order knowledge paradigm, resources had to support multiple levels in order to assess depth of knowledge. This resulted in three unique higher order categories (representing three functional domains) of intrusions, malicious software, and improper usage. Under each of the higher order categories, there were three lower order categories, the subcategory, mitigation, and priority. Within each of these lower order categories were three unique options each with a different rule set for classification. This structure made for 21 unique answers that for any event, which is a major upgrade from the nine that were available in previous versions of *NeoCITIES*.

Since the simulation moved to a different context and relied on individual work, new scenarios were designed and implemented. In previous *NeoCITIES* research, scenarios consisted of 5-18 events that were shared amongst the team. Since each team-member had individual events that were not shared, *teamNETS* scenarios consisted of 15-36 events with 94 unique events written for the entire experiment. Additionally, since the events represented 3 unique functional domains, the data associated for each was significantly different from the others, adding to the complexity of event design.

Finally, possibly one of the biggest contributions of the experimental construction and design was the method for manipulating transactive memory structures within the ad-hoc teams. Previous research had relied on teams either having predetermined or naturally forming transactive memory systems through task training, practice or longitudinal interactions. While this supported more rich and realistic transactive memory systems, from the perspective of a controlled experiment it was not a preferable method. By manipulating the training received prior to the task, our results (via the transactive memory field measure), showed a successful manipulation of the teams transactive memory structure across conditions. This method should help inform future controlled experiments in transactive memory, and will allow researchers to better extract and experiment on specific aspects of transactive memory utilization in collaborative work.

Experimental Evaluations of Cyber Teams

While not the entire focus, this study presents a major step forward in bringing cyber tasks, environments and teams into the laboratory. Building off research conducted by Tyworth et al. (2012) roles, resources and scenarios were constructed to best represent the task and collaborations present within the cyber environment. Though the data and tasks were simplified for the target participant base (undergraduates), the individual and collaborative processes that were built into the simulation mimicked the processes of real world cyber analysts.

Although it seemed trivial in the beginning, the construction of the roles, events, and scenarios to maintain ecological validity with the cyber environment, while being manageable for the participants was a major challenge in the development of this research project. Countless hours went into the design of each individual functional domain, and the higher/lower order categories so that they were unique, realistic, and understandable. From both rounds of pilot testing, almost all the events were modified to make them more accessible to the participants. Even though the study itself had general success, in retrospect further work needs to go into event and/or training development to help improve participant's scores.

Even with the simplified context, this study serves as a contribution, by enabling researcher to understand teams within the context of cyber security. Our findings reiterate those found in the Tyworth et al. (2012) qualitative study, showing the breakdown of collaboration across functional domains in cyber security. Though there is limited applicability of these specific results to the cyber domain, the research platform supports scalability and complex data sets.

Experiment Results

The final contribution of this research is the results and findings of the experiment that hope to inform future research in relation to transactive memory.

The foremost practical contribution from this study was the negative impact of the shared virtual feedback interface. Though I hypothesized that shared virtual feedback would be beneficial for teams by sharing information about their performance, almost the complete opposite happened. Teams receiving shared virtual feedback, communicated less, made more errors, and had lower perceived transactive memory. This is not to say that shared virtual feedback is always going to be detrimental, but it is important that teams are trained to use them as supplementary tools to *improve* their collaboration, rather than a means to *replace* collaboration.

One of the major theoretical contributions of this study was the comparison of integrated and differentiated transactive memory structures in the distributed context. Overall, I hypothesized that teams with differentiated structures would outperform teams with integrated structures, but the results were not able to substantiate that claim. From a performance standpoint, both the differentiated and integrated structure teams performed similarly. After closer examination, teams in the integrated condition were able to make up for their lack of depth in each functional domain through communication and information sharing. Even though teams in the differentiated condition had higher report completeness and made fewer errors, they communicated very little, which may have impeded their ability to perform above average. From a transactive memory standpoint, teams with differentiated structures scored higher on all transactive memory metrics than teams in the integrated condition.

Finally, the results that showed the linkage between transactive memory and situation awareness may serve to be a major contribution to the field. Previous research has done little in terms of linking transactive memory to other theoretical theories, which has limited our understanding of the construct as a whole. Based on our results, we can make the claim that there is some linkage between a team's perceived transactive memory system and their situation awareness. While we cannot present a complete understanding of what this means, this finding should open the door for future research in linking the two constructs.

Limitations

Several issues in the design and execution of this experiment pose limitations to the results and findings in this document.

The main limitation associated with study was the participant pool. Being a team research study a large number of subjects were required in order to achieve a satisfactory N. Since recruiting a significant number of actual cyber security analysts to satisfy our requirements was impractical, undergraduate college students were used. The participant pool was predominantly 20-year-old males who had a limited understanding of cyber security. Though they were unfamiliar with cyber security, it should be noted that many of the classes where recruiting was focused had a strong emphasis on group work, so the macrocognitive aspects of this study should hold valid.

Because recruiting was limited to one department, and participants divided with another similar study, the final N was not as high as it could have been. Optimally, I would have an N of 100 (or 300 participants) but that would have required going outside of the department to recruit participants. Additionally, since one researcher ran all the studies, to achieve a higher N, significantly more time and/or resources would have been required. Another limitation that was a result of the recruiting mechanism was the total length of the experiment. Since students received extra credit for their participation, the study was limited to a reasonable timeframe that was representative of their payment. Optimally the study would run over a longer period or multiple sessions so we could better assess transactive memory in longitudinal or longer tasks. This would have required another method of paying participants, and would have required significantly more events to be developed, thus pushing the timeline back even more.

In order to capture enough performance data within the time constraints of the study, the time allocated to training the participants was streamlined. While many of the teams were able to gain an adequate understanding of the task, numerous teams would have benefitted from further explanation of the interface and higher/lower order categories. In addition, most teams would have benefitted from another training scenario to improve their understanding of more complex events and collaborations. Also as discussed earlier, the training associated with the ATM interface was limited to maintain an experimental consistency with the other condition. As our results showed, participants may have benefitted from further training of how to leverage the feedback to improve their collaboration, rather than leaning on it as a replacement for communication.

Finally, the adaptation of the Human Performance Scoring model from traditional resource allocation to its current interpretation may need further investigation. While the scores had a normal distribution, the scoring model may have been too sensitive for the more complex context and decision-making requirements of *teamNETS*.

Chapter 7

Future Work and Conclusion

Future Work

Future Analyses

The findings and results presented in this dissertation represent only a fraction of the data collected from this study. Due to time constraints and limiting the scope, there was not an enough time to merge, code and analyze all of the available data.

From the simulation, possibly the richest source of data that has yet to be explored are the raw chat logs for each team. Due to minimal resources (only one researcher), and an aggressive timeline, there was not sufficient time to code and analyze the chat transcripts, which totaled close to 3000 lines of text. Future analyses on these chat logs may use the NeoCITIES communication inventory (Hellar, 2009; Pfaff, 2008), Crew Situation Awareness coding methodology (Mosier & Chidester, 1991), transactive memory coding mechanism (Sarcevic, et al., 2008), or other more inductive coding methodologies. This data can be used in conjunction with the other metrics to better understand how specific team processes impact transactive memory and overall team performance.

From the survey, there is even more opportunities for follow up analyses to better understand the findings presented in this study. In the introductory survey, measures were used to collect information about general demographics (e.g., gender, age, academic information) and other individual differences such as video game experience, motivation to lead, comfort and experience in distributed teamwork, and opinions on teamwork. While some of these were used as controls in the hierarchical linear regression, future analyses could be used to understand individual differences and their impact on transactive memory and team performance. Other survey metrics that were not analyzed include measures of self-efficacy, interdependence, and evaluation of the interface. Future analysis may use these to understand the performance and cognitive outcomes of the previous results. Additionally, after coding of the chat logs has been completed, metrics from the performance surveys and evaluations by subject matter experts can be used to complete a metric for transactive memory structure (Austin, 2003).

Finally, the statistics conducted for this dissertation are only the beginning of potential analysis. While no variables were found to impact performance, follow up analysis can look at interaction effects between different variables and assess their impact. Additionally, more complex analysis can look at the interactions between the different dimensions of transactive memory, as collected by the Lewis (2003) field measure, and understand their impact on distributed team performance.

Future Research

In addition to potential future analyses, the results found in this study, can better inform future research studies focused on cyber security teams, transactive memory, and distributed collaborations in general.

While the current study did a respectable job of mimicking the collaboration present in many cyber analyst teams, the data, and decision-making processes/outcomes are significantly simpler in comparison to their real world counterparts. Since *teamNETS* can handle multiple data types, and be easily expandable, future research on distributed cyber teams may integrate more realistic data sets and complex decision-making tasks. Previous research using the *NETS* platform used raw intrusion detection data in an IDS categorization task, can be consulted as a basis for improving the fidelity of the simulation (Mancuso, et al., 2012). Future research using *teamNETS* could use raw data such as IDS Alerts, Firewall Data, and Network Access Control Logs across the three roles for a more realistic scenario. While this data would allow for a richer and more ecologically valid cyber security task, significant effort would have to put into developing each scenario and training materials to ensure the participants could adequately complete the task.

As discussed, the current simulation supports a very loose style of collaboration where the majority of the work was individual, but situated within a larger collaborative system. While this was more representative of real cyber analyst teams, it may minimize the impact of transactive memory systems. To better assess the role of transactive memory in tighter distributed collaborations numerous modifications to the *teamNETS* simulation are possible. For one, in the current system you can only send events from one player to another. Future versions of *teamNETS* rather than sharing the event or information, player should be able to share Action Reports. In this case, two players can work together to collectively fill out and file an Action Report. Currently, in *teamNETS* there is very little interdependency and no interdependent events. In previous version of *NeoCITIES,* interdependent events, which required action from more than one player, were effective tools in studying team collaboration and cognition (Hamilton, et al., 2010). Rather than each event being malicious software, intrusion or improper usage, events should support multiple higher order categories, which in turn would require players to communicate, collaborate and coordinate their actions effectively to achieve the highest score.

The measures collected in the surveys for this study were constrained based on the experiment time limit and current research questions. Future research could add new metrics to collect data about workload, affect, and even different situation awareness metrics. One specific metric that was initially supposed to be used for this study, but had to be cut due to complexity was a transactive memory scale based on SAGAT (Endsley, et al., 1988). This tool could better help triangulate the interactions between situation awareness and transactive memory. Additionally, other individual difference metrics can be added to better understand the design of teams to best support and leverage transactive memory systems.

Finally, the present study only presents an introductory assessment into interdisciplinary research in transactive memory. While still an interesting problem, synchronous online collaboration tools, like used in this study, are being replaced by asynchronous tools with both humans and agents operating within the workspace. Future research should address not only synchronous tools, but also the impact of agents, social media, and collective knowledge stores on transactive memory and distributed team performance.

Conclusion

This dissertation represents an interdisciplinary investigation into the role of transactive memory systems in distributed team collaborations. Set within the context of cyber security, a new team based simulation, *teamNETS*, was developed to address several of the proposed interdisciplinary perspectives for transactive memory research. Using *teamNETS* an experiment was conducted to better understand the role of shared virtual feedback and transactive memory structures affected distributed team performance.

When first beginning this research, a thorough investigation into what had been done in transactive memory had to be conducted. Based on the review, it was found that the majority of research took uni-disciplinary perspectives and focused either on cognitive, socio-organizational, or technological aspects of transactive memory. From an understanding of previous perspectives on transactive memory, and current work being done in interdisciplinary research, several prospective research directions, problems and questions were proposed. The goal of each research direction is to understand the role of transactive memory within a more modern context, as well assess how it has changed and evolved from our traditional understanding.

To address a few of the interdisciplinary research directions posed in the literature review, a new team based simulation was developed. Based on previous research with the *NeoCITIES* simulation, as well as an understanding of the cyber environment and cyber teams, the *teamNETS* simulation was built upon the *NETS* platform. *TeamNETS* was developed to represent three disparate functional domains of cyber security. To address the transactive memory research questions, resources were expanded to include higher and lower order knowledge. Using this, each resource had meta-data which a player could attach to potentially increase their score. This added depth allows researchers to assess specialization within the different functional domains of cyber security.

Using the *teamNETS* simulation, a team based human-in-the-loop experiment was designed to assess the role of shared virtual feedback and transactive memory structures in improving the performance and transactive memory in distributed teams. Contrary to expectations, it was found that the shared virtual feedback interface was actually detrimental to team's performance and transactive memory formation. Since teams who received shared virtual feedback via the ATM relied on it as a replacement to typical distributed collaborations, they were not able to see any sort of performance increase, and in some cases had negative results when compared to teams without shared virtual feedback. For the transactive memory structure, little was found in terms of behavioral or performance differences. It is shown that teams with integrated structures participated in tighter collaborative processes as they communicated more via the chat, while teams with differentiated structures relied more on individual work. It was hypothesized that if teams in the differentiated structure were trained to properly communicate they could have improved their performance. Unfortunately, based on the current analyses, there was no conclusive evidence to support transactive memory improving team performance in distributed collaboration. Teams reported having medium to high levels of transactive memory, thus supporting previous claims by Jackson & Moreland (2009) that distributed interactions may hamper transactive memory utilization rather than formation. A final finding, and potentially the most interesting in informing future research, was the interactions between transactive memory and situation awareness. Though they seem to be conceptually linked, very little research has approached how the two constructs relate to each other. Though still preliminary, our findings suggest that teams with high perceived situation awareness are more likely to have high perceived transactive memory. These findings pose interesting implications for future research in transactive memory, distributed teams, and cyber security.

Though the present study did not change the traditional understanding of transactive memory and nor does it fully move it into interdisciplinary space, it serves as a first step in pushing myself, and hopefully others, to use transactive memory as a lens to understand the role of technology in our lives. Contrary to some of the previous research, the results of this study show that the formation and utilization of transactive memory in distributed collaborations is possible, but more work and research will have to be conducted in the domain. Finally, it is important to remember that this research is only a small portion of the potential for applying transactive memory to interdisciplinary research. As technology continues to grow and evolve, it is important that we continue to push the bounds of our understanding of not only transactive memory, but move other social, cognitive and organizational theories out of their traditional perspectives and into an interdisciplinary space.

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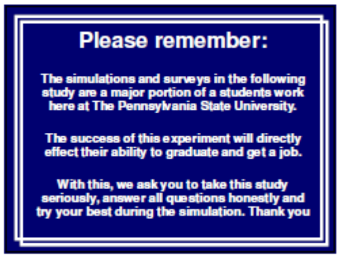
Appendix A

TeamNETS Training Materials

Welcome to the TeamNETS Experiment

These PowerPoint Slides will guide you through the study.

DO NOT begin without the permission of the experimenter.



Please remember:

The simulations and surveys in the following study are a major portion of a students work here at The Pennsylvania State University.

The success of this experiment will directly effect their ability to graduate and get a job.

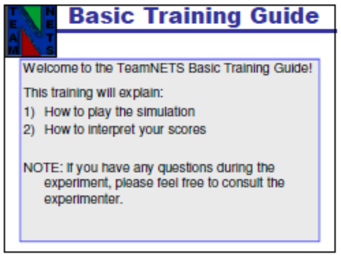
With this, we ask you to take this study seriously, answer all questions honestly and try your best during the simulation. Thank you

Please complete the first survey by clicking the link below. Once finished you may continue to the next slide

SURVEY 1

Please review the following slides on BASIC TeamNETS Training…

DO NOT RUSH through these slides. You will need to know this information to participate in TeamNETS.

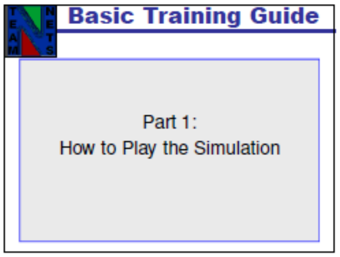


Basic Training Guide

Welcome to the TeamNETS Basic Training Guide!

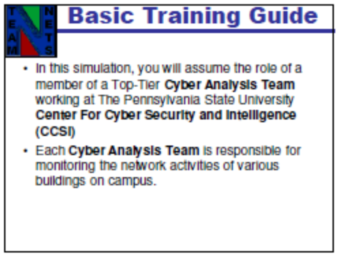
This training will explain:
1) How to play the simulation
2) How to interpret your scores

NOTE: If you have any questions during the experiment, please feel free to consult the experimenter.



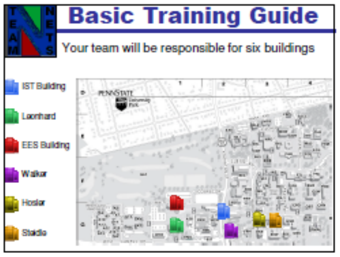
Basic Training Guide

Part 1:
How to Play the Simulation



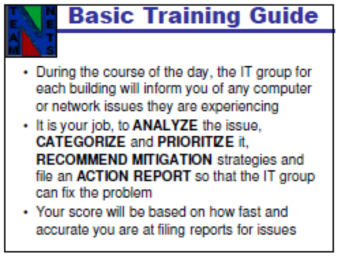
Basic Training Guide

- In this simulation, you will assume the role of a member of a Top-Tier **Cyber Analysis Team** working at The Pennsylvania State University **Center For Cyber Security and Intelligence (CCSI)**
- Each **Cyber Analysis Team** is responsible for monitoring the network activities of various buildings on campus.



Basic Training Guide

Your team will be responsible for six buildings



Basic Training Guide

- During the course of the day, the IT group for each building will inform you of any computer or network issues they are experiencing
- It is your job, to **ANALYZE** the issue, **CATEGORIZE** and **PRIORITIZE** it, **RECOMMEND MITIGATION** strategies and file an **ACTION REPORT** so that the IT group can fix the problem
- Your score will be based on how fast and accurate you are at filing reports for issues

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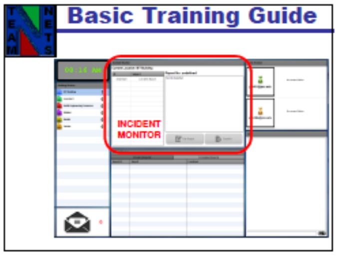
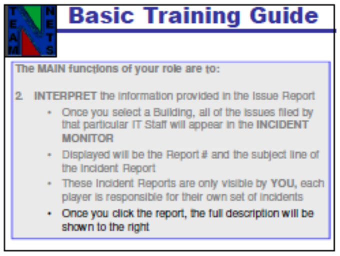


Basic Training Guide



Basic Training Guide

The MAIN functions of your role are to:

2. **INTERPRET** the information provided in the Issue Report
   - Once you select a Building, all of the issues filed by that particular IT Staff will appear in the **INCIDENT MONITOR**
   - Displayed will be the Report # and the subject line of the Incident Report
   - These Incident Reports are only visible by **YOU**, each player is responsible for their own set of incidents
   - Once you click the report, the full description will be shown to the right

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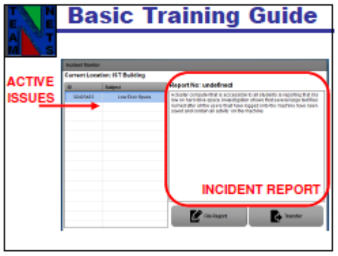
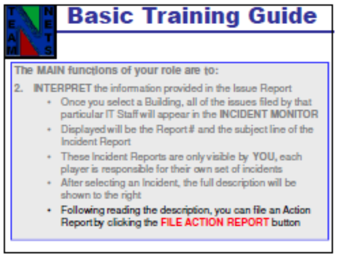


Basic Training Guide



Basic Training Guide

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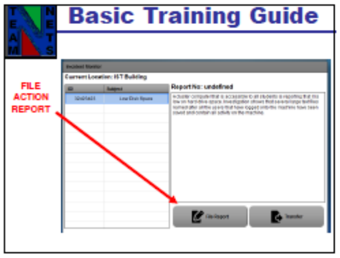
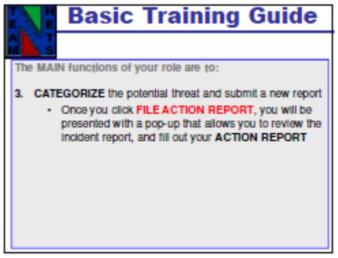
   - These Incident Reports are only visible by **YOU**, each player is responsible for their own set of incidents
   - After selecting an Incident, the full description will be shown to the right
   - Following reading the description, you can file an Action Report by clicking the **FILE ACTION REPORT** button

---



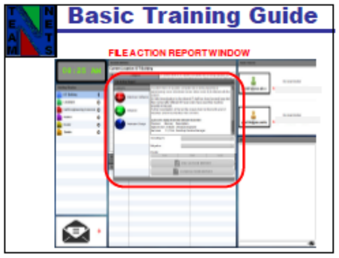
Basic Training Guide



Basic Training Guide

The MAIN functions of your role are to:

3. **CATEGORIZE** the potential threat and submit a new report
   - Once you click **FILE ACTION REPORT**, you will be presented with a pop-up that allows you to review the incident report, and fill out your **ACTION REPORT**

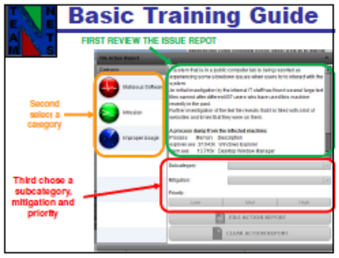


Basic Training Guide

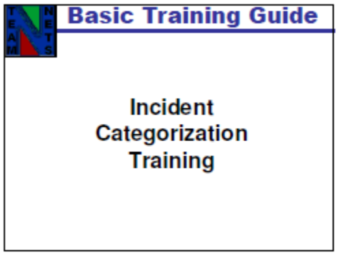
Basic Training Guide

The MAIN functions of your role are to:

3. **CATEGORIZE** the potential threat and submit a new report
   - Once you click the **FILE REPORT**, you will be presented with a pop-up that allows you to review the incident report, fill out your **ACTION REPORT**
   - There are **three main categories** of action reports you can file **MALICIOUS SOFTWARE**, **INTRUSIONS** and **IMPROPER USAGE**
   - Once you select a category, you can then optionally attach other information about the incidents **SUBCATEGORY**, **MITIGATIONS**, and **PRIORITY**

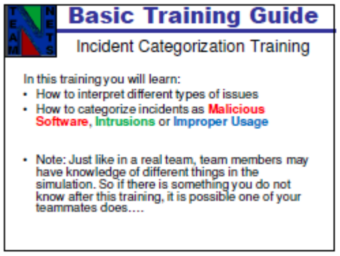


Basic Training Guide



Basic Training Guide

Incident Categorization Training



Basic Training Guide

Incident Categorization Training

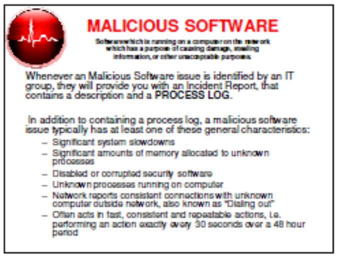
In this training you will learn:
- How to interpret different types of issues
- How to categorize incidents as **Malicious Software**, **Intrusions** or **Improper Usage**

- Note: Just like in a real team, team members may have knowledge of different things in the simulation. So if there is something you do not know after this training, it is possible one of your teammates does….

Basic Training Guide

Main Categories

In TeamNETS there are three main categories of incidents that may occur….



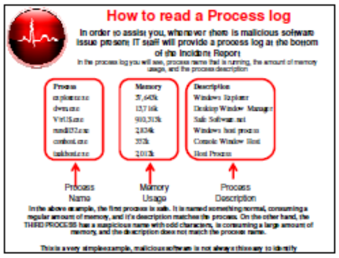
MALICIOUS SOFTWARE

Software which is running on a computer on the network which has a purpose of causing damage, stealing information, or other unacceptable purposes.

Whenever an Malicious Software issue is identified by an IT group, they will provide you with an Incident Report, that contains a description and a **PROCESS LOG.**

In addition to containing a process log, a malicious software issue typically has at least one of these general characteristics:

- Significant system slowdowns
- Significant amounts of memory allocated to unknown processes
- Disabled or corrupted security software
- Unknown processes running on computer
- Network reports consistent connections with unknown computer outside network, also known as "Dialing out"
- Often acts in fast, consistent and repeatable actions, i.e. performing an action exactly every 30 seconds over a 48 hour period



How to read a Process log

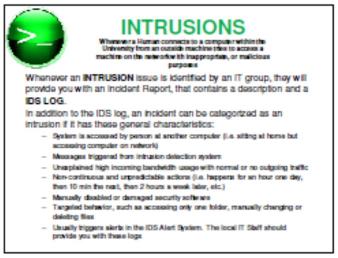
In order to assist you, whenever there is malicious software issue present IT staff will provide a process log at the bottom of the Incident Report

In the process log you will see, process name that is running, the amount of memory usage, and the process description

Process	Memory	Description
explorer.exe	37,645k	Windows Explorer
dwm.exe	13,716k	Desktop Window Manager
Vir!!$.exe	910,313k	Safe Software.net
rundll32.exe	2,824k	Windows host process
conhost.exe	332k	Console Window Host
taskhost.exe	2,012k	Host Process

In the above example, the first process is safe. It is named something normal, consuming a regular amount of memory, and it's description matches the process. On the other hand, the THIRD PROCESS has a suspicious name with odd characters, is consuming a large amount of memory, and the description does not match the process name.

This is a very simple example, malicious software is not always this easy to identify



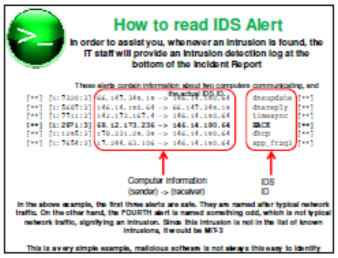
INTRUSIONS

Whenever a Human connects to a computer within the University from an outside machine tries to access a machine on the network with inappropriate, or malicious purposes

Whenever an **INTRUSION** issue is identified by an IT group, they will provide you with an Incident Report, that contains a description and a **IDS LOG.**

In addition to the IDS log, an incident can be categorized as an intrusion if it has these general characteristics:

- System is accessed by person at another computer (i.e. sitting at home but accessing computer on network)
- Messages triggered from intrusion detection system
- Unexplained high incoming bandwidth usage with normal or no outgoing traffic
- Non-continuous and unpredictable actions (i.e. happens for an hour one day, then 10 min the next, then 2 hours a week later, etc.)
- Manually disabled or damaged security software
- Targeted behavior, such as accessing only one folder, manually changing or deleting files
- Usually triggers alerts in the IDS Alert System. The local IT Staff should provide you with these logs



How to read IDS Alert

In order to assist you, whenever an Intrusion is found, the IT staff will provide an Intrusion detection log at the bottom of the Incident Report

These alerts contain information about two computers communicating, and the actual IDS ID.

```
[**] [1:7320:3] 66.147.34.18 -> 146.14.190.64  dnsupdate [**]
[**] [1:5687:3] 146.14.190.64 -> 66.147.34.18  dnsreply  [**]
[**] [1:7711:3] 142.173.167.4 -> 146.14.190.64 timesync  [**]
[**] [1:2971:3] 68.12.173.236 -> 146.14.190.64 BACK      [**]
[**] [1:1265:3] 170.231.2.3 -> 146.14.190.64   dhcp      [**]
[**] [1:7654:3] 17.244.63.106 -> 146.14.190.64 app_frag1 [**]
```

In the above example, the first three alerts are safe. They are named after typical network traffic. On the other hand, the FOURTH alert is named something odd, which is not typical network traffic, signifying an intrusion. Since this intrusion is not in the list of known intrusions, it would be MIT-3

This is a very simple example, malicious software is not always this easy to identify

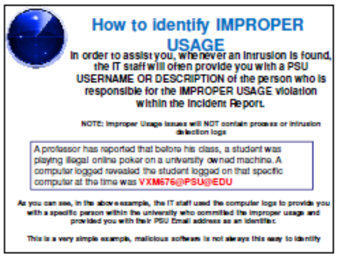
IMPROPER USAGE

Whenever a Human who is physically present on University campus, and on network attached machine exhibits inappropriate, malicious or unacceptable behaviors

Whenever an IMPROPER USAGE issue is identified by an IT group, they will provide you with an Incident Report, that contains a description and a **USERNAME** or **DESCRIPTION**.

In addition to the **USERNAME** or **DESCRIPTION**, an incident can be categorized as improper usage if it has these general characteristics:

- System is accessed directly (i.e. person physically sitting at computer)
- Triggers monitoring system such as website logger, email monitoring, software validation system
- Connected to reports from other people within the university (i.e. reports of suspicious behavior)
- Does not trigger intrusion detection system
- Knows passwords to access system (e.g. doesn't have to use password cracker)
- Unauthorized media (external hard drives, flash drives, ect…) in secure area
- Can be traced back to other incidents (i.e. person received pay cut, student, failed class, etc.)



How to identify IMPROPER USAGE

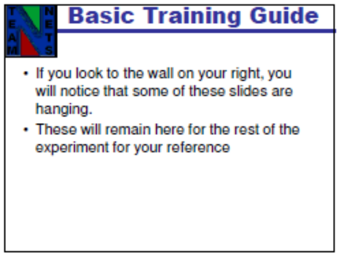
In order to assist you, whenever an Intrusion is found, the IT staff will often provide you with a PSU USERNAME OR DESCRIPTION of the person who is responsible for the IMPROPER USAGE violation within the Incident Report.

NOTE: Improper Usage issues will NOT contain process or intrusion detection logs

A professor has reported that before his class, a student was playing illegal online poker on a university owned machine. A computer logged revealed the student logged on that specific computer at the time was **VXM676@PSU@EDU**

As you can see, in the above example, the IT staff used the computer logs to provide you with a specific person within the university who committed the improper usage and provided you with their PSU Email address as an identifier.

This is a very simple example, malicious software is not always this easy to identify



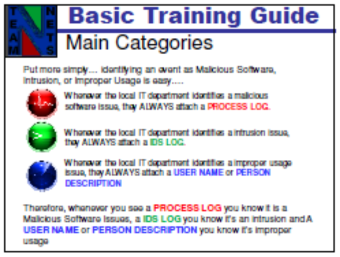
Basic Training Guide

- If you look to the wall on your right, you will notice that some of these slides are hanging.
- These will remain here for the rest of the experiment for your reference

Basic Training Guide

Main Categories

Within each main category there are different guidelines for assigning a **SUB-CATEGORY**, **PRIORITY**, and **MITIGATION**… These are different for every category, so if you know how to Prioritize an INTRUSION, you cannot use these same rules for Malicious Software and Improper Usage



Basic Training Guide

Main Categories

Put more simply…. identifying an event as Malicious Software, Intrusion, or Improper Usage is easy….

Whenever the local IT department identifies a malicious software issue, they ALWAYS attach a **PROCESS LOG.**

Whenever the local IT department identifies a intrusion issue, they ALWAYS attach a **IDS LOG.**

Whenever the local IT department identifies a improper usage issue, they ALWAYS attach a **USER NAME** or **PERSON DESCRIPTION**

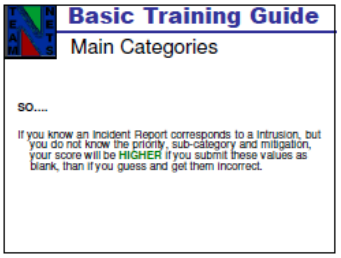
Therefore, whenever you see a **PROCESS LOG** you know it is a Malicious Software Issues, a **IDS LOG** you know it's an intrusion and A **USER NAME** or **PERSON DESCRIPTION** you know it's improper usage

Basic Training Guide

Main Categories

In order to help the IT department solve the issue as quickly as possible and maximize your points in the game, you need to attach information about the **SUBCATEGORY, MITIGATIONS**, and **PRIORITY.**

The more correct information you attach to an **ACTION REPORT** the HIGER your score. BUT the more incorrect information you attach, the LOWER your score

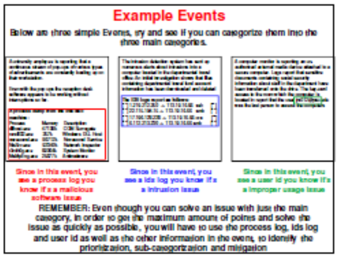


Basic Training Guide

Main Categories

SO….

If you know an Incident Report corresponds to a Intrusion, but you do not know the priority, sub-category and mitigation, your score will be HIGHER if you submit these values as blank, than if you guess and get them incorrect.



Example Events

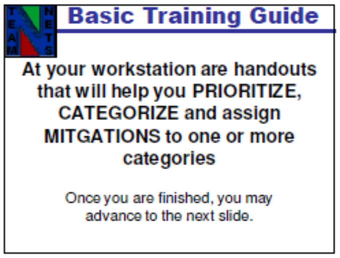
Below are three simple Events, try and see if you can categorize them into the three main categories.

Since in this event, you see a process log you know it's a malicious software issue

Since in this event, you see a ids log you know it's a intrusion issue

Since in this event, you see a user id you know it's a improper usage issue

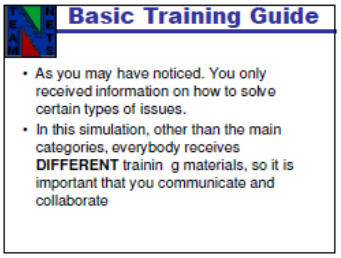
REMEMBER: Even though you can solve an issue with just the main category, in order to get the maximum amount of points and solve the issue as quickly as possible, you will have to use the process log, ids log and user id as well as the other information in the event, to identify the prioritization, sub-categorization and mitigation



Basic Training Guide

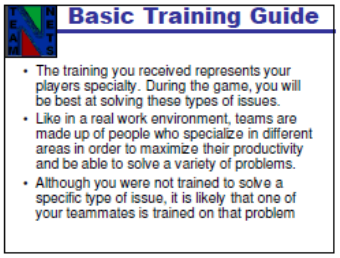
At your workstation are handouts that will help you PRIORITIZE, CATEGORIZE and assign MITGATIONS to one or more categories

Once you are finished, you may advance to the next slide.



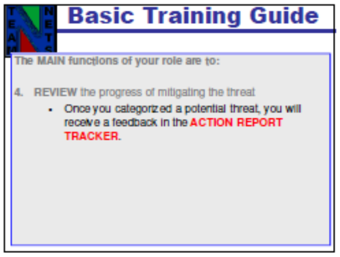
Basic Training Guide

- As you may have noticed. You only received information on how to solve certain types of issues.
- In this simulation, other than the main categories, everybody receives **DIFFERENT** trainin g materials, so it is important that you communicate and collaborate



Basic Training Guide

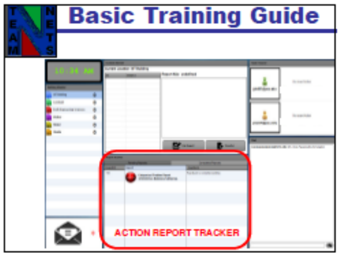
- The training you received represents your players specialty. During the game, you will be best at solving these types of issues.
- Like in a real work environment, teams are made up of people who specialize in different areas in order to maximize their productivity and be able to solve a variety of problems.
- Although you were not trained to solve a specific type of issue, it is likely that one of your teammates is trained on that problem



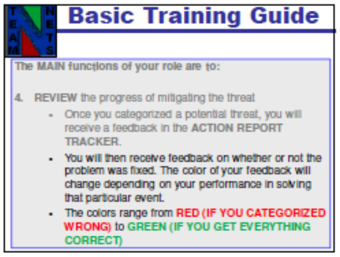
Basic Training Guide

The MAIN functions of your role are to:

4. **REVIEW** the progress of mitigating the threat
   - Once you categorized a potential threat, you will receive a feedback in the **ACTION REPORT TRACKER.**



Basic Training Guide



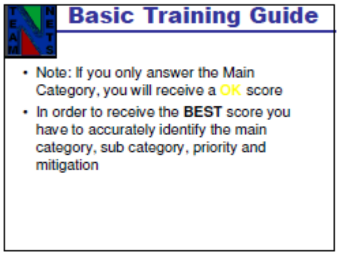
Basic Training Guide

The MAIN functions of your role are to:

4. **REVIEW** the progress of mitigating the threat
   - Once you categorized a potential threat, you will receive a feedback in the **ACTION REPORT TRACKER.**
   - You will then receive feedback on whether or not the problem was fixed. The color of your feedback will change depending on your performance in solving that particular event.
   - The colors range from **RED (IF YOU CATEGORIZED WRONG)** to **GREEN (IF YOU GET EVERYTHING CORRECT)**

Basic Training Guide

ACTION REPORT TRACKER



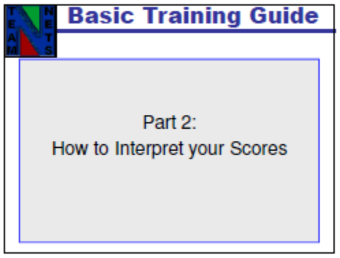
Basic Training Guide

- Note: If you only answer the Main Category, you will receive a OK score
- In order to receive the **BEST** score you have to accurately identify the main category, sub category, priority and mitigation

Basic Training Guide

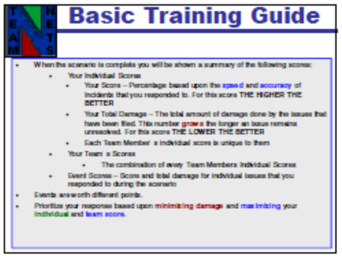
The MAIN functions of your role are to:

4. REVIEW the progress of mitigating the threat
   - Once you categorized a potential threat, you will receive a feedback in the REPORT TRACKER.
   - You will then receive feedback on whether or not the problem was fixed.
   - The color of your feedback will change depending on your performance in solving that particular event.
   - If you correctly fixed the problem, the report will file itself into your Completed Reports
   - If the problem is not fixed, the original incident report will be returned to the INCIDENT MONITOR



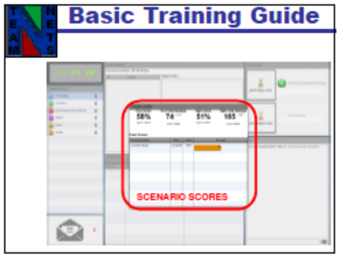
Basic Training Guide

Part 2:
How to Interpret your Scores

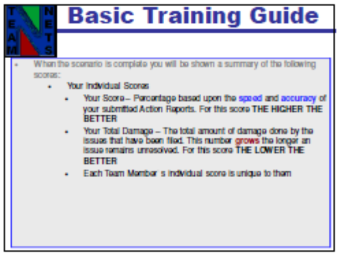


Basic Training Guide

- When the scenario is complete you will be shown a summary of the following scores:
  - Your Individual Scores
    - Your Score – Percentage based upon the speed and accuracy of incidents that you responded to. For this score THE HIGHER THE BETTER
    - Your Total Damage – The total amount of damage done by the issues that have been filed. This number grows the longer an issue remains unresolved. For this score THE LOWER THE BETTER
    - Each Team Member s individual score is unique to them
  - Your Team s Scores
    - The combination of every Team Members Individual Scores
  - Event Scores – Score and total damage for individual issues that you responded to during the scenario
- Events are worth different points.
- Prioritize your response based upon minimizing damage and maximizing your individual and team score.

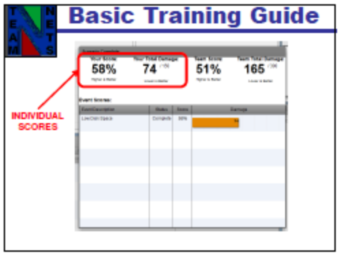


Basic Training Guide

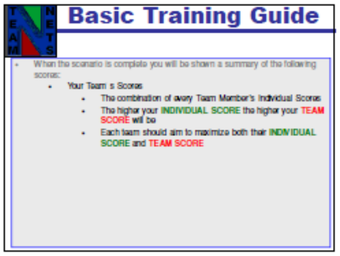


Basic Training Guide

- When the scenario is complete you will be shown a summary of the following scores:
  - Your Individual Scores
    - Your Score – Percentage based upon the speed and accuracy of your submitted Action Reports. For this score THE HIGHER THE BETTER
    - Your Total Damage – The total amount of damage done by the issues that have been filed. This number grows the longer an issue remains unresolved. For this score THE LOWER THE BETTER
    - Each Team Member s individual score is unique to them

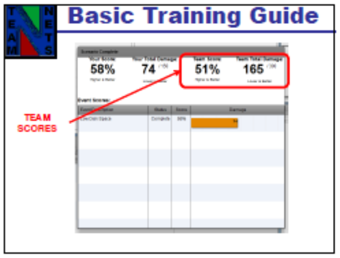


Basic Training Guide

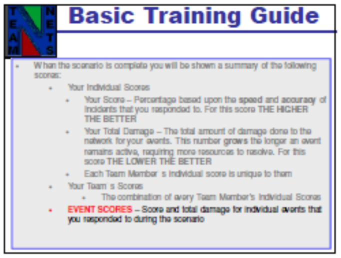


Basic Training Guide

- When the scenario is complete you will be shown a summary of the following scores:
  - Your Team s Scores
    - The combination of every Team Member's Individual Scores
    - The higher your INDIVIDUAL SCORE the higher your TEAM SCORE will be
    - Each team should aim to maximize both their INDIVIDUAL SCORE and TEAM SCORE



Basic Training Guide



Basic Training Guide

- When the scenario is complete you will be shown a summary of the following scores:
  - Your Individual Scores
    - Your Score – Percentage based upon the speed and accuracy of incidents that you responded to. For this score THE HIGHER THE BETTER
    - Your Total Damage – The total amount of damage done to the network for your events. This number grows the longer an event remains active, requiring more resources to resolve. For this score THE LOWER THE BETTER
    - Each Team Member s individual score is unique to them
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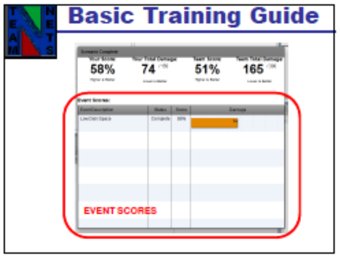
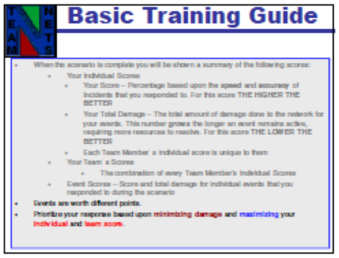
  - EVENT SCORES – Score and total damage for individual events that you responded to during the scenario



Basic Training Guide



Basic Training Guide

- When the scenario is complete you will be shown a summary of the following scores:
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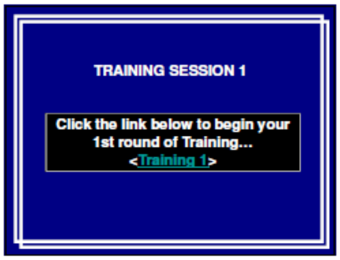
  - Event Scores – Score and total damage for individual events that you responded to during the scenario
- Events are worth different points.
- Prioritize your response based upon minimizing damage and maximizing your individual and team score.

CONGRATULATIONS!

You' re now ready to Practice what you learned during training.

PLEASE WAIT AT THIS SLIDE
until you receive further instructions from the Experimenter.



TRAINING SESSION 1

Click the link below to begin your 1st round of Training...
<Training 1>

TRAINING SESSION 1: SOLUTIONS

For your reference, here are the solutions to the events you received in Session 1. If you have any questions feel free to ask the researcher.

Kids be complaining	Sub-category: Priority: Mitigation:	MS-SC-PHI Medium MS-MIT-1
No Email, Yes Problem	Sub-category: Priority: Mitigation:	MS-SC-VRS Medium MS-MIT-1
I don' t need no stinkin outlook	Sub-category: Priority: Mitigation:	MS-SC-PHI Low MS-MIT-3
There goes my A	Sub-category: Priority: Mitigation:	MS-SC-WRM HIGH MS-MIT-1

TRAINING SESSION 1: SOLUTIONS

For your reference, here are the solutions to the events you received in Session 1. If you have any questions feel free to ask the researcher.

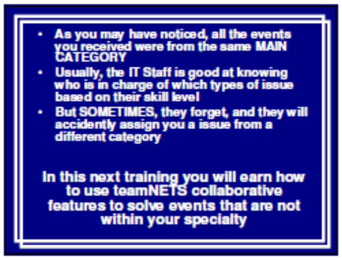
Unhappy customers	Sub-category: Priority: Mitigation:	IN-SC-VND Low IN-MIT-2
No Laggers	Sub-category: Priority: Mitigation:	IN-SC-SRN Low IN-MIT-1
They want to take away our social security	Sub-category: Priority: Mitigation:	IN-SC-BHH High IN-MIT-3
Don' t trust me	Sub-category: Priority: Mitigation:	IN-SC-VND Medium IN-MIT-1

TRAINING SESSION 1: SOLUTIONS

For your reference, here are the solutions to the events you received in Session 1. If you have any questions feel free to ask the researcher.

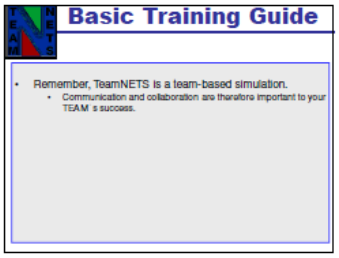
Computer InfraXXXion	Sub-category: Priority: Mitigation:	IU-SC-INV Low IU-MIT-1
Peggle Revenge	Sub-category: Priority: Mitigation:	IU-SC-MAL Medium IU-MIT-2
My Prediction? WoW	Sub-category: Priority: Mitigation:	IU-SC-INV High IU-MIT-1
Microsoft sounds angrier than usual	Sub-category: Priority: Mitigation:	IU-SC-MAL Medium IN-MIT-3

- You should now know how to:
  - Interpret Incident Reports,
  - File Action Reports, and
  - Interpret scores in TeamNETS.
- Your second training session will focus on communication and collaboration with your teammates.



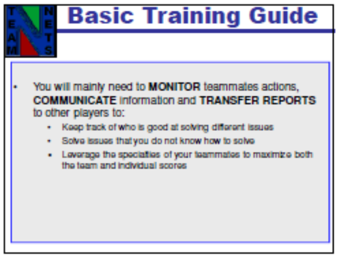
- As you may have noticed, all the events you received were from the same MAIN CATEGORY
- Usually, the IT Staff is good at knowing who is in charge of which types of issue based on their skill level
- But SOMETIMES, they forget, and they will accidently assign you a issue from a different category

In this next training you will earn how to use teamNETS collaborative features to solve events that are not within your specialty



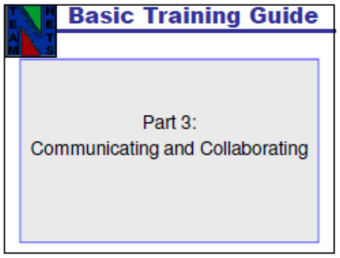
Basic Training Guide

- Remember, TeamNETS is a team-based simulation.
  - Communication and collaboration are therefore important to your TEAM's success.



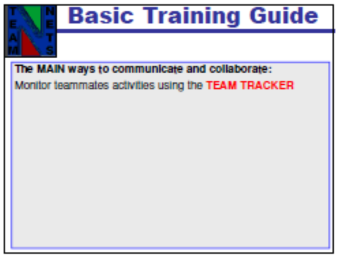
Basic Training Guide

- You will mainly need to **MONITOR** teammates actions, **COMMUNICATE** information and **TRANSFER REPORTS** to other players to:
  - Keep track of who is good at solving different issues
  - Solve issues that you do not know how to solve
  - Leverage the specialties of your teammates to maximize both the team and individual scores



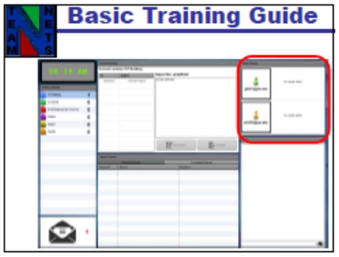
Basic Training Guide

Part 3:
Communicating and Collaborating

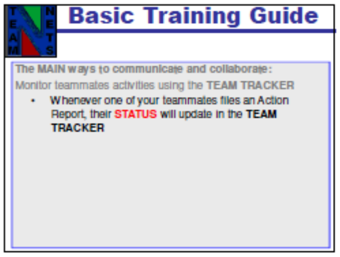


Basic Training Guide

The MAIN ways to communicate and collaborate:
Monitor teammates activities using the **TEAM TRACKER**



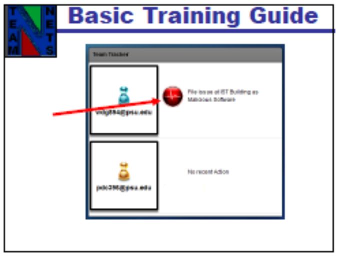
Basic Training Guide



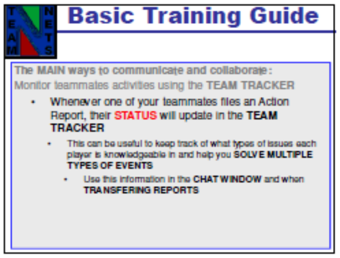
Basic Training Guide

The MAIN ways to communicate and collaborate:
Monitor teammates activities using the **TEAM TRACKER**

- Whenever one of your teammates files an Action Report, their **STATUS** will update in the **TEAM TRACKER**



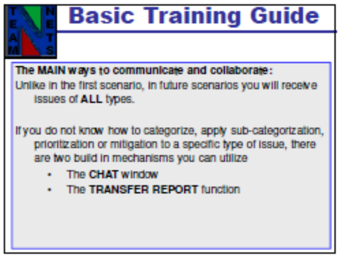
Basic Training Guide



Basic Training Guide

The MAIN ways to communicate and collaborate:
Monitor teammates activities using the **TEAM TRACKER**

- Whenever one of your teammates files an Action Report, their **STATUS** will update in the **TEAM TRACKER**
  - This can be useful to keep track of what types of issues each player is knowledgeable in and help you **SOLVE MULTIPLE TYPES OF EVENTS**
    - Use this information in the **CHAT WINDOW** and when **TRANSFERING REPORTS**

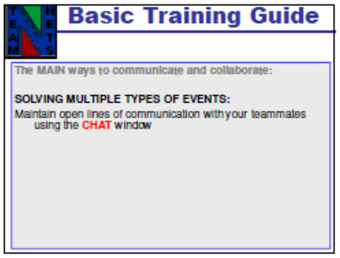


Basic Training Guide

The MAIN ways to communicate and collaborate:
Unlike in the first scenario, in future scenarios you will receive issues of **ALL** types.

If you do not know how to categorize, apply sub-categorization, prioritization or mitigation to a specific type of issue, there are two build in mechanisms you can utilize

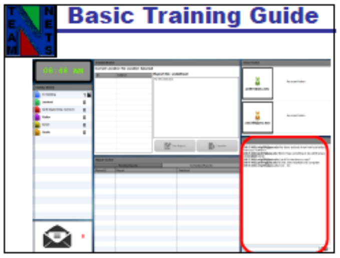
- The **CHAT** window
- The **TRANSFER REPORT** function



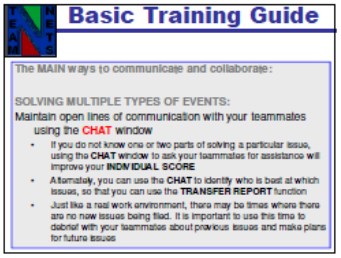
Basic Training Guide

The MAIN ways to communicate and collaborate:

SOLVING MULTIPLE TYPES OF EVENTS:
Maintain open lines of communication with your teammates using the **CHAT** window



Basic Training Guide

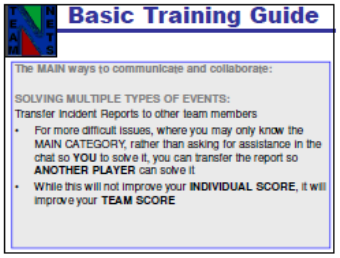


Basic Training Guide

The MAIN ways to communicate and collaborate:

SOLVING MULTIPLE TYPES OF EVENTS:
Maintain open lines of communication with your teammates using the **CHAT** window

- If you do not know one or two parts of solving a particular issue, using the **CHAT** window to ask your teammates for assistance will improve your **INDIVIDUAL SCORE**
- Alternately, you can use the **CHAT** to identify who is best at which issues, so that you can use the **TRANSFER REPORT** function
- Just like a real work environment, there may be times where there are no new issues being filed. It is important to use this time to debrief with your teammates about previous issues and make plans for future issues

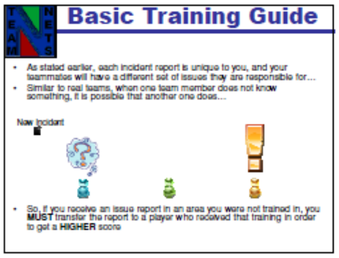


Basic Training Guide

The MAIN ways to communicate and collaborate:

SOLVING MULTIPLE TYPES OF EVENTS:
Transfer Incident Reports to other team members

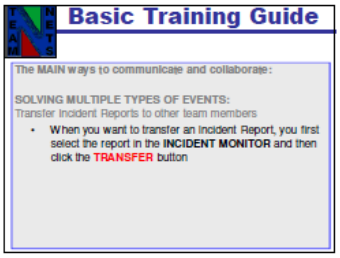
- For more difficult issues, where you may only know the MAIN CATEGORY, rather than asking for assistance in the chat so **YOU** to solve it, you can transfer the report so **ANOTHER PLAYER** can solve it
- While this will not improve your **INDIVIDUAL SCORE**, it will improve your **TEAM SCORE**



Basic Training Guide

- As stated earlier, each incident report is unique to you, and your teammates will have a different set of issues they are responsible for…
- Similar to real teams, when one team member does not know something, it is possible that another one does…

- So, if you receive an issue report in an area you were not trained in, you **MUST** transfer the report to a player who received that training in order to get a **HIGHER** score

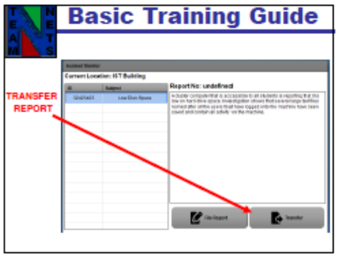


Basic Training Guide

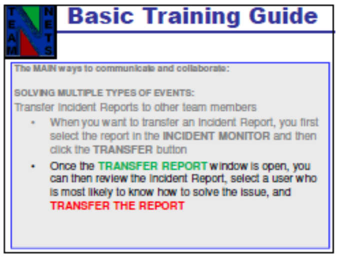
The MAIN ways to communicate and collaborate:

SOLVING MULTIPLE TYPES OF EVENTS:
Transfer Incident Reports to other team members

- When you want to transfer an Incident Report, you first select the report in the **INCIDENT MONITOR** and then click the **TRANSFER** button



Basic Training Guide



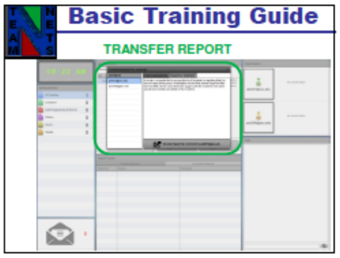
Basic Training Guide

The MAIN ways to communicate and collaborate:

SOLVING MULTIPLE TYPES OF EVENTS:

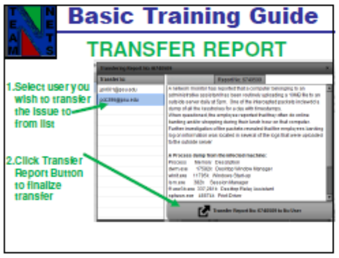
Transfer Incident Reports to other team members

- When you want to transfer an Incident Report, you first select the report in the **INCIDENT MONITOR** and then click the **TRANSFER** button
- Once the **TRANSFER REPORT** window is open, you can then review the Incident Report, select a user who is most likely to know how to solve the issue, and **TRANSFER THE REPORT**



Basic Training Guide

TRANSFER REPORT

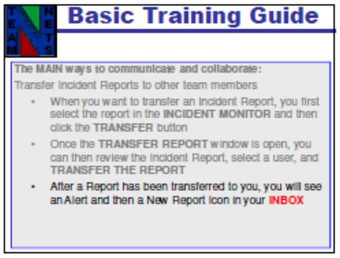


Basic Training Guide

TRANSFER REPORT

1.Select user you wish to transfer the issue to from list

2.Click Transfer Report Button to finalize transfer

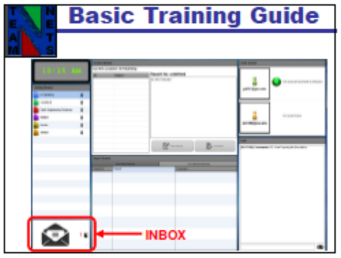


Basic Training Guide

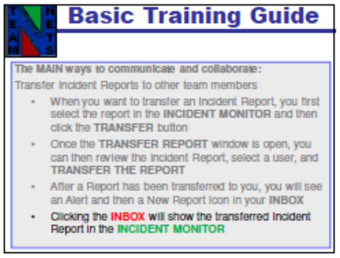
The MAIN ways to communicate and collaborate:

Transfer Incident Reports to other team members

- When you want to transfer an Incident Report, you first select the report in the **INCIDENT MONITOR** and then click the **TRANSFER** button
- Once the **TRANSFER REPORT** window is open, you can then review the Incident Report, select a user, and **TRANSFER THE REPORT**
- After a Report has been transferred to you, you will see an Alert and then a New Report icon in your **INBOX**



Basic Training Guide

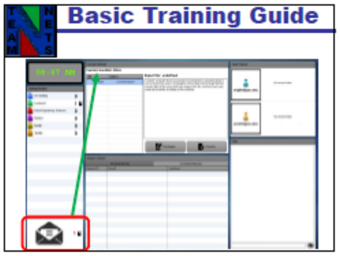


Basic Training Guide

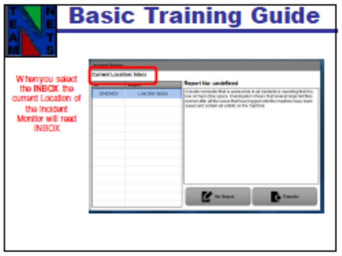
The MAIN ways to communicate and collaborate:

Transfer Incident Reports to other team members

- When you want to transfer an Incident Report, you first select the report in the **INCIDENT MONITOR** and then click the **TRANSFER** button
- Once the **TRANSFER REPORT** window is open, you can then review the Incident Report, select a user, and **TRANSFER THE REPORT**
- After a Report has been transferred to you, you will see an Alert and then a New Report icon in your **INBOX**
- Clicking the **INBOX** will show the transferred Incident Report in the **INCIDENT MONITOR**

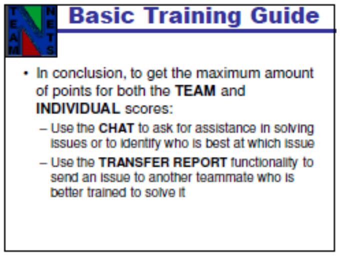


Basic Training Guide



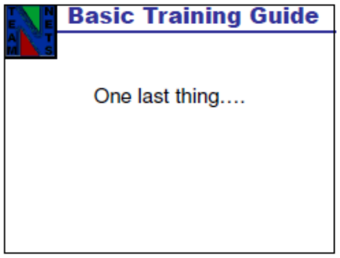
Basic Training Guide

When you select the INBOX the current Location of the Incident Monitor will read INBOX



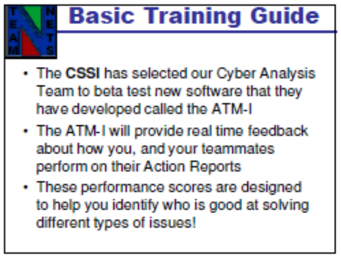
Basic Training Guide

- In conclusion, to get the maximum amount of points for both the **TEAM** and **INDIVIDUAL** scores:
  - Use the **CHAT** to ask for assistance in solving issues or to identify who is best at which issue
  - Use the **TRANSFER REPORT** functionality to send an issue to another teammate who is better trained to solve it



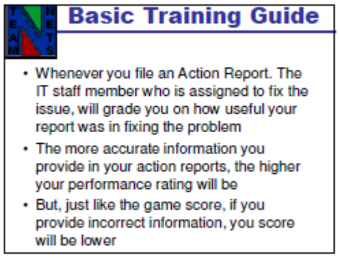
Basic Training Guide

One last thing….



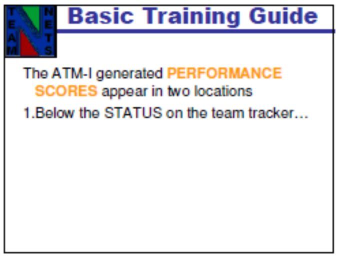
Basic Training Guide

- The **CSSI** has selected our Cyber Analysis Team to beta test new software that they have developed called the ATM-I
- The ATM-I will provide real time feedback about how you, and your teammates perform on their Action Reports
- These performance scores are designed to help you identify who is good at solving different types of issues!



Basic Training Guide

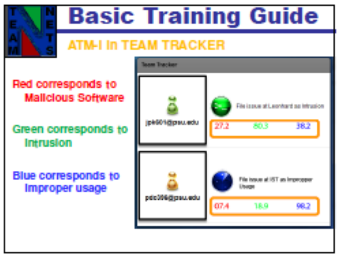
- Whenever you file an Action Report. The IT staff member who is assigned to fix the issue, will grade you on how useful your report was in fixing the problem
- The more accurate information you provide in your action reports, the higher your performance rating will be
- But, just like the game score, if you provide incorrect information, you score will be lower



Basic Training Guide

The ATM-I generated PERFORMANCE SCORES appear in two locations

1.Below the STATUS on the team tracker…



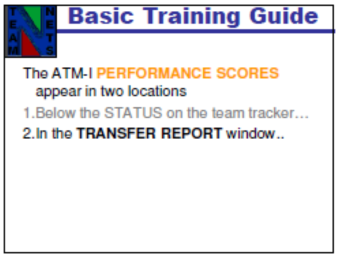
Basic Training Guide

ATM-I in TEAM TRACKER

Red corresponds to Malicious Software

Green corresponds to Intrusion

Blue corresponds to Improper usage

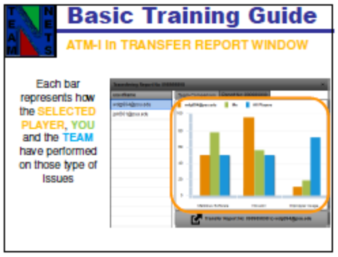


Basic Training Guide

The ATM-I PERFORMANCE SCORES appear in two locations

1.Below the STATUS on the team tracker…

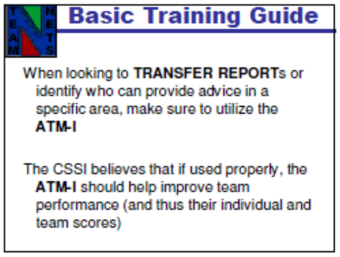
2.In the **TRANSFER REPORT** window..



Basic Training Guide

ATM-I in TRANSFER REPORT WINDOW

Each bar represents how the SELECTED PLAYER, YOU and the TEAM have performed on those type of issues



Basic Training Guide

When looking to **TRANSFER REPORT**s or identify who can provide advice in a specific area, make sure to utilize the **ATM-I**

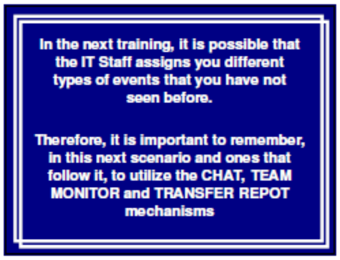
The CSSI believes that if used properly, the **ATM-I** should help improve team performance (and thus their individual and team scores)

CONGRATULATIONS!

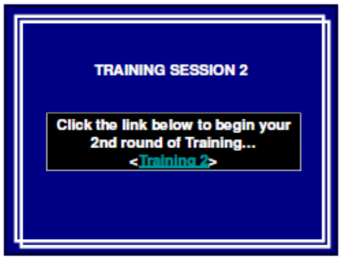
You're now ready to Practice what you learned during your second round of training.

PLEASE WAIT AT THIS SLIDE

until you receive further instructions from the Experimenter.


In the next training, it is possible that the IT Staff assigns you different types of events that you have not seen before.

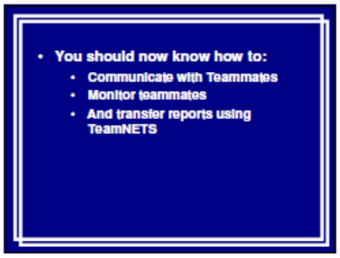
Therefore, it is important to remember, in this next scenario and ones that follow it, to utilize the CHAT, TEAM MONITOR and TRANSFER REPOT mechanisms

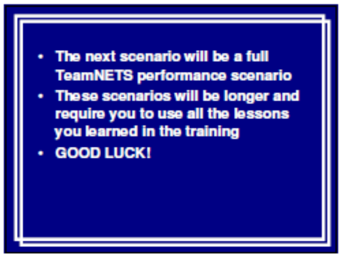

TRAINING SESSION 2

Click the link below to begin your 2nd round of Training…
<Training 2>


Please complete the second survey by clicking the link below. Once finished you may continue to the next slide

SURVEY 2


- You should now know how to:
  - Communicate with Teammates
  - Monitor teammates
  - And transfer reports using TeamNETS


- The next scenario will be a full TeamNETS performance scenario
- These scenarios will be longer and require you to use all the lessons you learned in the training
- GOOD LUCK!


PLEASE WAIT AT THIS SLIDE
until you receive further instructions from the Experimenter.

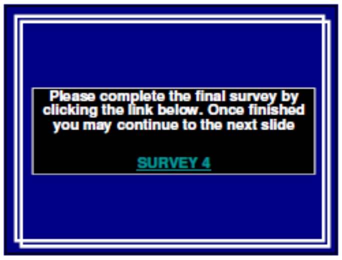

Click the link below to begin your Performance session…
<Performance 1 >


Please complete the third survey by clicking the link below. Once finished you may continue to the next slide

SURVEY 3


PLEASE WAIT AT THIS SLIDE
until you receive further instructions from the Experimenter.


Click the link below to begin your Performance session…
<Performance 2 >


Please complete the final survey by clicking the link below. Once finished you may continue to the next slide

SURVEY 4


Please wait for researcher to signal that is ok to leave.

You may advance to the next slide.


THANK YOU FOR YOUR PARTICIPATION!

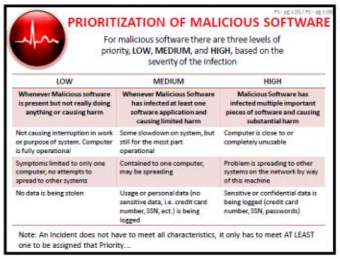
Please direct any questions on the study to Vincent Mancuso at vfm105@ist.psu.edu

Appendix B

Incident Training Materials

Differentiated Condition

Player 1

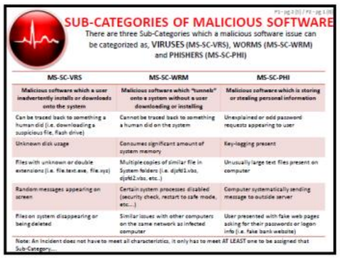


PRIORITIZATION OF MALICIOUS SOFTWARE

For malicious software there are three levels of priority, **LOW**, **MEDIUM**, and **HIGH**, based on the severity of the infection

LOW	MEDIUM	HIGH
Whenever Malicious software is present but not really doing anything or causing harm	**Whenever Malicious Software has infected at least one software application and causing limited harm**	**Malicious Software has infected multiple important pieces of software and causing substantial harm**
Not causing interruption in work or purpose of system. Computer is fully operational	Some slowdown on system, but still for the most part operational	Computer is close to or completely unusable
Symptoms limited to only one computer, no attempts to spread to other systems	Contained to one computer, may be spreading	Problem is spreading to other systems on the network by way of this machine
No data is being stolen	Usage or personal data (no sensitive data, i.e. credit card number, SSN, ect.) is being logged	Sensitive or confidential data is being logged (credit card number, SSN, passwords)

Note: An Incident does not have to meet all characteristics, it only has to meet AT LEAST one to be assigned that Priority....

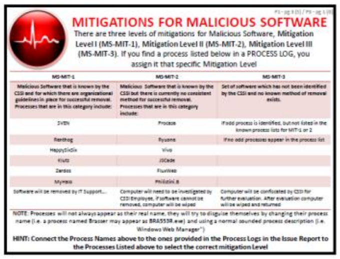


SUB-CATEGORIES OF MALICIOUS SOFTWARE

There are three Sub-Categories which a malicious software issue can be categorized as, **VIRUSES (MS-SC-VRS)**, **WORMS (MS-SC-WRM)** and **PHISHERS (MS-SC-PHI)**

MS-SC-VRS	MS-SC-WRM	MS-SC-PHI
Malicious software which a user inadvertently installs or downloads onto the system	**Malicious software which "tunnels" onto a system without a user downloading or installing**	**Malicious software which is storing or stealing personal information**
Can be traced back to something a human did (i.e. downloading a suspicious file, flash drive)	Cannot be traced back to something a human did on the system	Unexplained or odd password requests appearing to user
Unknown disk usage	Consumes significant amount of system memory	Key-logging present
Files with unknown or double extensions (i.e. file.text.exe, file.xyz)	Multiple copies of similar file in System folders (i.e. djsfd1.vbs, djsfd2.vbs, etc..)	Unusually large text files present on computer
Random messages appearing on screen	Certain system processes disabled (security check, restart to safe mode, etc...)	Computer systematically sending message to outside server
Files on system disappearing or being deleted	Similar issues with other computers on the same network as infected computer	User presented with fake web pages asking for their passwords or logon info (i.e. fake bank website)

Note: An Incident does not have to meet all characteristics, it only has to meet AT LEAST one to be assigned that Sub-Category....



MITIGATIONS FOR MALICIOUS SOFTWARE

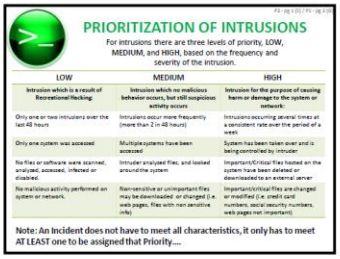
There are three levels of mitigations for Malicious Software, **Mitigation Level I (MS-MIT-1)**, **Mitigation Level II (MS-MIT-2)**, **Mitigation Level III (MS-MIT-3)**. If you find a process listed below in a PROCESS LOG, you assign it that specific Mitigation Level

MS-MIT-1	MS-MIT-2	MS-MIT-3
Malicious Software that is known by the CSSI and for which there are organizational guidelines in place for successful removal. Processes that are in this category include:	**Malicious Software that is known by the CSSI but there is currently no consistent method for successful removal. Processes that are in this category include:**	**Set of software which has not been identified by the CSSI and no known method of removal exists.**
SVEN	[illegible]	If odd process is identified, but not listed in the known process lists for MIT-1 or 2
Renthog	[illegible]	If no odd processes appear in the process list
[illegible]	Vivo	
[illegible]	JSCode	
Zardoz	FluxWeb	
[illegible]	[illegible]	
Software will be removed by IT Support...	Computer will need to be investigated by CSSI Employee, if software cannot be removed, computer will be wiped	Computer will be confiscated by CSSI for further evaluation. After evaluation computer will be wiped and returned

NOTE: Processes will not always appear as their real name, they will try to disguise themselves by changing their process name (i.e. a process named Brasser may appear as BRA553R.exe) and using a normal sounded process description (i.e. Windows Web Manager")

HINT: Connect the Process Names above to the ones provided in the Process Logs in the Issue Report to the Processes Listed above to select the correct mitigation Level

Player 2

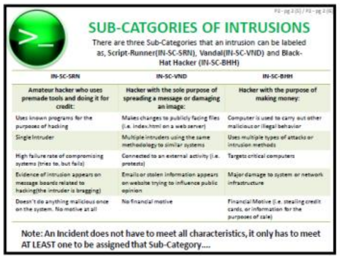


PRIORITIZATION OF INTRUSIONS

For intrusions there are three levels of priority, **LOW**, **MEDIUM**, and **HIGH**, based on the frequency and severity of the intrusion.

LOW	MEDIUM	HIGH
Intrusion which is a result of Recreational Hacking:	**Intrusion which no malicious behavior occurs, but still suspicious activity occurs**	**Intrusion for the purpose of causing harm or damage to the system or network:**
Only one or two intrusions over the last 48 hours	Intrusions occur more frequently (more than 2 in 48 hours)	Intrusions occurring several times at a consistent rate over the period of a week
Only one system was accessed	Multiple systems have been accessed	System has been taken over and is being controlled by intruder
No files or software were scanned, analyzed, accessed, infected or disabled.	Intruder analyzed files, and looked around the system	Important/Critical files hosted on the system have been deleted or downloaded to an external server
No malicious activity performed on system or network.	Non-sensitive or unimportant files may be downloaded or changed (i.e. web pages, files with non sensitive info)	Important/critical files are changed or modified (i.e. credit card numbers, social security numbers, web pages not important)

Note: An Incident does not have to meet all characteristics, it only has to meet AT LEAST one to be assigned that Priority....

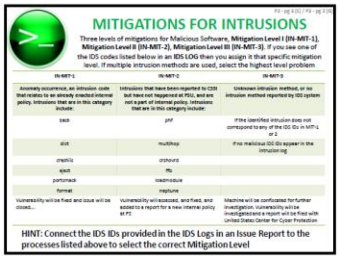


SUB-CATGORIES OF INTRUSIONS

There are three Sub-Categories that an intrusion can be labeled as, **Script-Runner(IN-SC-SRN)**, **Vandal(IN-SC-VND)** and **Black-Hat Hacker (IN-SC-BHH)**

IN-SC-SRN	IN-SC-VND	IN-SC-BHH
Amateur hacker who uses premade tools and doing it for credit:	**Hacker with the sole purpose of spreading a message or damaging an image:**	**Hacker with the purpose of making money:**
Uses known programs for the purposes of hacking	Makes changes to publicly facing files (i.e. index.html on a web server)	Computer is used to carry out other malicious or illegal behavior
Single Intruder	Multiple intruders using the same methodology to similar systems	Uses multiple types of attacks or intrusion methods
High failure rate of compromising systems (tries to, but fails)	Connected to an external activity (i.e. protests)	Targets critical computers
Evidence of intrusion appears on message boards related to hacking(the intruder is bragging)	Emails or stolen information appears on website trying to influence public opinion	Major damage to system or network infrastructure
Doesn't do anything malicious once on the system. No motive at all	No financial motive	Financial Motive (i.e. stealing credit cards, or information for the purposes of sale)

Note: An Incident does not have to meet all characteristics, it only has to meet AT LEAST one to be assigned that Sub-Category....



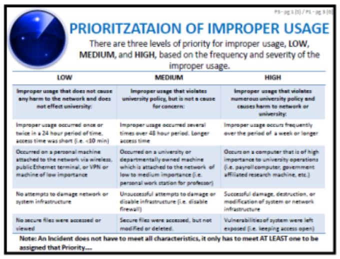
MITIGATIONS FOR INTRUSIONS

Three levels of mitigations for Malicious Software, **Mitigation Level I (IN-MIT-1)**, **Mitigation Level II (IN-MIT-2)**, **Mitigation Level III (IN-MIT-3)**. If you see one of the IDS codes listed below in an **IDS LOG** then you assign it that specific mitigation level. If multiple intrusion methods are used, select the highest level problem

IN-MIT-1	IN-MIT-2	IN-MIT-3
Anomaly occurrence, an intrusion code that relates to an already enacted internal policy. Intrusions that are in this category include:	**Intrusions that have been reported to CSSI but have not happened at PSU, and are not a part of internal policy. Intrusions that are in this category include:**	**Unknown intrusion method, or no intrusion method reported by IDS system**
back	phf	If the identified intrusion does not correspond to any of the IDS IDs in MIT-1 or 2
dict	multihop	If no malicious IDS IDs appear in the intrusion log
[illegible]	[illegible]	
eject	ffb	
[illegible]	loadmodule	
format	neptune	
Vulnerability will be fixed and issue will be closed...	Vulnerability will assessed, and fixed, and added to a report for a new internal policy at PS	Machine will be confiscated for further investigation. Vulnerability will be investigated and a report will be filed with United States Center for Cyber Protection

HINT: Connect the IDS IDs provided in the IDS Logs in an Issue Report to the processes listed above to select the correct Mitigation Level

Player 3

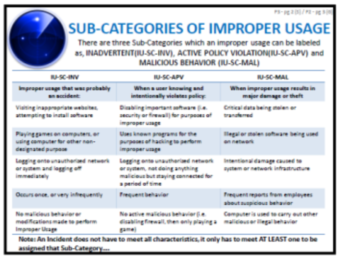


PRIORITZATAION OF IMPROPER USAGE

There are three levels of priority for improper usage, **LOW**, **MEDIUM**, and **HIGH**, based on the frequency and severity of the improper usage.

LOW	MEDIUM	HIGH
Improper usage that does not cause any harm to the network and does not effect university:	**Improper usage that violates university policy, but is not a cause for concern:**	**Improper usage that violates numerous university policy and causes harm to network or university:**
Improper usage occurred once or twice in a 24 hour period of time, access time was short (i.e. <10 min)	Improper usage occurred several times over 48 hour period. Longer access time	Improper usage occurs frequently over the period of a week or longer
Occurred on a personal machine attached to the network via wireless, public Ethernet terminal, or VPN or machine of low importance	Occurred on a university or departmentally owned machine which is attached to the network of low to medium importance (i.e. personal work station for professor)	Occurs on a computer that is of high importance to university operations (i.e. payroll computer, government affiliated research machine, etc.)
No attempts to damage network or system infrastructure	Unsuccessful attempts to damage or disable infrastructure (i.e. disable firewall)	Successful damage, destruction, or modification of system or network infrastructure
No secure files were accessed or viewed	Secure files were accessed, but not modified or deleted.	Vulnerabilities of system were left exposed (i.e. keeping access open)

Note: An Incident does not have to meet all characteristics, it only has to meet AT LEAST one to be assigned that Priority....

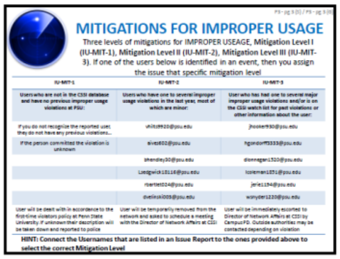


SUB-CATEGORIES OF IMPROPER USAGE

There are three Sub-Categories which an improper usage can be labeled as, **INADVERTENT(IU-SC-INV)**, **ACTIVE POLICY VIOLATION(IU-SC-APV)** and **MALICIOUS BEHAVIOR (IU-SC-MAL)**

IU-SC-INV	IU-SC-APV	IU-SC-MAL
Improper usage that was probably an accident:	**When a user knowing and intentionally violates policy:**	**When improper usage results in major damage or theft**
Visiting inappropriate websites, attempting to install software	Disabling important software (i.e. security or firewall) for purposes of improper usage	Critical data being stolen or transferred
Playing games on computers, or using computer for other non-designated purpose	Uses known programs for the purposes of hacking to perform improper usage	Illegal or stolen software being used on network
Logging onto unauthorized network or system and logging off immediately	Logging onto unauthorized network or system, not doing anything malicious but staying connected for a period of time	Intentional damage caused to system or network infrastructure
Occurs once, or very infrequently	Frequent behavior	Frequent reports from employees about suspicious behavior
No malicious behavior or modifications made to perform Improper Usage	No active malicious behavior (i.e. disabling firewall, then only playing a game)	Computer is used to carry out other malicious or illegal behavior

Note: An Incident does not have to meet all characteristics, it only has to meet AT LEAST one to be assigned that Sub-Category....



MITIGATIONS FOR IMPROPER USAGE

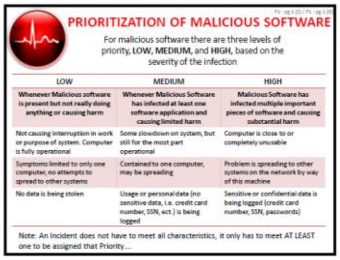
Three levels of mitigations for IMPROPER USEAGE, **Mitigation Level I (IU-MIT-1)**, **Mitigation Level II (IU-MIT-2)**, **Mitigation Level III (IU-MIT-3)**. If one of the users below is identified in an event, then you assign the issue that specific mitigation level

IU-MIT-1	IU-MIT-2	IU-MIT-3
Users who are not in the CSSI database and have no previous improper usage violations at PSU:	**Users who have one to several improper usage violations in the last year, most of which are minor:**	**User who has had one to several major improper usage violations and/or is on the CSSI watch list for past violations or other information about the user:**
If you do not recognize the reported user, they do not have any previous violations...	[illegible]	[illegible]
If the person committed the violation is unknown	[illegible]	[illegible]
	[illegible]	[illegible]
	[illegible]	[illegible]
	[illegible]	[illegible]
	[illegible]	[illegible]
User will be dealt with in accordance to the first-time violators policy at Penn State University. If unknown their description will be taken down and reported to police	User will be temporarily removed from the network and asked to schedule a meeting with the Director of Network Affairs at CSSI	User will be immediately escorted to Director of Network Affairs at CSSI by Campus PD. Outside authorities may be contacted depending on violation

HINT: Connect the Usernames that are listed in an Issue Report to the ones provided above to select the correct Mitigation Level

Integrated Condition

Player 1

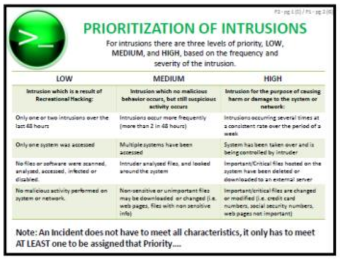


PRIORITIZATION OF MALICIOUS SOFTWARE

For malicious software there are three levels of priority, **LOW, MEDIUM,** and **HIGH,** based on the severity of the infection

LOW	MEDIUM	HIGH
Whenever Malicious software is present but not really doing anything or causing harm	**Whenever Malicious Software has infected at least one software application and causing limited harm**	**Malicious Software has infected multiple important pieces of software and causing substantial harm**
Not causing interruption in work or purpose of system. Computer is fully operational	Some slowdown on system, but still for the most part operational	Computer is close to or completely unusable
Symptoms limited to only one computer, no attempts to spread to other systems	Contained to one computer, may be spreading	Problem is spreading to other systems on the network by way of this machine
No data is being stolen	Usage or personal data (no sensitive data, i.e. credit card number, SSN, ect.) is being logged	Sensitive or confidential data is being logged (credit card number, SSN, passwords)

Note: An Incident does not have to meet all characteristics, it only has to meet AT LEAST one to be assigned that Priority....



PRIORITIZATION OF INTRUSIONS

For intrusions there are three levels of priority, LOW, MEDIUM, and HIGH, based on the frequency and severity of the intrusion.

LOW	MEDIUM	HIGH
Intrusion which is a result of Recreational Hacking:	**Intrusion which no malicious behavior occurs, but still suspicious activity occurs**	**Intrusion for the purpose of causing harm or damage to the system or network:**
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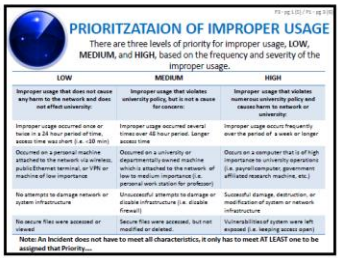
No files or software were scanned, analyzed, accessed, infected or disabled.	Intruder analyzed files, and looked around the system	Important/Critical files hosted on the system have been deleted or downloaded to an external server
No malicious activity performed on system or network.	Non-sensitive or unimportant files may be downloaded or changed (i.e. web pages, files with non sensitive info)	Important/critical files are changed or modified (i.e. credit card numbers, social security numbers, web pages not important)

Note: An Incident does not have to meet all characteristics, it only has to meet AT LEAST one to be assigned that Priority....



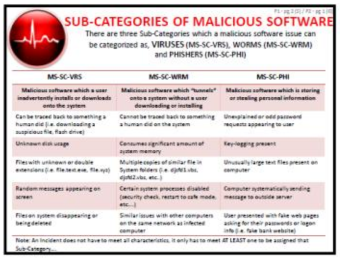
PRIORITZATAION OF IMPROPER USAGE

There are three levels of priority for improper usage, **LOW, MEDIUM,** and **HIGH,** based on the frequency and severity of the improper usage.

LOW	MEDIUM	HIGH
Improper usage that does not cause any harm to the network and does not effect university:	**Improper usage that violates university policy, but is not a cause for concern:**	**Improper usage that violates numerous university policy and causes harm to network or university:**
Improper usage occurred once or twice in a 24 hour period of time, access time was short (i.e. <10 min)	Improper usage occurred several times over 48 hour period. Longer access time	Improper usage occurs frequently over the period of a week or longer
Occurred on a personal machine attached to the network via wireless, public Ethernet terminal, or VPN or machine of low importance	Occurred on a university or departmentally owned machine which is attached to the network of low to medium importance (i.e. personal work station for professor)	Occurs on a computer that is of high importance to university operations (i.e. payroll computer, government affiliated research machine, etc.)
No attempts to damage network or system infrastructure	Unsuccessful attempts to damage or disable infrastructure (i.e. disable firewall)	Successful damage, destruction, or modification of system or network infrastructure
No secure files were accessed or viewed	Secure files were accessed, but not modified or deleted.	Vulnerabilities of system were left exposed (i.e. keeping access open)

Note: An Incident does not have to meet all characteristics, it only has to meet AT LEAST one to be assigned that Priority....

Player 2

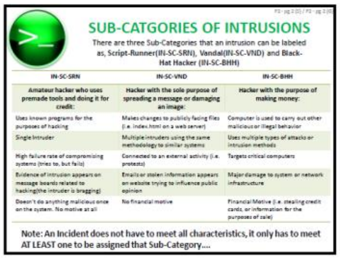


SUB-CATEGORIES OF MALICIOUS SOFTWARE

There are three Sub-Categories which a malicious software issue can be categorized as, **VIRUSES** (MS-SC-VRS), WORMS (MS-SC-WRM) and PHISHERS (MS-SC-PHI)

MS-SC-VRS	MS-SC-WRM	MS-SC-PHI
Malicious software which a user inadvertently installs or downloads onto the system	**Malicious software which "tunnels" onto a system without a user downloading or installing**	**Malicious software which is storing or stealing personal information**
Can be traced back to something a human did (i.e. downloading a suspicious file, flash drive)	Cannot be traced back to something a human did on the system	Unexplained or odd password requests appearing to user
Unknown disk usage	Consumes significant amount of system memory	Key-logging present
Files with unknown or double extensions (i.e. file.text.exe, file.sys)	Multiple copies of similar file in System folders (i.e. djsfd1.vbs, djsfd2.vbs, etc..)	Unusually large text files present on computer
Random messages appearing on screen	Certain system processes disabled (security check, restart to safe mode, etc...)	Computer systematically sending message to outside server
Files on system disappearing or being deleted	Similar issues with other computers on the same network as infected computer	User presented with fake web pages asking for their passwords or logon info (i.e. fake bank website)

Note: An Incident does not have to meet all characteristics, it only has to meet AT LEAST one to be assigned that Sub-Category....

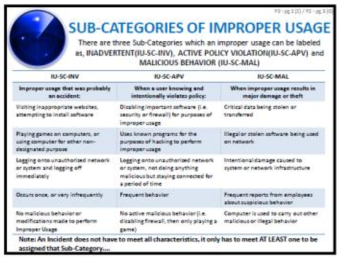


SUB-CATGORIES OF INTRUSIONS

There are three Sub-Categories that an intrusion can be labeled as, Script-Runner(IN-SC-SRN), Vandal(IN-SC-VND) and Black-Hat Hacker (IN-SC-BHH)

IN-SC-SRN	IN-SC-VND	IN-SC-BHH
Amateur hacker who uses premade tools and doing it for credit:	**Hacker with the sole purpose of spreading a message or damaging an image:**	**Hacker with the purpose of making money:**
Uses known programs for the purposes of hacking	Makes changes to publicly facing files (i.e. index.html on a web server)	Computer is used to carry out other malicious or illegal behavior
Single Intruder	Multiple intruders using the same methodology to similar systems	Uses multiple types of attacks or intrusion methods
High failure rate of compromising systems (tries to, but fails)	Connected to an external activity (i.e. protests)	Targets critical computers
Evidence of intrusion appears on message boards related to hacking(the intruder is bragging)	Emails or stolen information appears on website trying to influence public opinion	Major damage to system or network infrastructure
Doesn't do anything malicious once on the system. No motive at all	No financial motive	Financial Motive (i.e. stealing credit cards, or information for the purposes of sale)

Note: An Incident does not have to meet all characteristics, it only has to meet AT LEAST one to be assigned that Sub-Category....



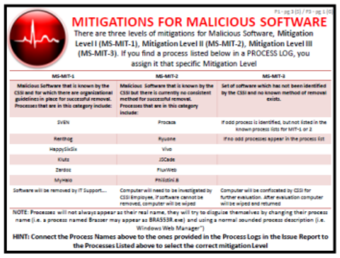
SUB-CATEGORIES OF IMPROPER USAGE

There are three Sub-Categories which an improper usage can be labeled as, INADVERTENT(IU-SC-INV), ACTIVE POLICY VIOLATION(IU-SC-APV) and MALICIOUS BEHAVIOR (IU-SC-MAL)

IU-SC-INV	IU-SC-APV	IU-SC-MAL
Improper usage that was probably an accident:	**When a user knowing and intentionally violates policy:**	**When improper usage results in major damage or theft**
Visiting inappropriate websites, attempting to install software	Disabling important software (i.e. security or firewall) for purposes of improper usage	Critical data being stolen or transferred
Playing games on computers, or using computer for other non-designated purpose	Uses known programs for the purposes of hacking to perform improper usage	Illegal or stolen software being used on network
Logging onto unauthorized network or system and logging off immediately	Logging onto unauthorized network or system, not doing anything malicious but staying connected for a period of time	Intentional damage caused to system or network infrastructure
Occurs once, or very infrequently	Frequent behavior	Frequent reports from employees about suspicious behavior
No malicious behavior or modifications made to perform Improper Usage	No active malicious behavior (i.e. disabling firewall, then only playing a game)	Computer is used to carry out other malicious or illegal behavior

Note: An Incident does not have to meet all characteristics, it only has to meet AT LEAST one to be assigned that Sub-Category....

Player 3



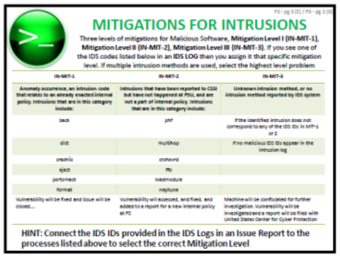
MITIGATIONS FOR MALICIOUS SOFTWARE

There are three levels of mitigations for Malicious Software, **Mitigation Level I (MS-MIT-1), Mitigation Level II (MS-MIT-2), Mitigation Level III (MS-MIT-3).** If you find a process listed below in a PROCESS LOG, you assign it that specific Mitigation Level

MS-MIT-1	MS-MIT-2	MS-MIT-3
Malicious Software that is known by the CSSI and for which there are organizational guidelines in place for successful removal. Processes that are in this category include:	**Malicious Software that is known by the CSSI but there is currently no consistent method for successful removal. Processes that are in this category include:**	**Set of software which has not been identified by the CSSI and no known method of removal exists.**
SVEN	Procaca	If odd process is identified, but not listed in the known process lists for MIT-1 or 2
Renthog	Ryuone	If no odd processes appear in the process list
HappySixSix	Vivo	
Klutz	JSCade	
Zerdoc	FluxWeb	
MyHalo	Philistini.B	
Software will be removed by IT Support....	Computer will need to be investigated by CSSI Employee, If software cannot be removed, computer will be wiped	Computer will be confiscated by CSSI for further evaluation. After evaluation computer will be wiped and returned

NOTE: Processes will not always appear as their real name, they will try to disguise themselves by changing their process name (i.e. a process named Brasser may appear as BRAS53R.exe) and using a normal sounded process description (i.e. Windows Web Manager")

HINT: Connect the Process Names above to the ones provided in the Process Logs in the Issue Report to the Processes Listed above to select the correct mitigation Level

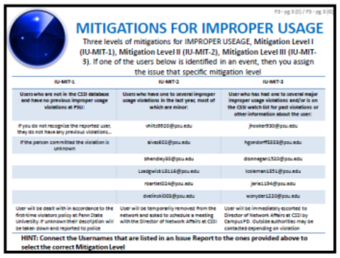


MITIGATIONS FOR INTRUSIONS

Three levels of mitigations for Malicious Software, **Mitigation Level I (IN-MIT-1), Mitigation Level II (IN-MIT-2), Mitigation Level III (IN-MIT-3).** If you see one of the IDS codes listed below in an **IDS LOG** then you assign it that specific mitigation level. If multiple intrusion methods are used, select the highest level problem

IN-MIT-1	IN-MIT-2	IN-MIT-3
Anomaly occurrence, an intrusion code that relates to an already enacted internal policy. Intrusions that are in this category include:	**Intrusions that have been reported to CSSI but have not happened at PSU, and are not a part of internal policy. Intrusions that are in this category include:**	**Unknown intrusion method, or no intrusion method reported by IDS system**
back	phf	If the identified intrusion does not correspond to any of the IDS IDs in MIT-1 or 2
dict	multihop	If no malicious IDS IDs appear in the intrusion log
crashiis	crshovrd	
eject	ffb	
portsweep	loadmodule	
format	neptune	
Vulnerability will be fixed and issue will be closed....	Vulnerability will assessed, and fixed, and added to a report for a new internal policy at PS	Machine will be confiscated for further investigation. Vulnerability will be investigated and a report will be filed with United States Center for Cyber Protection

HINT: Connect the IDS IDs provided in the IDS Logs in an Issue Report to the processes listed above to select the correct Mitigation Level



MITIGATIONS FOR IMPROPER USAGE

Three levels of mitigations for IMPROPER USEAGE, **Mitigation Level I (IU-MIT-1), Mitigation Level II (IU-MIT-2), Mitigation Level III (IU-MIT-3).** If one of the users below is identified in an event, then you assign the issue that specific mitigation level

IU-MIT-1	IU-MIT-2	IU-MIT-3
Users who are not in the CSSI database and have no previous improper usage violations at PSU:	**Users who have one to several improper usage violations in the last year, most of which are minor:**	**User who has had one to several major improper usage violations and/or is on the CSSI watch list for past violations or other information about the user:**
If you do not recognize the reported user, they do not have any previous violations...	vhilts9920@psu.edu	jhooker930@psu.edu
If the person committed the violation is unknown	aives602@psu.edu	hgondorff3333@psu.edu
	bhendley30@psu.edu	dlonnegan1520@psu.edu
	Lsedgwick18116@psu.edu	icoleman1851@psu.edu
	rbartlet024@psu.edu	jerie1194@psu.edu
	dvelinski003@psu.edu	wsnyder1220@psu.edu
User will be dealt with in accordance to the first-time violators policy at Penn State University. If unknown their description will be taken down and reported to police	User will be temporarily removed from the network and asked to schedule a meeting with the Director of Network Affairs at CSSI	User will be immediately escorted to Director of Network Affairs at CSSI by Campus PD. Outside authorities may be contacted depending on violation

HINT: Connect the Usernames that are listed in an Issue Report to the ones provided above to select the correct Mitigation Level

Appendix C

TeamNETS Scenarios

Training Scenario 1

Assigned Player	Event Name	Dispatch Time	Answer
1	Kids be complainin	0:11	Malicious Software
2	Uphappy Customers	0:14	Intrusion
3	Computer InfraXXXion	0:17	Improper Usage
1	No Email, Yes Problem	1:03	Malicious Software
2	No Laggers	1:07	Intrusion
3	Peggle Revenge	1:00	Improper Usage
1	I don't need no stinkin outlook.	1:59	Malicious Software
2	They want to take away our social security	1:56	Intrusion
3	My Prediction? Wow	1:53	Improper Usage
1	There goes my A.	2:42	Malicious Software
2	Don't trust me	2:49	Intrusion
3	Microsoft sounds angrier than usual	2:45	Improper Usage

Training Scenario 2

Assigned Player	Event Name	Dispatch Time	Answer
1	It wasn't me	0:23	Malicious Software
2	If at first you don't succeed	0:20	Intrusion
3	That doesn't look like homework	0:17	Improper Usage
1	Royalty free my adjfs	1:06	Malicious Software
2	And the point was?	1:03	Intrusion
3	He loves his sports	1:09	Improper Usage
1	Flash drive fail	1:59	Improper Usage
2	Uncle Sam's gonna be mad	2:05	Malicious Software
3	Mad at NIST?	2:02	Intrusion
1	Is that Greek?	2:48	Malicious Software
2	How do you like us now?	2:45	Intrusion
3	Late night raids	2:51	Improper Usage
1	Cool file system bro	3:47	Intrusion
2	10 in 20-10	3:44	Improper Usage
3	Tell Aunt Linda I said Hi!	3:41	Malicious Software
1	But what about my coffee?	4:45	Malicious Software
2	Occupy the Alumni	4:48	Intrusion
3	Drawing dead	4:51	Improper Usage

Performance Scenario 1

Assigned Player	Event Name	Dispatch Time	Answer
1	There goes my tenure.	0:34	Malicious Software
2	My bad yo	0:28	Improper Usage
3	Just curious, I swear!	0:31	Intrusion
1	Called their bluff	1:57	Improper Usage
2	Photoshop for free!!!	2:00	Intrusion
3	This isn't the bank I'm looking for	1:54	Malicious Software
1	Can this simulator crash?	2:36	Malicious Software
2	1337 Cred baby!	2:33	Intrusion
3	Change your preferences	2:30	Improper Usage
1	Adobe doesn't like your kind	3:39	Improper Usage
2	Twitter sucks anyways	3:36	Malicious Software
3	All your payroll are belong to us	3:42	Intrusion
1	Bah-Humbug	4:12	Intrusion
2	Just be patient, yo	4:18	Malicious Software
3	Your website sucks anyways	4:15	Improper Usage
1	Quit changing the program	5:40	Intrusion
2	Confidential Research	5:34	Malicious Software
3	50 on the Penguins	5:37	Improper Usage
1	IRB is gonna be PISSSSED	7:18	Intrusion
2	Cool servers bro	7:21	Improper Usage
3	Class is canceled	7:15	Malicious Software
1	Flash drive fail	8:37	Malicious Software
2	Try and fail me now	8:34	Improper Usage
3	Occupy PSU, Really?	8:41	Intrusion
1	Happy Birthday	9:50	Improper Usage
2	Smash the state	9:47	Intrusion
3	Please login	9:53	Malicious Software

Performance Scenario 2

Assigned Player	Event Name	Dispatch Time	Answer
1	Spreading the sickness	0:19	Malicious Software
2	Shoot this down	0:16	Intrusion
3	Torrent at home pls	0:13	Improper Usage
1	How's my performance now?	1:05	Improper Usage
2	Make money money	1:11	Malicious Software
3	Free airfare	1:08	Intrusion
1	My identity now	2:16	Malicious Software
2	Be proud at home	2:19	Improper Usage
3	Who wants movies?	2:22	Intrusion
1	That's a lot of travel	3:46	Intrusion
2	I can seeeeeee you	3:49	Malicious Software
3	But I want to watch it now	3:43	Improper Usage
1	That's not mine, I swear	4:35	Malicious Software
2	Good luck with that project	4:32	Improper Usage
3	Feds be angry	4:29	Intrusion
1	Read on your own network	5:38	Improper Usage
2	Buy more stuff	5:35	Malicious Software
3	Ride the bus	5:41	Intrusion
1	For Sale: Super Computer	5:56	Intrusion
2	Free megaupload	6:02	Improper Usage
3	What's your score?	5:59	Malicious Software
1	End(of the line)Note	6:23	Improper Usage
2	Seems like you're doing well	6:17	Intrusion
3	IT got pwned	6:20	Malicious Software
1	Buy more coffee!	7:29	Malicious Software
2	P-I-T-T	7:32	Intrusion
3	Don't anger the help	7:35	Improper Usage
1	Check out my latest single	8:36	Improper Usage
2	We fail, you fail	8:33	Intrusion
3	Nooooo Reservations	8:39	Malicious Software
1	Addicted to WoW	10:04	Intrusion
2	Nice hand	10:00	Improper Usage
3	You should proofread more	10:07	Malicious Software
1	Let's have a party	11:15	Intrusion
2	Check your flash drives please	11:18	Malicious Software
3	This poker is really popular	11:21	Improper Usage
1	Spreading the sickness	0:19	Malicious Software

Appendix D

Summary of Survey Constructs

Survey 1: Introductory Survey

- Demographics – Age, gender, academic info (4 items)
- Team Experience (1 item)
- Distributed Team Experience (1 item)
- Distributed Team Comfort (1 item)
- Cyber security experience (7 items)
- Type of games played (1 item)
- Hours playing specific gaming genres (5 items)
- NeoCITIES Experience
- Motivation to Lead (5 items)
- Preference working in teams (5 items)

Survey 2: Delivered after Training Scenario 2

- Training Assessment (10 items)
- Initial Interface Assessment (6 items)

Survey 3: Delivered after Performance 1

- Perception of Transactive Memory System (15 items)
- Structure of Transactive Memory System (24 items)
- Interdependence among team members (5 items)
- Leadership emergence (1 item)
- Team Processes and communication (12 items)
- Situation Awareness Rating Technique (6 item)
- Mission Awareness Rating Scale (5 items)

Survey 4: Delivered after Performance 2

- Team Familiarity (3 item scale)
- Task Assessment – Difficulty, perception, etc. (5 items)
- Perception of Transactive Memory System (15 items)
- Structure of Transactive Memory System (24 items)
- Self Efficacy for TeamNETS Success (8 items)
- Perceived expertise in TeamNETS (2 items)
- Interdependence among team members (5 items)
- Leadership emergence (1 item)
- Team Processes and communication (12 items)
- Situation Awareness Rating Technique (6 item)
- Mission Awareness Rating Scale (5 items)
- Perceived frequency of use of interface components (7 items)
- Perceived utility of interface components (7 items)
- Likes and dislikes of interface (2 items)

Appendix E

Summary of Pilots

Event Design Pilot

The following table presents an overview of the basic analysis that were conducted on the responses from the first round of pilot testing. To calculate these numbers, I compared all responses against their higher and lower order answers, and coded for their accuracy. Once coded, several calculations provided insight into improving the events and training. Calculations for overall correctness, the correctness of each lower-order category informed adjustments to event difficulty.

Specifically, the Mitigation training was adjusted to be slightly vaguer so not to create disparity across participants in the integrated condition. For higher order categories the results showed that the malicious software was overall the easiest higher-order event category. Steps were taken to clarify the other categories, as well as make solving malicious software events less obvious.

First Pilot Analysis

Total Right:	**39**	**% Right:**	**34.21%**
Total Wrong:	**75**	**% Wrong:**	**65.79%**
Total Priority Right:	**65**	**% P Right:**	**57.02%**
Total Priority Wrong:	**49**	**%P Wrong:**	**42.98%**
Total Mit Right:	**95**	**% M Right:**	**83.33%**
Total Mit Wrong:	**19**	**% M Wrong:**	**16.67%**
Total SC Right:	**78**	**% SC Right:**	**68.42%**
Total SC Wrong:	**36**	**%SC Wrong:**	**31.58%**
Total Problems:	**104**	**% Problems:**	**30.41%**
Total Events with 1:	**49**	**% with 1 Prob:**	**65.33%**
Total Events with 2:	**23**	**% with 2 Prob:**	**30.67%**
Total Events with 3:	**3**	**% with 3 Prob:**	**4.00%**
MS Right:	**17**	**% MS Right:**	**44.74%**
MS Wrong	**21**	**%MS Wrong**	**55.26%**
MS P Wrong:	**9**		
MS SC Wrong:	**7**		
MS MIT Wrong:	**12**		
IN Right:	**11**	**% IN Right:**	**28.95%**
IN Wrong:	**27**	**% IN Wrong:**	**71.05%**
IN P Wrong:	**21**		
IN SC Wrong:	**6**		
IN MIT Wrong:	**8**		
IU Right:	**11**	**% IU Right:**	**0.289474**
IU Wrong:	**27**	**% IU Wrong:**	**0.710526**
IU P Wrong:	**19**		
IU SC Wrong:	**6**		
IU MIT Wrong:	**16**		

TeamNETS Pilot

The following results summarize the analyses conducted on the full *teamNETS* pilot that was conducted. This pilot experiment was conducted as a full experiment, and focused not only on improving the events and training, but also improving the interface and scenario pacing.

Sample:

- 50 undergraduates enrolled in IST 211 (16 three person teams, one two person team)
- General Demographics:
    - 73.5 % Male
    - 32% Freshmen, 34% Sophomore, 22% Junior, 10% Senior
    - Team Experience:
        - 63 % of the participants reported having a high level of experience working in teams, only 10% reported little team experience
        - On the other hand 63% reported having little distributed team experience, while 14% reported no distributed team experience at all.
        - Though, 49 % still reported moderately comfortable, and only a total of 12% reported one of the uncomfortable ratings
    - Leadership Preference:
        - On a scale of 1-5 (Strongly Disagree – Strongly Agree), participants rated
    - Cyber Experience:
        - Only 12 % of the participants rated having absolutely no cyber experience prior to this study
        - 69% of the participants have taken an intro-class related to cyber security, and 29% have taken multiple class.
        - Only 1 participant has held a job related to cyber security
        - 22% hope to one day hold a job in cyber security
    - Game Experience
        - Only 4 participants have participated in previous simulation research (NeoCities)

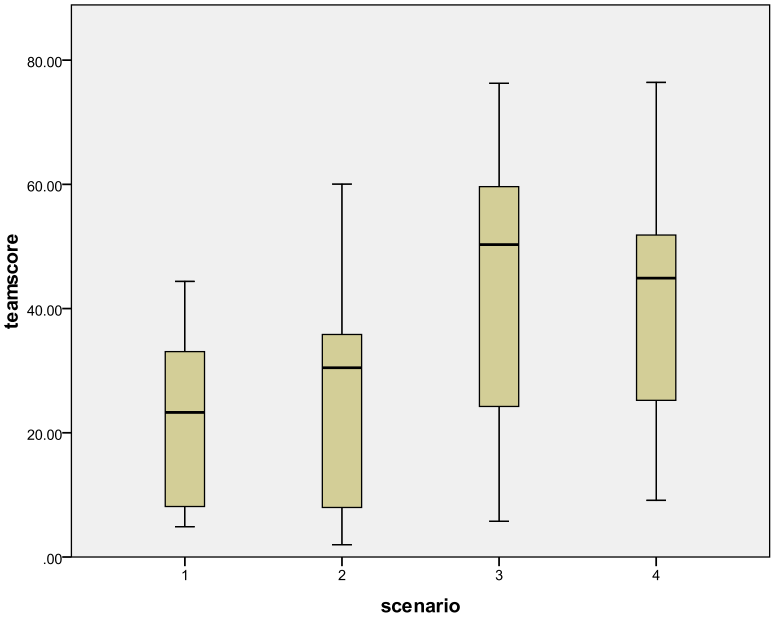
- 22 % of participants reported not playing any type of games, while 43 % reported playing console games, 12 % computer games and 22 % report both

Scenario Analysis

Participants played four scenarios, two training, and two performance scenarios. Note that the scores here represent data across several iterations of each scenario.

Performance Across Scenarios

	Training 1	Training 2	Perf 1	Perf 2
N	13	15	15	15
Mean	22.97	25.19	42.47	40.96
Std. Deviation	13.27	17.73	22.86	20.73
Minimum	4.88	1.97	5.77	9.12
Maximum	44.37	60.05	76.28	76.41



Teams in the generalist condition (M=28.11, SD = 19.38) performed significantly better than teams in the specialist condition (40.01, SD = 20.74), p=.03. There was no significant difference between teams in the shared virtual feedback (M=34.13, SD=22.43) and the no shared virtual feedback (M=31.97, SD=18.29) conditions.

Role Analysis

To assess the workload on the three roles, a One-way analysis of variance was conducted. The results showed no significant difference between the three roles.

Performance Across Roles

	Player 1	Player 2	Player 3
N	58.00	58.00	57.00
Mean	37.21	36.65	40.93
Std. Deviation	21.60	20.89	23.43
Minimum	0.00	0.00	0.00
Maximum	80.34	75.95	83.28

Event Analysis:

Descriptive Statistics were run, and events with low means (< 20) and upper bound confidence levels (<30) were extracted, and edited for consistency. Extracted events include:

- Big Brother is Watching (Mean = 0.05, 95% UB=28.2)
    - This event was removed when events were trimmed down
- Cool filesystem bro (M=11.75, UB=28.71)
    - Initial report said that the virus and malware programs were not running, which may cause users to jump to conclusions, so the language was changed
- No Laggers (M=10.25, UB=27.21)
    - Clarified event description to focus on the fact that somebody gained access to repurpose the machine, rather than the fact that the machine was being used as a game host
- Tell Aunt Linda I said Hi (M=10.87, UB=25.90)
    - Took focus off the fact of the network monitor, highlighted that there was a process running on the computer

- Uncle Sam's gonna be mad (M=12.619, 27.65)
    - Took focus off the communication, highlighted that there was a process running on the computer

Task Assessment

- 48 % of participants found the task Neutral in terms of difficulty. Only 14 % found it any level easy, while 38 % found it a level of difficult (32% reported difficult, while 6% reported very difficult)
- 52% of participants agreed that their team was able to successfully complete the simulation
- 62% of participants thought there was adequate time provided to complete tasks in the simulation

Interface Evaluations:

Perceived Usefulness of interface components:

Statistic	*Mean*	*Variance*	*Standard Deviation*	*Total Responses*
(A) Location Tracker	4.26	0.85	0.92	50
(B) Information Tracker	4.3	1.07	1.04	50
(C) Report Tracker	3.68	1.32	1.15	50
(D) Team Monitor	3.04	2	1.41	50
(E) File Report Terminal	4.32	0.75	0.87	50
(F) Transfer Report Terminal	4.08	0.93	0.97	50
(G) Chat Terminal	3.86	0.98	0.99	50

Frequency of use:

Statistic	*Mean*	*Variance*	*Standard Deviation*	*Total Responses*
(A) Location Tracker	4.52	0.91	0.95	50
(B) Information Tracker	4.44	0.9	0.95	50
(C) Report Tracker	3.5	0.99	0.99	50
(D) Team Monitor	2.7	1.19	1.09	50
(E) File Report Terminal	4.28	1.19	1.09	50
(F) Transfer Report Terminal	3.7	1.19	1.09	50
(G) Chat Terminal	3.1	1.11	1.05	50

The only thing that is troublesome here is that participants find very little utility for the team monitor. This was also present in the open ended questions. This has been an issue with NeoCITIES 3.0 for years now, and since the current version is more or less a rehash of that one, this is not surprising. Further analysis shows that participants in the shared virtual feedback conditions do find the team monitor to be slightly more useful (M=3.14 vs M=2.94) but both display relatively similar accounts on their frequency of use.

Appendix F

Development of ATM

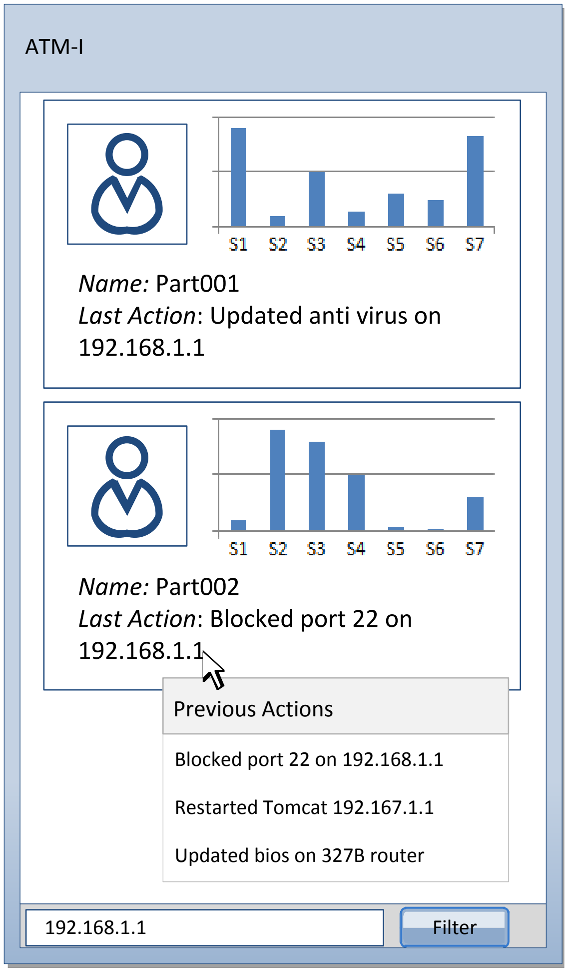
Prototype Design

When designing an artifact to be used as an augmented or virtual transactive memory, Keel (2007) proposes that you must accomplish three things:

- System must be able to learn about the expertise, knowledge and task foci of the individuals though a careful analysis of the activities within the virtual environment.
- System must be able to usefully represent the interconnected knowledge amongst the users
- System must be able to determine who needs to know what based on their current foci or task

The shared virtual feedback mechanism, the Augmented Transactive Memory interface, or ATM, implemented these requirements into a tangible interface component. Previous attempts at designing systems to serve as a virtual transactive memory took an approach of using complex visualizations that transmitted information in a dynamic display. While this is a perfectly acceptable methodology at approaching the problem, I chose to take more of a minimalist stance. I designed a very simple mock-up was designed to implement the design conventions from the research area of awareness, as well as the three requirements for a virtual transactive memory and the concept of the TEP unit.

This mock-up, as seen in Figure 25, includes embodiments, expressive artifacts and filtration mechanisms to better support its usability and utility in the NeoCITIES 4.0 experiment.



ATM-I

Name: Part001
Last Action: Updated anti virus on 192.168.1.1

Name: Part002
Last Action: Blocked port 22 on 192.168.1.1

Previous Actions

Blocked port 22 on 192.168.1.1
Restarted Tomcat 192.167.1.1
Updated bios on 327B router

192.168.1.1

Figure 25: Mock of Augmented Transactive Memory Interface for NeoCITIES 4.0

Several pieces of information will be available for each teammate in the simulation. First, something that has never been implemented into NeoCITIES will be an avatar for each player. This will serve as a visual embodiment of each player who is operating within the workspace. In order to provide feedthrough on everybody's actions within the workspace, under their picture will be an expressive artifact nametag that provides the user with the name of the user, as well as their most current action within the workspace. This artifact will update as the user performs more actions in the workspace. The user can then click the last action to see a full list of every action that user has taken in the workspace. The next interface component is the graph to the right of the user's avatars. These graphs, are broken down into a set of skills (which will be designed based on the interviews with the experts) and show that particular users performance on events within each of the categories. This will allow participants to categorize an information ticket that they do not know how to solve, and then check to see who has performed the best with that type of information in the team. Similarly to the expressive artifact providing feedthrough on the participant’s action, this graph will update in real-time, based on the actors performance in the workspace. The final aspect of the interface, which has been included to provide a method for information filtration, is the search mechanism at the bottom. In the situation displayed in the mockup that user only wanted to see information that was related to the computer at the location 192.168.1.1. This will allow the users to sift through all the information that is provided, and get to what they need for their current task.

This mockup is designed to provide full TEP units (Brandon & Hollingshead, 2004) for each actor within the system. The action indicator provides the ability to enter information about your current task (T) in the search bar, the skill graph provides information on a user’s expertise (E), and the information and photo on the actor provides the people information (P). If implemented correctly, this interface intervention tool should assist users in forming a more complete transactive memory system during a virtual collaboration. In the conditions of the experiment that the ATM-I is not present, this interface will be presented but without the relevant TEP information.

Before implementing into the system fully, this mockup will be presented to both target users of the simulation and cyber security experts to ensure its usability and utility within the context of the simulation and cyber security.

Final Design

After reevaluating the design mock-up, and discussions with the research team, there were several alterations made. Because of the time sensitivity of the *teamNETS* task, the more interactive portions of the interface were removed to make sure that it could be used as a supplementary tool, rather than an interactive portion of the game. This resulted in the removal of the information filtration mechanisms, and previous action history mechanisms. The other major change was adding the ATM information to the transfer report window. This allowed users to more quickly access the information necessary to make a correct decision when transferring events. Figure 26 shows the two implementation of the ATM.

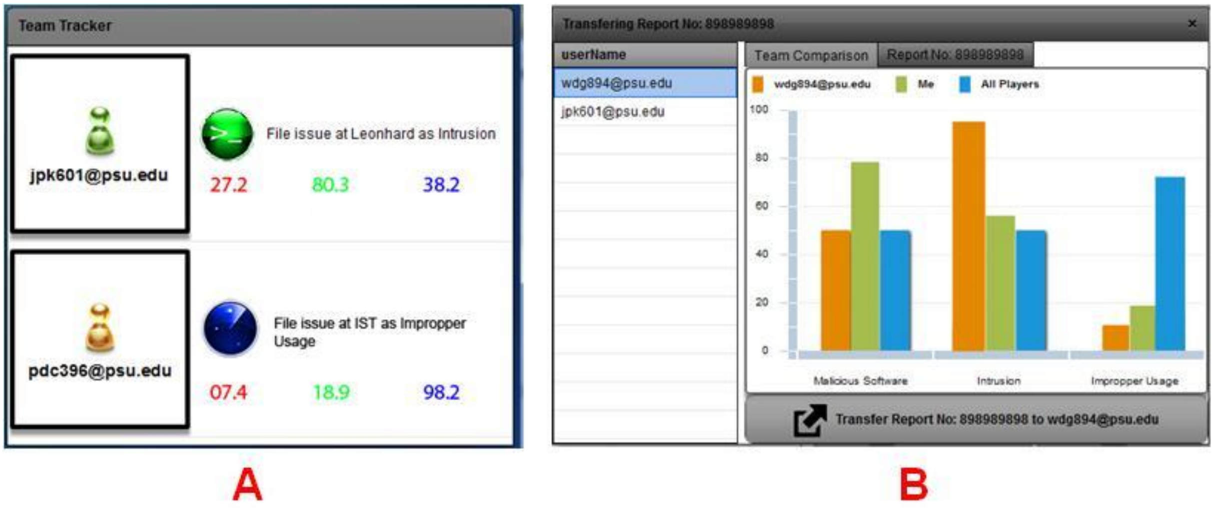


Figure 26: Final Implementation of ATM

In the team tracker (A), thee ATM reports scores that are color coded for each functional domain. As each player files reports, these scores are continuously updated to provide a running average for the scenario. In the transfer report window (B), the bar chart visualization from the original mock up was used to show each players skills across each functional domain. A major edit that was added to this, based off feedback from the second pilot test was the inclusion of relative score bars. On the ATM in the transfer report window (B), you can see three bars for each functional domain. For each functional domain, the first bar (orange) represents the score of the selected player, the second bar (green) represents the current players score, and finally the last bar (blue) represents the team average. This was added so players could understand where each user fell within each functional domain, rather than giving them an arbitrary number.

In conditions that did not receive the ATM, in the team tracker, there would be blank space where the numbers are, and in the transfer report window there would be the event description where the bar charts are.

VITA

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Education:

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Fellowships & Awards

- CogSIMA Student Travel Award, 2012
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Selected Publications

- Mancuso, V, McNeese, M, Effects of Integrated and Differentiated Knowledge Structures on Distributed Team Cognition. To be published In 56th Annual Meeting of Human Factors and Ergonomics Society Annual Meeting (Boston, MA, 2012).
- Mancuso, V., Minotra, D., Giacobe, N., McNeese, M., Tyworth, M., idsNETS: An Experimental Platform to Study Situation Awareness for Intrusion Detection Analysts. 2012 IEEE Conference on Cognitive Methods in Situation Awareness and Decision Support, (New Orleans, LA, 2012)
- Mancuso, V., Parr, A., McMillan, E., Tesler, R., McNeese, M., Hamilton, K. and Mohammed, S., Once Upon a Time: Behavioral, Affective and Cognitive Effects of Metaphorical Storytelling as a Training Intervention. In 55th Annual Meeting of Human Factors and Ergonomics Society Annual Meeting, (Las Vegas, NV, 2011), SAGE Publications, 2113-2117.
- Mancuso, V., Hamilton, K., McMillan, E., Tesler, R., Mohammed, S. and McNeese, M., What’s on “Their” Mind: Evaluating Collaborative Systems Using Team Mental Models. In 55th Annual Meeting of Human Factors and Ergonomics Society Annual Meeting, (Las Vegas, NV, 2011), SAGE Publications, 1284-1288.
- Mancuso, V., Hamilton, K., Tesler, R., Mohammed, S., McNeese, M. An Experimental Evaluation of the Effectiveness of Endogenous and Exogenous Fantasy in Computer-Based Simulation Training. Submitted to Simulation & Gaming: An Interdisciplinary Journal of Theory, Practice and Research (UNDER REVIEW)

Research Experience

- Research Assistant, Cyber Situational Awareness (Multi University Research Initiative sponsored by Army Research Lab), 08/10-CURRENT
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