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AN INTEGRATIVE SIMULATION TO STUDY TEAM COGNITION IN EMERGENCY CRISIS MANAGEMENT

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Teamwork has become one of the hallmarks of emergency crisis management (ECM). Success in managing emergency situations is highly dependent on teams working together to accomplish prioritized goals. Therefore, given the importance of teamwork, team cognition has been realized as an important component to address the emerging complexity, extreme workload, and uncertain conditions that can underlie emergency response. Many variables affect teams and their subsequent cognition. Understanding the effects of awareness, attention, temporality, common ground, team mental model development, and culture on team cognition provides insight into effective and efficient management of emergencies. As a research group, for more than a decade, we have studied team cognition within the context of ECM through the basis of simulations using the NeoCITIES platform. The purpose of this paper is to share our experiences using the NeoCITIES platform to conduct basic team cognitive research and share our visions for future research trajectories for the greater Human Factors community.

INTRODUCTION

Emergency management responders are constantly tasked with making complex, high-impact decisions under high stress. The inherent stress, and complexity of decision making such environments often push the boundaries of human cognition. When emergencies happen, cognition is placed under extreme conditions made up of complex interdependencies among individual assessment and action, information availability, and coordination/communication of teamwork. Responders must make quick, deliberate decisions, under extreme temporal stress, with only piecemeal information at their disposal. These situations can quickly unfold and deteriorate with emerging fragments, uncertain probabilities, and high-risk stakes that result in a crisis wherein teams are often called into action. Subsequently, the importance of team cognition has been realized within the emergency crisis management (ECM) community. Team cognition is traditionally defined as *"cognitive activity that occurs at a team level"* (Cooke et al., 2007). Literature often indicates the success or performance of a team is linked to team cognition (Salas et al., 2008). Multiple studies have indicated the importance of team cognition and team performance, showing that breakdowns in team cognition adversely affect team performance (Wilson et al., 2007).

ISSUES AND CHALLENGES OF TEAMWORK WITHIN ECM

Within the Human Factors community, researchers have been working towards understanding the complexities of teamwork in ECM. This work has often led to the development of technologies to support the collaborative and cognitive work that takes place in such an environment. Even with a greater understanding, and new tools at our disposal, there are still many remaining challenges and issues that center on team cognition and information use. Emergent complexity is typically present and requires adaptive re-planning, recognition of constraints in the domain, and generates constant demands for awareness. This is very apparent in the areas of decision-making (Pfaff, et al. 2013) and information sharing (DeChurch & Mesmer-Magnus, 2010), where information, technology, and people must be combined into an effective system in order to accomplish *teamwork*.

The geographic distribution of many teams adds multiple complexities such as delayed response times, lack of face-to-face interaction, and the loss of rich contextual information. Yet, distributed teams often face even further challenges. While "distributed" is typically representative of the geographic distribution, it is often the case that these teams are distributed temporally, contextually, and culturally, adding even more complexities to their tasks. Technology has enabled both synchronous and asynchronous models of communication as a means to distribute work to collaborative team members across these boundaries. Work that comes together across these varying boundaries imposes different information based constraints that often have interdependencies impacting future work. Within our research, we have recently examined unique ideas such as how temporal work is part of team mental models (Mohammed et al., 2012), attention disruptions/management, and most recently how cultural differences can produce impacts in planning, decision-making, and communication. Many of the above areas of human-work interaction have been studied by our research group utilizing the multiple-methods approach of the Living Lab Framework (McNeese, 1996) to produce deeper levels of understanding.

This paper emphasizes our use of the NeoCITIES simulation platform to explore variables of interest within ECM that highlight team cognition, information use, culture, and human-centered perspectives to technology. After reviewing the NeoCITIES platform and associated research projects, we then present lessons learned and the contributions that the NeoCITIES platform has afforded to multiple research domains. Finally, we conclude by describing future work that is envisioned.

NEOCITIES: AN INTERACTIVE SIMULATION ENVIRONMENT FOR EMERGENCY CRISIS MANAGEMENT

The NeoCITIES simulation was developed from an earlier, more basic-level simulation for ECM (CITIES; Wellens & Ergener, 1988). Today, the elements of crisis management and response that were resident in the first and many subsequent versions of NeoCITIES (e.g. Hamilton et al., 2010; Hellar & McNeese, 2010) are highly salient for studying how distributed teams work in homeland security operations, terrorist situations, and disaster management. The NeoCITIES simulation specifies emergency events of varying importance that emerge in a fictitious city environment wherein each member of the team assesses the situation, makes decisions about processing emerging events with available resources, and monitors the ongoing state of the city with their partners. This basic simulation context is the basis for many iterations of NeoCITIES simulations, which have been developed and refined through different versions (for differing experimental purposes) over the last ten years.

The NeoCITIES Simulation

In NeoCITIES, participants play the role of ECM in a small college town. Teams of three individuals are formed, with each member of the team assuming the role of police, fire, and hazard material response units respectively. NeoCITIES demands individuals in each role assess the gravity of each episode, collect data to inform situational awareness, make decisions on appropriate responses and the allocation of scarce resources, and share information through communication across agencies.

Using this basic formula, NeoCITIES continues to afford multiple interdisciplinary research projects that connect scholars from information science, psychology, and geographical sciences. As a platform, the NeoCITIES simulation structure and immersive user interface offers an ideal platform for conducting interdisciplinary research in fields such as human factors, human-computer interaction and computer-supported cooperative work. Due to the simplicity and flexibility of the NeoCITIES simulation, researchers are able to easily operationalize varying cognitive constructs as variables of interest to develop a longitudinal understanding of human cognition and work in distributed team settings. Using previously established metrics and measures, as well as developing new and novel ones, NeoCITIES has allowed us to hone in specific aspects of team cognition and behaviors that leading researchers have identified as critical needs in team research (Mohammed & Dumville, 2001).

The development of NeoCITIES has been iterative with new features being consistently added. The current NeoCITIES simulation version 3.1 has been advanced to enable scenario flexibility (e.g. easily prototyped interfaces), while creating an immersive and engaging environment for the participants (Hamilton et al., 2010). The simulation has been used to explore theoretical frameworks and models and to test and evaluate experimental independent and dependent variables within distributed cognition. Past variables have included time pressure, the role of hidden knowledge, emotion, decision aiding, adaptive interfaces, situation awareness, team mental models, team training, the use of metaphors, and other variables related to issues of teams performing in ECM. Notwithstanding, the basic conceptual framework of understanding how distributed teams' situational awareness and decision making are impacted by a variety of variables remains unchanged. The next section will discuss the experimental research we have conducted over the years in more detail.

From Theory to Practice: Applying NeoCITIES

During the development of NeoCITIES, researchers and developers worked hand-in-hand to ensure development of a rich and immersive environment that supported measurement of numerous aspects of team behavior, processes, and cognition. Each focus was carefully and extensively reviewed in the literature and pilot tested within the NeoCITIES environment to ensure accurate capture of the necessary elements to extract, correlate, and interpret their role in team process and performance. The following section presents several of the variables of interest that we have investigated over the last several years.

Team Situation Awareness. The formation of accurate Situation Awareness (SA) has been shown to be an important factor in numerous domains, such as emergency response (Blandford & Wong, 2004), C4i systems (Salmon et al., 2008), surgical teams (Hazlehurst et al., 2007), and cyber security (Tyworth et al., 2012). Since its inception in the late 1980s, models of SA have been extensively tested to better understand how teams process situational knowledge (cf. Salmon et al., 2008).

It was evident in our own research that the NeoCITIES simulation offered an intriguing platform for the measurement of SA. Stemming from the recommendation of leading team scientists (e.g. Lewis, 2003; Mohammed et al., 2010), NeoCITIES design enables data elicitation (scenario performance, communication analysis, survey/questionnaire data) on varying levels, specifically the ability to hone in individual and teams actual (SAGAT; Endsley, 1995), perceived (Mars, SART; Mathews & Beal, 2002; Taylor, 1990), and behavioral situation awareness (HPSM; Hellar & McNeese, 2012).

Team Mental Models. Team mental models (TMM) are a team's shared understanding and representation of relevant team knowledge (Mohammed & Dumville, 2001). These mental models have been measured in relation to taskwork, teamwork, and temporality (Mohammed et al., 2010). TMM's have been shown to have a positive correlation with team processes and performance in complex environments (e.g. Mathieu, et al, 2000; DeChurch & Mesmer-Magnus, 2010). Teams whose members share models of both taskwork and teamwork can better anticipate the needs and actions of other members, thus becoming a more effective team (DeChurch & Mesmer-Magnus, 2010; Mathieu et al., 2000).

While much of the previous research in TMM has focused on singular methods of measurement and one type of TMM (e.g. Ellis, 2006), NeoCITIES supported the measurement of different types of TMM, with varying measurements (paired omparisons, concept maps). The differentiated roles, rich contextual scenarios, and inherent temporal demands of NeoCITIES enable researchers to measure TMM based on taskwork, teamwork and temporal perceptions (Mohammed et al., 2010). Using the two most popular forms of measurement, paired comparison ratings and concept maps (Mohammed et al., 2010), TMM were measured at multiple times during each experimental session at both the content and structural levels.

Transactive Memory. Transactive memory, a complementary team cognitive process/outcome to TMM, has been an important research thread for almost 30 years (Wegner et al., 1985). Through a transactive memory system, an individual can use another as an external store of information and knowledge that they do not possess (Moreland & Myaskovsky, 2000) through a cooperative division of labor for learning, remembering and communicating relevant task knowledge to a team or group (Lewis, 2003). This concept is complementary to TMM, because where they are concerned with the commonality between team knowledge, transactive memory systems focus on the divergent nature of the team knowledge, and how that knowledge transfers and divides across a group.

Building on NeoCITIES 3.1, we developed a branch simulation that contained greater role differentiation and built in support for measuring transactive memory at behavioral, perceived and actual levels (TeamNETS; Mancuso & McNeese, 2012). The collaborative nature of the task clearly supported the use of the Lewis (2003) Perceived Transactive Memory Scale, which was easily implemented in post-task surveys. Additionally, in the TeamNETS expansion, an explicit sharing mechanism allowed team members to transfer individual (rather than shared, as in previous versions) events to others. This created an explicitly measurable behavior, where an individual received an event, and then transferred it to somebody that had the expertise to better solve it, which was evidential of a strong transactive memory system. Also, a new post-task survey was implemented, the Specialization index, which allowed an elicitation of the knowledge structure of each team member, which could then be extracted to show the differentiation of knowledge in a team (where high differentiation would represent transactive knowledge encoding).

LESSONS LEARNED AND CONSIDERATIONS

From our experiences we have learned numerous lessons that are not only applicable to our own future research, but the Human Factors community at large. One of the primary best practices we have learned is the importance of juxtaposing knowledge elicitation and ethnographic results with the theoretical foundations of any study. This helps ensure congruence, coherence, and compatibility among different kinds of knowledge that can work together as inputs into the design of the simulation and the scenarios that formulate the context that the simulation is designed to emulate. Speaking to this further, we have learned that what is good for an expert-level user is not the same as what our naïve participants (college students) know. Therein, a practitioner must be very sensitive to how the context and the appropriation of control-display sequences are designed for students. The ability to translate knowledge gained from an expert to a student is one of the most challenging issues we have addressed. This has significant impacts on decisions made in the simulation design – such as how the tasks, processes, and overall interaction are implemented in the scaled world (e.g., realism versus practical feasibility tradeoffs).

Experimentally, the importance of operationalizing the cognitive construct of interest appropriately is a constant thread in our own research. For example, when studying TMM versus Transactive Memory, the level of interdependence and divergence of team members was a major consideration that had to be correctly implemented into the simulation. In addition to appropriate scenario designs and manipulations, external measurement tools have played a large role in our ability to measure team cognitive processes. While behaviors (e.g. interface interactions and measurable decisions) and communicative processes have helped identify team cognitive attributes, the knowledge gleaned from external measurement devices such as surveys and mental model elicitors, substantially increased our abilities to hone in the cognitive constructs of interest. Though it is important to note that the addition of these measurement tools is not as trivial as adding a simple survey at the end. Significant effort had to be put into adding rich contextual scenarios (to support SAGAT), conducting thorough task analyses (for team mental model grids), and developing divergent roles (for transactive memory measurement), to enhance the already established NeoCITIES platform.

From a design and implementation standpoint, NeoCITIES has been, and will always be, a give and take between optimality and practicality. On one hand, our goal is to create a rich and immersive environment that engages participants and elicits realistic cognitive behaviors from them. On the other hand, as Human Factors researchers, our training and experiences requires us to focus on experimental control and capturing meaningful and representative data across experiments. While having an open world would offer more realistic conditions, allowing participants become fully immersed in the environment, it would make drawing conclusions across experimental trials difficult, if not impossible. Thus, careful consideration into the design of the interface, and scenarios must be put into each NeoCITIES experiment. Creating an environment that is seemingly open (from the participants point of view), but maintains an appropriate level of control (from the researchers point of view), continues to be a major challenge in every experiment we run.

REFLECTIONS AND CONTRIBUTIONS OF TEN YEARS OF NEOCITIES RESEARCH

Over the last decade, NeoCITIES has been an invaluable tool in understanding team cognitive behavior under varying conditions. NeoCITIES has facilitated bringing complex real world problems into the lab for deep study, to create scaled worlds of problem solving/decision making that inform practice, but also facilitate technological interventions to see how technologies impact human-work interaction under different contextual variations.

By utilizing a consistent simulation environment over the last decade, we have the unique ability to step back and reflect longitudinally at both basic and applied research levels. From our work we have made numerous contributions to not only the understanding of basic team cognition, but also the use of simulations in Human Factors research, and cognitive and collaborative processes within ECM. In the following sections we provide a brief overview of some of our meta-findings from the last decade of NeoCITIES research.

Contributions to Team Cognition Research

Across our studies we have found significant differences between team cognition, team SA, team mental models, and team performance. In the literature, many of the constructs are lumped together and mutually dependent, however our findings have shown that while they are sometimes complementary, they are each unique and differentiable constructs (e.g. Team SA does not always contribute to increased performance, and visa versa).

NeoCITIES has enabled us to bridge the gap between Human-Computer Interaction and Computer Supported Cooperative work, and more traditional disciplines such as I/O and Cognitive Psychology. This enables us to speak to how team cognition functions, generally and within a computer mediated context. In our research of transactive memory, our results show that while team cognitive interface support artifacts increased team's perceptive and actual transactive memory systems, it caused them to under-rely on collaborative processes, which in turn decreased their overall performance. On the other hand, when assessing issues in individual cognitive performance, we found that interface elements can be effective tools in facilitating distributed cognition and increasing performance. This raises a unique, albeit anecdotal, finding, that highlights the importance of grounding in communication, and the emergent nature of the team mind.

Contributions to Simulation Research

The emphasis and time placed on the design of rich and interactive scenarios serves as an exemplar in the field for studying situated cognition within university-level Human Factors research. While time consuming, the rigor and the time spent on scenario design has afforded the ability to run over two thousand undergraduate participants over the last ten years, through various NeoCITIES related studies. Furthermore, the effort placed on increasing the accessibility of the scenarios (and the training) facilitates experimental sessions that do not fatigue the participants, and minimizes upfront costs (thus enabling a larger subject pool). While the environment and scenarios may not be as realistic as some higher fidelity simulations, we have placed great emphasis on maintaining the macrocognitive elements of our environments of interest, thus our data is able to speak to higher-level team and individual cognitive processing principals and add to our basic research understanding of those constructs.

Contributions to ECM

ECM is a complex phenomenon that is dependent on the effective use of teams, technologies, and people orchestrated for interdependent action. NeoCITIES provides us with an interactive test bed for understanding human/system integration and team performance within scenarios specifically developed to emphasize the complexities within the domain of emergency crisis management. From our research we have uncovered unique attributes of the role of team cognition in emergency response. We have found that while the introduction of new tools/technologies can supply distinct advantages to assist teamwork (under certain conditions), they can also introduce a meta-level cost that can detract from the development of a common ground under time constraints. It is also the case that individual and team work in ECM is a two way street, again time-contingencies often make the difference in success or failure. If individual decision-making is needed at a point in time, but at that time team members are trying to remotely communicate, then there can be overall team process loss. Likewise, if a team is trying to establish sensemaking with a new uncertain event when an individual area of responsibility is sending off critical time-sensitive alarms, team process loss can ensue. Therein, many of the temporality issues we have uncovered are very important in ECM in terms of successfully establishing: a) the integration of teams, technologies, and information; and b) the resilience of team mental models, team situational awareness, transactive memory, and team performance. Distributed cognition in ECM is much more difficult than face-to-face cognition, but with the predominance of the web and smart phones it is becoming more of the rule rather than the exception. Therein, the studies we have conducted to understand the context of ECM demonstrate how team cognition and collaborative technologies can be orchestrated for team process gains, given specified conditions.

FUTURE RESEARCH

The nature of work in today's world is shifting in scope towards a more international focus and outlook. Teams are now composed of individuals or groups from multiple nations, who are expected to accomplish specific goals. This expansion towards the international context occurs in business, military, peacekeeping operations, and crisis environments. What is little understood about environments like these, beyond the chaotic and emergent nature of crises events, is how cultural differences amongst team members affects the team's ability to effectively function, particularly when they may be dealing with an affected population that does not share a similar cultural background.

To date, NeoCITIES has only been used in a controlled domestic environment. However, an untapped opportunity is its use in a culturally diverse and international environment to determine if and how culture plays into team cognition, situational awareness, and performance. The initial step in exploring the cultural impact will be implementing a small pilot study involving participants at a British and an American university. The study will examine how culturally homogeneous teams, characterized by nationality, respond to an identical crisis. The objective of the experiment focuses on how culture influences the ways in which humans respond to crisis situations, and assesses the differences that may emerge at a national level.

The scenario and corresponding events will be contextualized to participants' environment and language. For example, HAZMAT response will be replaced with Environment Service and Military who would perform the HAZMAT tasks in a British environment. Language inconsistencies will be corrected to reduce the likelihood of biases emerging from language clues.

The study's goals are to establish a proof of concept that broad multi-cultural studies are possible and to identify and mitigate the practical challenges in setting up international studies. Notwithstanding, the actual implementation of an international experiment requires a sound project plan, robust communication among the partners, the identification of appropriately responsible points of contact (e.g. project management, contextualization, and technical implementation) to facilitate a successful multinational experience.

CONCLUSIONS

Through the utilization of NeoCITIES over the past decade we have amassed a great deal of knowledge about team cognition within the context of ECM. The importance of team cognition is amplified within the context of ECM. In the time and information sensitive context of ECM, team cognition must be developed efficiently and effectively. If teams fail to develop an accurate and similar concept of team cognition, their performance will most likely suffer. In ECM, performance cannot suffer– the stakes are too high. Through our research we have explored many variables of team cognition, specifically within the context of ECM. We encourage researchers to continue to explore the role of team cognition within this domain. We also encourage researchers to view our usage of the NeoCITIES simulation as an integrative framework and/or methodology for conducting future team cognition research this context and community.

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