5.12 Zero-Fidelity Simulation: Engaging Team Coordination without Physical, Functional, or Psychological Re-Creation

Zero-Fidelity Simulation: Engaging Team Coordination without Physical, Functional, or Psychological Re-Creation

Zachary O. Toups
Crisis Response Innovative Technologies Lab
Disaster Preparedness & Response, Texas Engineering Extension Service
+ Texas Center for Applied Technology
+ Interface Ecology Lab | Texas A&M University
zachary.toups@teexmail.tamu.edu

William A. Hamilton
Interface Ecology Lab | Texas A&M University
bill@ecologylab.net

Andruid Kerne
Interface Ecology Lab | Texas A&M University
andruid@ecologylab.net

Abstract. Team coordination is essential across domains, enabling efficiency and safety. As technology improves, our temptation is to simulate with ever-higher fidelity, by making simulators re-create reality through their physical interfaces, functionality, and by making participants believe they are undertaking the simulated task. However, high-fidelity simulations often miss salient human-human work practices. We introduce the concept of zero-fidelity simulation (ZFS), a move away from literal high-fidelity mimesis of the concrete environment. ZFS alternatively models cooperation and communication as the basis of simulation. The ZFS Team Coordination Game (TeC) is developed from observation of fire emergency response work practice. We identify ways in which team members are mutually dependent on one another for information, and use these as the basis for the ZFS game design. The design creates a need for cooperation by restricting individual activity and requiring communication. The present research analyzes the design of interdependence in the validated ZFS TeC game. We successfully simulate interdependence between roles in emergency response without simulating the concrete environment.

NOMENCLATURE

FER – Fire Emergency Responder; any trained response professional dispatched for firefighting, rescue, command, etc.

IC – Incident Commander; the person responsible for coordinating response to an emergency incident, as defined by the Incident Command System.

TeC – The Team Coordination [Game]; a zero-fidelity simulation of the information- and human-centered aspects of teams in fire emergency response work.

1.0 INTRODUCTION

Team coordination is an essential aspect of work contexts in which tasks are too large or complex for one person. In the emergency response domain, such work must be performed quickly in a dangerous, high-stress environment. Coordination consists of cooperation and communication within a team to accomplish a set of shared objectives.

The present research begins with an investigation of team coordination in fire emergency response work practice [21]. To address a discovered need for team coordination education, we developed a game in which players exercise cooperation and communication, rather than addressing the whole firefighting experience. In this process, we abstracted out firefighting's varied perspectives, sources of information, and communication. We situated them within a stressful game environment. We hypothesize that the result, while barely recognizable as a simulation, constitutes a *zero-fidelity* simulation (ZFS) of team coordination. The ZFS Team Coordination Game (TeC) offers a focused educational experience that our research has shown to be effective for engaging emergency responders in team coordination [19][20]. By design, it eschews many of the typical notions of simulator fidelity: physical, functional, and psychological.

Game mechanics are the activities that players undertake in a game [14]. They are experiential building blocks in which a player makes a decision and the game responds with a change in state. A *core game mechanic* is a mechanic that is repeated during play.

In this paper, we present TeC core mechanics and connect them to practice. We show how the interdependency between players engages them in processes of communication like that of emergency responders. Evidence comes from a series of user studies of TeC using fire emergency response students. Details of the studies can be found in [19][20].

In the following sections, we address background in team coordination, including details of fire emergency response work practice. We define zero-fidelity simulation in the context of simulation in general, then the Team Coordination Game in specific. We cover, in-depth, the interdependency of action and information in the game, beginning with a demonstrative scenario taken from user study data. We conclude by discussing the implications of ZFSes and our design considerations in successfully building a ZFS.

2.0 TEAM COORDINATION

Team coordination is characterized by the synchronization of action by multiple individuals to accomplish a task. Cooperative action and communication are essential. Team effectiveness and efficiency is improved if team members are skilled at coordinating.

Individuals build and maintain *mental models*, cognitive structures that support problem solving by predicting future outcomes [6]. When *shared* [10], mental models enable team members to predict each other's needs, informationally and practically. This leads to *implicit coordination*, collaborating with reduced communication [5]. Implicit coordination theory posits that communication is costly, in terms of time, cognitive, and technological bandwidth. Conserving bandwidth, for example by providing needed information without being asked, is thus beneficial [11].

Distributed cognition theory accounts for the ways that information is split out among individuals, artifacts, and time [8]. It addresses the ways in which individuals transform information across media to make use of it. Distributed cognition forms the basis for our understanding of information-centric team tasks and informs the design of TeC.

2.1 Fire Emergency Response

The present research is based on fire emergency response work practice. We began with an ethnographic investigation at one of the world's largest firefighter training schools, Brayton Field in College Station, Texas, USA [21]. We interviewed expert responders and observed high-fidelity simulation burn training exercises, in which students fight actual fires.

Fire emergency response is accomplished by distributing a number of small teams in and around the fireground. An incident commander (IC) directs the response from a distance, possibly consulting information artifacts. The IC relies on reports from deployed responders, as well as observations of the incident as a whole. In this context, information is distributed among team members, and each team must develop situation awareness by integrating first-hand and communicated data. The IC constructs plans for the deployed teams, while the teams gather and share information and use it to take situated action [17] in the context of the plan. *Information is distributed* throughout the team, and resolving and sharing information is central to response. While responders prefer to communicate face-to-face, radio is frequently necessary to connect teams that are distributed. Radio is problematic, because it is half-duplex and difficult to understand.

Our results indicated a successful team coordination simulation should capture the ways that information is distributed and force participants to mix communication modalities (face-to-face, radio) [21]. Based on our observations, it was clear that there was a need for educating communication under stress, but no need to directly mimic the context of firefighting. Students needed to learn to implicitly coordinate in a distributed cognition environment.

3.0 ZERO-FIDELITY SIMULATION

Simulations are operational environments that facilitate learning and practicing; they are typically defined in terms of *fidelity*, the degree to which a simulation recreates some aspect of a real environment and activity. Fidelity is multidimensional; a broad classification identifies how a simulation re-creates a target environment physically, functionally, or psychologically [1][2][13]. Physical fidelity addresses the way in which the simulator resembles the target environment, while functional fidelity is the degree to which the environment reacts appropriately. In a flight simulator, physical fidelity addresses the controls and gauge configuration, while functional fidelity addresses the way those gauges and the view from the cockpit change in response to the controls. Psychological fidelity identifies the degree to which a participant believes they are undertaking a task in the target environment.

While the temptation is to build systems with ever-higher fidelity, assuming automatic skill transfer, we take a different tack: *we do not re-create the target environment at all.* A number of approaches address high-fidelity simulation, employing complex algorithms and graphics processing power to construct a realistic virtual environment [16][18]. These achieve a high level of physical and functional fidelity with the assumption that psychological fidelity follows [7]. Even in low-fidelity simulations, high psychological fidelity is essential; participants should *believe* that they are working on a particular task, despite the simulator not completely recreating the task environment [3][9]. *Zero-fidelity simulation* is different in that the suspension of disbelief is not required to effectively participate in the simulation, yet educational value is retained.

Zero-fidelity simulation engages the participant in the information- and human-centered aspects of the simulated activity. Tasks are then re-situated in an alternative environment. The ZFS Team Coordination Game that we present does not encourage players to believe that they are fighting fire, nor does it address the physical activity of firefighting, yet we have shown that FER students engage in and improve in the same communication and team coordination tasks required in fire emergency response and carry their skills forward into

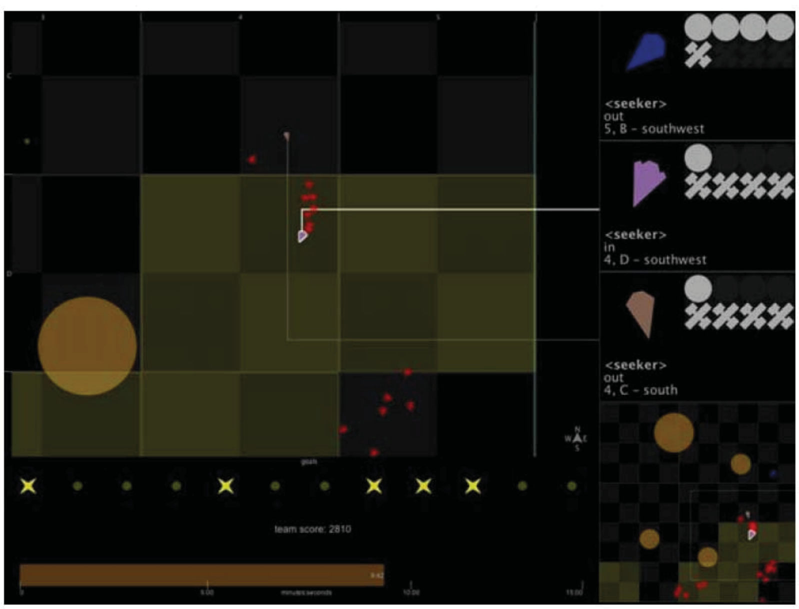

Figure 1. Coordinator game interface. The main view shows terrain with all entities in it; yellow regions contain goals. Walls (visible to seekers) cannot be seen. The right column shows the status of each seeker; a mini-map is at the bottom. Below the main view is the list of goals (here, five remain un-collected), team score, and the time remaining.

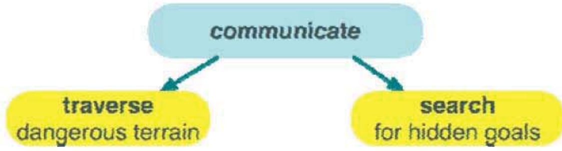

Figure 2. Core mechanics of TeC. Traversing and searching and dependent on communication.

high-fidelity burn training exercises [19][20].

4.0 ZFS TEAM COORDINATION GAME

The Team Coordination Game is engineered to simulate the distributed cognition environment of fire emergency response. Participants are mutually dependent on one another for information. Here, we present TeC's information distribution across roles, terrain and game entities, core mechanics, and motivation through score.

4.1 Roles & Information Distribution

Players take on the role of the *coordinator* or a *seeker*. These roles are differentiated by the player's agency in the game world and are the axis along which information is distributed.

Players in the seeker role control a seeker *avatar* in the game environment. They have a high-detail view of the terrain around them (Figure 3). Some information is specifically hidden and is only available to the coordinator.

The coordinator cannot directly act in the game world, rather s/he must communicate with the seekers to manage information and develop strategy. In this way, the coordinator role is like that of an IC. The coordinator has access to low-detail information about the entire game world (Figure 1).

To engage players in mixing communication modalities [21], games are run in one of two conditions: co-located or distributed. In the co-located condition, all seekers play around a table, while the coordinator is isolated and may only be reached using a half-duplex radio. In the distributed condition, all players must use the radio to communicate. In some cases, players can use fast, face-to-face communication, while in others they must use the slow, lossy radio. This leads to careful decision making about which modality to use.

4.2 Terrain & Game Entities

TeC game play is made up of interactions between game entities. Seekers drive *avatars*. *Threats* chase avatars and take them out of play, preventing them from collecting *goals*, the main objective. Game *terrain* limits how seekers' avatars move in the simulation.

Game terrain consists of a number of elements that influence play. Walls impede avatars in the virtual environment; walls are visible to seekers, but not the coordinator. Offline regions of the terrain make a seeker invisible to the coordinator as well as threats, but prevent the seeker from collecting goals. Bases are safe for seekers, but are invisible to them; such information is available only to the coordinator.

Seeker players act in the simulation by controlling avatars. Seekers may move in terrain, observe their local surroundings in high detail, and search out and collect goals. Seeker avatars have *hit points* (HP). When a seeker avatar has HP the seeker is *in*, if the seeker avatar has 0 HP then it is *out* and unable to succeed at collecting goals. To regain HP, seekers must wait in a base.

Threats protect *goals* and pursue seekers in the game world; they represent danger (Figure 3, a., c., d., e.). When in contact with a threat, seekers loose HP. Threats are controlled by a continuous flocking simulation [12]. Within this simulation, threats patrol and guard goals and also pursue nearby seekers. Seekers that are collecting goals attract more threats. Threats do not pursue offline or out seekers.

Seekers collect goals in the environment. To collect a goal, a seeker must either point his/her avatar at the goal or move on top of it for a brief period. Seekers must be online and in to collect. Cooperative goals require multiple seekers to collect the goal simultaneously. A goal indicates how many seekers are required by the number of rings around it

(Figure 3, a., b., d., e.). These rings fill with the collecting seekers' colors to indicate progression (Figure 3, b., d., e.).

4.3 Core Game Mechanics

TeC is built up from three core mechanics: traversing dangerous terrain, searching, and communicating (Figure 2). In practice, each of these is a suite of activities executed in coordination by players (Figure 4). To succeed, seekers must traverse dangerous terrain to search for goals, while the whole team engages in communication.

4.4 Motivation Through Score

Players are motivated to engage in TeC's core mechanics and increase performance through score. Score in TeC is a shared by the entire team and is computed in such a way as to motivate the core mechanics and team coordination. The team receives points for being in dangerous terrain, for collecting goals, and for completing a game faster than the allotted time. Collecting cooperative goals nets significantly more points than individual goals. Points are deducted when a seeker is taken out. Also, no points are awarded if the seeker is not in danger, discouraging players from hiding in bases or offline areas.

5.0 INTERDEPENDENCE BY DESIGN

In this section, we look at the three core mechanics of TeC. Seekers engage in traversal and searching. Each of these core mechanics is a suite of other game mechanics, and each of those mechanics is dependent on information that may or may not be available to any one seeker.

When the necessary information is not available to a particular player, that player must engage in the third core mechanic: communication. Communication is one of the most critical components of team coordination and the most important core mechanic. The designed information distribution engages players in communication in service to the other two core mechanics. We connect the core mechanics to observed activities in fire emergency response work practice. We begin with a

a.) using information from the coordinator, [Seeker 1] finds a cooperative goal (yellow star; gray rings indicate number of players) and threat (red entity to upper-left)

b.) communicating to troubleshoot collection failure (colored circles indicate who is successfully collecting the goal); green, [Seeker 2], is not assisting

c.) [Seeker 2] escapes the threat

d.) [Seeker 2] finds another cooperative goal while being attacked by a threat

e.) [Seeker 3] assists in collecting

f.) the team escapes

Figure 3. Simulation scenario from user study data demonstrating core mechanics. Seekers traverse terrain and search for goals while communicating.

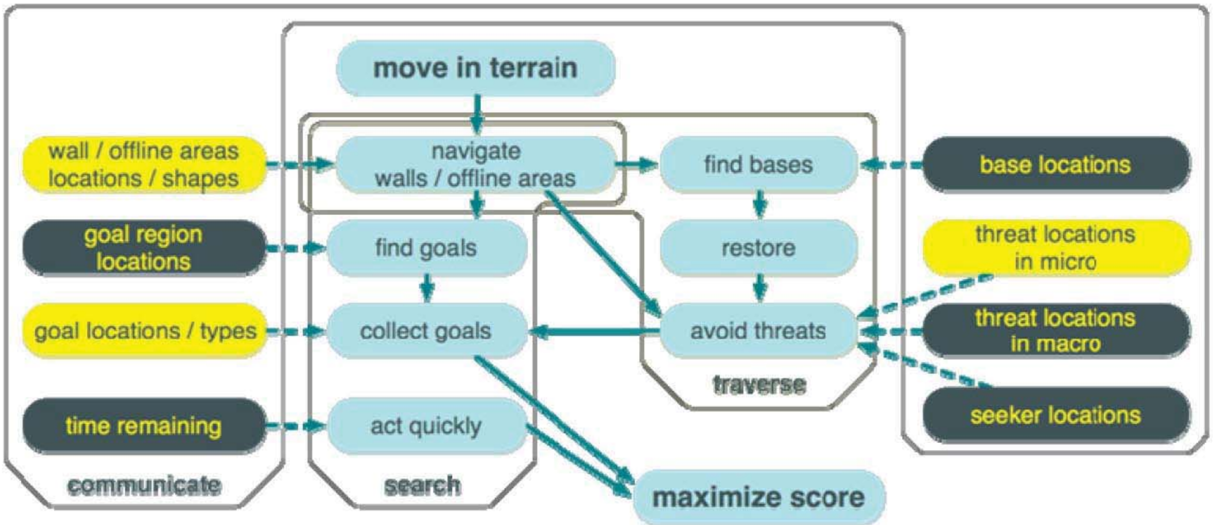

Figure 4. Interdependency of game mechanics and information sources in TeC. Seekers engage with game mechanics (light blue); game mechanics that are pre-requisite to others are shown with an arrow. Information sources come from a seeker's own interface, the interfaces of other seekers, and the coordinator. Communication is essential to get timely information and maximize score. Seeker information sources are in yellow; coordinator sources are in dark gray. Core mechanics that encompass game mechanics and information sources are outlined.

scenario taken from user study data with fire emergency response students that illustrates the mechanics in action. Figure 4 diagrams game mechanics and their interdependencies with information sources, situating these with the core mechanics of traverse, search, and communicate.

5.1 Scenario

The present scenario is an account from actual game play data from a user study of FER students enrolled at Brayton Field [19]. Team calTEXANADA is nearing ten minutes left in their fifth TeC game. As it will turn out, three of the team members will be in the top 10 of their class at the Firefighter Training Academy (2nd, 4th, and 6th). By now, they are starting to play effectively as a team.

In this game, the three seekers are seated around a table at notebook computers, facing one another (co-located condition). The fourth team member, the coordinator, observes the simulation world from another room and communicates with the seekers using a half-duplex radio.

At the beginning of this scenario, the coordinator calls to the seekers and informs them that there is a goal nearby; one seeker acknowledges for the team. With some searching and traversal around the terrain, [Seeker 1] spots a goal that will require cooperation by all three seekers to collect (Figure 3, a.). The move is risky: a threat is already closing on [Seeker 1] and collecting the goal will subject all three seekers to attack by that threat.

The seekers rush the goal as the threat comes closer. Two successfully start to collect it, but [Seeker 2] does not line up correctly (Figure 3, b.). A brief conversation resolves the problem. [Seeker 2] adjusts his position, and the three run away from the threat before it can attack.

[Seeker 2], now pursued, quickly tells his co-located teammates he is "…headed south! I'm headed south! I'm headed south!" (Figure 3, c.), urgently keeping them appraised of his escape plan. [Seeker 1] responds to tell him they are following; the team (and threat) follow [Seeker 2].

The coordinator implicitly coordinates, sharing information that only he has: there is a base nearby. [Seeker 2], however, has found another cooperative goal during his flight (Figure 3, d.). Having sustained only a little HP damage from the threat, he is still in and rushes the two-seeker goal while notifying his teammates of the information in his local scope and outside of theirs. [Seeker 1] and [Seeker 3] are far behind as another threat joins in the pursuit.

[Seeker 2] stays near the goal while being attacked by two threats. [Seeker 3] rushes through quickly and assists in collecting the goal (Figure 3, e.). All the seekers run away to safety before they are taken out completely by the threats (Figure 3, f.).

Throughout the scenario, the seekers evoke the core game mechanics while under stress: communicating, traversing dangerous terrain, and searching for goals. The seekers make use of rapid changes in information in their interfaces to respond to a failed goal-collection attempt. They opt to speak to each other face-to-face, instead of contacting their coordinator over radio. We also note that the coordinator performs implicit coordination when he notifies the seekers of a nearby base without them asking for it.

5.2 Traversing Dangerous Terrain

Like firefighters, seekers traverse dangerous terrain, *about which they have only partial information*. At a structure fire, firefighters and the IC must cooperate and communicate to construct a satisficing [15] image of the incident status. Firefighters move room-to-room, with limited visibility, to search for victims and develop a sense of the tactical details of the incident [4][21]. Important discoveries are relayed to other team members and acted upon. The environment consists of a number of health hazards, the most obvious of which are fire and structural collapse. The IC, safely located away, combines the perspectives from the various workers and uses contextualized external observations to make decisions and strategically direct the firefighting teams. Each part must combine perspectives from the others to succeed.

In TeC, seekers traverse a virtual environment that contains walls and threats while under a time limit. The threats and time limit create a stressful environment, while the walls impede progress. Unlike firefighting, threats do not behave like fire or other hazards and they cannot be defeated. As in firefighting, each part of the team has access to different pieces of the information picture. Seekers are aware of local walls and threats, but the coordinator is aware of time remaining, safe bases, and threats in macro. While under stress, seekers must communicate about navigation and rely on the coordinator to provide an overview and direct them strategically.

TeC simulates the information interdependence of the task of traversing dangerous terrain from firefighting. Firefighters and seekers traverse terrain, avoiding hazards and circumnavigating obstacles to search the environment. The IC / coordinator, isolated from those on the scene, develops strategy and communicates macro information about the situation, building on information provided by those in the field.

5.3 Searching for Hidden Goals

Searching physical environments involves plotting a careful and situationally informed route through a structure. Searches may be coordinated with help from the IC, who may have access to plans and who will provide strategic advice on where to search. Searches are also coordinated within the deployed teams, as the various perspectives and locations of firefighters are important. It is a waste of time, energy, and possibly lives to search an area multiple times, and so status reports are necessary. It is essential that the search be complete, that all victims be found, and that all fires are either suppressed or discovered and left to burn.

In TeC, seekers move through the game terrain to locate goals. To optimize score, seekers must find all goals in the minimum amount of time possible. The coordinator has an overview that includes the regions that contain goals, but no specific details. This enables the coordinator to direct seekers in macro, but not in micro. The micro situated actions of seekers are based on information that they, the seekers, have. This results in seeker-seeker information distribution.

TeC simulates the same individual-individual information distribution found in the structural search task. The alternate perspectives of seekers enable them to build up collective situation awareness and use distributed cognition to their advantage. This process is a simulation of the combining of individual perspectives required in structural search.

5.4 Communication

Communication is the most important core mechanic of TeC. Both traversal and searching rely on distributed information, thus requiring the use of communication. Similarly, in firefighting, team members must share information constantly to build situation awareness.

In our zero-fidelity simulation, we make use of half-duplex radios, like those FERs use. Such devices allow only one participant to broadcast at a time, meaning that bandwidth needs to be used carefully and thoughtfully. These considerations are thus brought into play by retaining the radio technology for communication.

6.0 DISCUSSION & CONCLUSION

Many of the interdependencies in TeC are analogs of the work practice of firefighting, but abstracted. TeC is specifically not themed, it is generic by design. This enables players to build their own interpretations of the game environment, some players, for example, called threats "bad guys" and others, despite the design, called them "fire" [20]. One team, Team Firestorm, noted that the threats were not at all like fire, but the stress they created encouraged them to communicate quickly [20]. The lack of theme opens the potential to use TeC in other domains.

All TeC core mechanics are information-centric. Players need information about the game environment and one another to make decisions about which game mechanic to engage when and how to parameterize such actions. Interdependency derives from the reliance on different team members to provide data about their own perspectives. The result is a need to engage in the core mechanic of communication.

TeC players learn team coordination skills [19][21]. Despite deriving from fire emergency response and building on the roles of firefighter and IC, players do *not* directly learn about firefighting, fireground tactics, or incident command. Rather, they learn how to make quick decisions about what information is needed by teammates, how best to communicate that information, and when it is essential. They learn to cooperate and communicate while under stress.

As a zero-fidelity simulation, the Team Coordination Game does *not* directly connect to the concrete environment. The tasks performed are *not* directly like those of fire emergency response, but the human-human interaction requirements are simulated. The interdependency between team members requires that they communicate efficiently to succeed. Score serves to motivate interaction with the core mechanics. The implication is that psychological re-creation, like physical and functional, is neither *retained* nor *needed to teach team coordination*. Other domains and tasks may benefit from this discovery, which indicates that expensive high-fidelity is not always the correct educational tool. We hypothesize that high-fidelity may even be distracting to learners, who, in expecting a replication of reality, may fixate on flaws in the simulation.

ACKNOWLEDGEMENTS

Special thanks to the workers and students at the Brayton Firefighter Training Field, especially Chief Cary Roccaforte. This material is based in part upon work supported by the National Science Foundation under Grant Numbers IIS-0803854 and IIS-0742947. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

[1] Alexander, A.L., Brunyé, T., Sidman, J., Weil, S.A. From Gaming to Training: A Review of Studies on Fidelity, Immersion, Presence, and Buy-In and Their

Effects on Transfer in PC-Based Simulations and Games. *DARWARS Training Impact Group Whitepaper* (Nov 2005).

[2] Allen, J. Maintenance Training Simulator Fidelity and Individual Differences in Transfer of Training. *Human Factors 28* (1986), 497–509.

[3] Beaubien, J.M., Parker, D.P. The Use of Simulation for Training Teamwork Skills in Health Care: How Low Can You Go? *Quality and Safety in Health Care 13* (2004), 51–56.

[4] Denef, S., Ramirez, L., Dyrks, T., Stevens, G. Handy Navigation in Ever-Changing Spaces: An Ethnographic Study of Firefighting Practices. *Proc. ACM Designing Interactive Systems* (2008), 184–192.

[5] Entin, E.E., Serfaty, D. Adaptive Team Coordination. *Human Factors 41*, 2 (June 1999), 312–325.

[6] Gentner, D., Stevens, A.L. *Mental Models*. Lawrence Earlbaum Assocs., Hillsdale, NJ, USA, 1983.

[7] Hays, R.T., Singer, M. J. *Simulation Fidelity in Training System Design: Bridging the Gap Between Reality and Training*. Recent Research in Psychology. Springer-Verlag, New York, NY, USA, 1989.

[8] Hutchins, E. *Cognition in the Wild*. MIT Press, Cambridge, MA, USA, 1995.

[9] Kozlowski, S.W.J., DeShon, R.P. A Psychological Fidelity Approach to Simulation-Based Training: Theory, Research and Principles. *Scaled Worlds: Development, Validation, and Applications*, S. G. Schiflett, L.R. Elliott, E. Salas, M.D. Coovert, Eds. Ashgate Pub. Ltd., 2004, 75–99.

[10] Mathieu, J.E., Goodwin, G.F., Heffner, T.S., Salas, E., Cannon-Bowers, J.A. The Influence of Shared Mental Models on Team Process and Performance. *Journal of Applied Psychology 85*, 2 (2000), 273–283.

[11] MacMillan, J., Entin, E.E., Serfaty, D. Communication Overhead: The Hidden Cost of Team Cognition. *Team Cognition: Understanding the Factors that Drive Process and Performance*, E. Salas, S.M. Fiore, Eds., 1st ed. American Psychological Association, Washington, DC, USA, 2004, 61–82.

[12] Reynolds, C.W. Flocks, Herds and Schools: A Distributed Behavioral Model. *Proc. ACM SIGGRAPH Annual Conference on Computer Graphics and Interactive Techniques* (1987), 25–34.

[13] Rehmann, A.J., Mitman, R.D., Reynolds, M.C. A Handbook of Flight Simulation Fidelity Requirements for Human Factors Research. Technical Report DOT/FAA/CT-TN95/46, Crew System Ergonomics Information Analysis Center, Wright-Patterson AFB, OH, Dec 1995.

[14] Salen, K., and Zimmerman, E. *Rules of Play: Game Design Fundamentals*. MIT Press, Cambridge, MA, USA, 2004.

[15] Simon, H.A. *Sciences of the Artificial*, 3rd ed. MIT Press, Cambridge, MA, USA, 1996.

[16] St. Julien, T.U., Shaw, C.D. Firefighter Command Training Virtual Environment. *Proc. Conference on Diversity in Computing* (2003), 30–33.

[17] Suchman, L. A. *Plans and Situated Actions: The Problem of Human Machine Communication*. Cambridge University Press, Cambridge, UK, 1987.

[18] Tate, D.L., Sibert, L., King, T. Using Virtual Environments to Train Firefighters. *Computer Graphics and Applications 17*, 6 (Nov-Dec 1997), 23–29.

[19] Toups, Z.O., Kerne, A., Hamilton, W.A., Shahzad, N. Zero-Fidelity Simulation of Fire Emergency Response: Improving Team Coordination Learning. *Proc. ACM SIGCHI Conference on Human Factors in Computing Systems* (2011), 1959–1968.

[20] Toups, Z.O., Kerne, A., Hamilton, W.A. The Team Coordination Game: A Zero-Fidelity Simulation from Fire Emergency Response Practice. *ACM Trans. Computer-Human Interaction* (2011), in press.

[21] Toups, Z.O., Kerne, A. Implicit Coordination in Firefighting Practice: Design Implications for Teaching Fire Emergency Responders. *Proc. ACM SIGCHI Conference on Human Factors in Computing Systems* (2007), 707–716.