NON-MIMETIC SIMULATION GAMES:
TEACHING TEAM COORDINATION FROM A GROUNDING IN PRACTICE

A Dissertation

by

PHOEBE OLIVIA TOUPS DUGAS

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2010

Major Subject: Computer Science

Non-mimetic Simulation Games:

Teaching Team Coordination from a Grounding in Practice

NON-MIMETIC SIMULATION GAMES:
TEACHING TEAM COORDINATION FROM A GROUNDING IN PRACTICE

A Dissertation

by

PHOEBE OLIVIA TOUPS DUGAS

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Approved by:

Chair of Committee,	Andruid Kerne
Committee Members,	Richard Furuta
	Charles D. Samuelson
	Scott Schaefer
Head of Department,	Valerie E. Taylor

August 2010

Major Subject: Computer Science

ABSTRACT

Non-mimetic Simulation Games:

Teaching Team Coordination from a Grounding in Practice. (August 2010)

Phoebe Olivia Toups Dugas, B.A., Southwestern University

Chair of Advisory Committee: Dr. Andruid Kerne

Fire emergency responders work in teams where they must communicate and coordinate to save lives and property, yet contemporary emergency response training expends few resources teaching team coordination. The present research investigates fire emergency response team coordination practice to develop a zero-fidelity simulation game to teach team coordination skills. It begins with an ethnographic investigation of fire emergency response work practice, develops the concept of *non-mimetic simulation* with games, iterates game designs, then evaluates game designs with non-fire emergency responders and fire emergency response students.

The present research defines a new type of simulation, *non-mimetic simulation*: an operational environment in which participants exercise skills without a re-creation of the concrete environment. In traditional simulation, the goal is to re-create the world as faithfully as possible, as this has clear value for teaching skills. Non-mimetic simulations capture abstract, human-centered aspects of a work environment from a grounding in practice. They provide an alternative, economical, focused environment in which to exercise skills. Constructed as games, they can provide intrinsic and extrinsic motivation to practice and learn.

The present work iterates a series of game designs in which players transform and share information with each other while under stress, engaging in processes of team coordination found in fire emergency response work practice. We demonstrate how the game successfully teaches participants how to become more effective at coordinating and communicating through user studies with non-fire emergency responders and fire emergency response students. Principles for the design of team coordination education, non-mimetic simulation, and cooperative game play are developed.

To everyone who understands that games don't need to be "serious" to be meaningful.

ACKNOWLEDGMENTS

I would like to thank my committee chair and friend, Andruid Kerne, for his guidance and constant exposure to the reality of running a lab. You taught me to be a mentor and a leader. I know this will be invaluable in the years to come.

Thanks also go to Cary Roccaforte, Program Coordinator at the Brayton Fire Training field. He patiently stuck with us through numerous late-night user studies, and has constantly provided valuable knowledge and support to the projects described herein.

Thank you to my research assistant and good friend, William A. Hamilton, without whom this project would have been insurmountable. I hope I can provide you the same support as you grow into your own role as researcher.

To my family, friends, and colleagues at home, in the Interface Ecology Lab, and beyond, thank you for your unending supply of moral, technical, and testing support. And thanks to the National Science Foundation and Houston Advanced Research Center, whose grants and fellowships supported this work.

Finally, thank you to my wife, Diana Vera Toups Dugas, who lovingly supported me and stood by me, even through all the late nights and long drives. Your understanding, wisdom, and patience carried me through the roughest parts of this work.

This material is based upon work supported by the National Science Foundation under Grant Nos. 0803854 and 0742947. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

TABLE OF CONTENTS

CHAPTER Page

CHAPTER | Page

CHAPTER Page

LIST OF TABLES

TABLE Page

LIST OF FIGURES

FIGURE Page

FIGURE Page

CHAPTER I

INTRODUCTION

> You get a good crew that works together all the time and they can do things just by gestures, body movement, and all that. You can communicate with each other without saying a word. . . not much has to be said, everybody knows what's going on.

anonymous firefighter / instructor, Firefighter Training Academy
Emergency Services Training Institute, Brayton Fire Training Facility
formative ethnographic interviews
November 11, 2005

> [In T^2_eC], . . . it's the learning of communication. . . . Learning how to play with others and communicate with others and doing that on the game kinda automatically carries over to how you're going to interact and do things. . . . And it's blanketed, it's not just with the game or with the fire service; once you learn how to communicate with a team, it just comes natural to start communicating like that.

anonymous Firefighter Training Academy student / study participant
Emergency Services Training Institute, Brayton Fire Training Facility
summative user study interviews
March 27, 2009

Fire emergency responders[1] (FERs) work under hard time constraints on action in dangerous situations to save lives and property. The complex nature of most emergency incidents means that firefighters work in multiple crews that must be coordinated to effectively search for victims and put out fires. *Team coordination* is an essential component of fire emergency response work, but it is not learned through education. Instead, the skills are learned on the job.

This dissertation follows the style of the *Association for Computing Machinery Transactions on Computer-Human Interaction.*

[1]We choose to use the term "fire emergency responder" (FER) throughout this dissertation, instead of "firefighter", because firefighter is a specific job. FER encompasses firefighters and other jobs in the emergency response domain, such as medics, engineers, and incident commanders. Details on FER work practice are described in Chapter III.

Training simulators mimic reality to provide a safe venue in which to train. They allow learners to practice procedures, familiarize themselves with equipment, and communicate with other workers on a team. Games are a form of simulation that are engaging and fun. Simulation games offer the potential to revolutionize education, attracting learners and keeping them engaged with the material.

The present research began as a way to fill a void in fire emergency response education. By investigating practice at one of the world's largest firefighter training facilities, we have come to understand the nature of fire emergency response work practice. We investigated the way FERs communicate and coordinate, and abstracted the skills used by FERs.

In learning about team coordination in the domain of FER work practice, we discovered no need to mimic fire and smoke to capture the aspects of human-human interaction. The present research investigates *non-mimetic simulation games* to teach *team coordination skills*. It develops the Teaching Team Coordination Game, T^2_eC, from a basis in fire emergency response work practice. In T^2_eC, FERs practice gathering, filtering, transforming, and sharing information with one another in an alternative, fun context. The principal hypothesis is that *by playing non-mimetic simulation games, developed from work practice, fire emergency responders learn to more effectively coordinate as a team.* To this end, we iteratively develop the T^2_eC game, testing with a variety of users. We then take the game back to the source, the Firefighter Training Academy, where FER students engage and improve their team coordination skills.

A. Hypotheses and Overview

The principal hypothesis—*by playing non-mimetic simulation games (*T^2_eC*), developed from work practice, FERs learn to more effectively coordinate as a team*—is developed through a number of hypotheses. In crafting a non-mimetic simulation game for FERs, we first test with non-FERs, as FERs' time is especially valuable and hard to schedule. For this first stage of the work, we relax the principal hypothesis: *by playing non-mimetic simulation games, developed from work practice,* players[2] *learn to more effectively coordinate as a team.* This hypothesis is supported by four others:

H-1-1 Through game play, participants will improve their ability to accomplish co-operative tasks.

H-1-2 Through game play, participants will improve their ability to coordinate.

H-1-3 Communication and activity in T^2_eC will resemble communication and activity of FERs.

H-1-4 The introduction of a scoring system will motivate play.

Once the relaxed principal hypothesis is established, the full principal hypothesis is supported by six others:

H-2-1 Through game play, participants will improve their ability to accomplish co-operative tasks.

H-2-2 Player roles, differentiated by information distribution and available action, will impact team communication.

[2] instead of FERs

H-2-3 Play condition, either co-located or distributed, will impact ability to accomplish cooperative tasks, reflecting a need to mix communication modalities.

H-2-4 Through game play, participants will improve their ability to implicitly coordinate.

H-2-5 Game play will be reflected in team coordination ability in burn training exercises.

H-2-6 Communication and activity in T^2_eC will resemble communication and activity in fire emergency response work practice.

1. Understanding Teams and Team Coordination

The present research begins with building an understanding of teams and team coordination (Chapters II–III). We start from a background in cognition: mental models, affordances and constraints, and move to distributed and team cognition (Chapter II). Using cognition as a foundation, we explore fire emergency response work practice (Chapter III). Work practice blends background from prior researchers in emergency response and disaster recovery with our own ethnographic field work at Brayton Fire Training Field to provide a rich, detailed understanding of how team coordination is learned and practiced by FERs. This understanding is used to develop a set of design principles for teaching team coordination.

2. Foundations and Development of T^2_eC

The next portion of this dissertation is the basis for and description of the T^2_eC game (Chapters IV–VI). Based on our understanding of team coordination, we develop the concept of non-mimetic simulation for teaching (Chapter IV). The concept of non-mimetic simulation came about because the implications for design from the ethnography indicated no need to mimic fire and smoke. Based on understanding from ethnographic fieldwork, and lessons learned from user studies with T^2_eC, we describe design principles for developing non-mimetic simulations.

We hypothesize that non-mimetic simulations built as games will be effective, as games engage participants both intrinsically and extrinsically. Chapter V covers game design background, starting with interaction design and semiotics. We develop the theory of affordances-as-signs, in which the affordance, consisting of a perceptible instantiation that maps to an action for an individual, becomes a *sign* in a system of signification: a perceptible signifier indicates action signified. The affordance-as-sign can then be applied to understand and develop games. What follows is an explanation of game design background, describing rules, play, and game mechanics. We develop our own game design framework describing how elements of a game interact with each other and the player. With an understanding of game mechanics, it is possible to describe our theory of using affordances-as-signs to represent game mechanics. The theory is developed from a number of case studies of existing commercial games. We develop design principles for engaging cooperative play, from data collected through a number of studies with T^2_eC. We close this chapter by exploring the background of mixed reality, in which computation is used to complement reality to create an engaging experience. While the T^2_eC game described here is not a mixed reality itself, it was developed with the intent of creating one later, and so lessons learned from existing mixed realities are incorporated into its design.

Using all foundations so far, we describe the T^2_eC game (Chapter VI). The bulk of the chapter is devoted to the "final" version of T^2_eC, version 2.0. This polished version is used in the user study that concludes this phase of the present research. The chapter outlines the operational elements, functional semantics, and representations in T^2_eC. It describes alternative roles that players take on, creating an operational distributed cognition environment where teamwork is essential. The chapter closes by looking at the design iterations that led to version 2.0 of T^2_eC, describing the initial prototypes and moving through version 1.0.

3. Evaluating T^2_eC

The concluding chapters (VII–X) discuss the evaluation methodology and findings with T^2_eC. Chapter VII describes the experiment setup, Coordinated Log + Audio Playback System (CLAPS), data sources, and analysis methods. The following two chapters describe user studies. Chapter VIII tests the relaxed principal hypothesis and hypotheses [H-1-1]–[H-1-4] with version 1.0 and non-FERs. Chapter IX tests the principal hypothesis and [H-2-1]–[H-2-6] using the iterated version 2.0 with FER students.

B. The Ecosystems Approach: Non-Linear, Iterative, Integrative Research

Ecosystems are characterized by meshes of interrelationships [Kerne 2005]; no single hierarchy exists. The present research crosses a number of disciplines and methods. It is nonlinear, iterative, and integrative. The process of the research unfolded over years; data feed back into the design process as new systems develop. In the present document, chapters are organized into as logical an order as possible, minimizing the need for forward references. Our original research is integrated with background. Some conclusions, such as design implications, appear before the data that motivates them. Because the work is iterative, these principles are incorporated into a series of T^2_eC system designs. A number of strange loops [Hofstadter 1979], where lower elements of a hierarchy impact the upper layers, exist due to the necessary linearity of presentation in this medium.

A concept map, Figure 1, is provided to make clear the relationships between the many and varied components of this research. A subset of this map is re-visited each chapter, to show where the linearly presented chapter fits into the non-linear whole through a magnified callout. Our hope is that this makes the story easier to follow.

C. Note about Pronouns

While this dissertation represents original work, I have a number of collaborators. Essential to this work were Andruid Kerne, William A. Hamilton, Cary Roccaforte, Nabeel Shahzad, and Alan Blevins, among others. Because my work was influenced by their insights, ideas, and collaborations, I use plural first-person pronouns throughout. In places where third person gendered pronouns are necessary, I make every effort to include both genders.

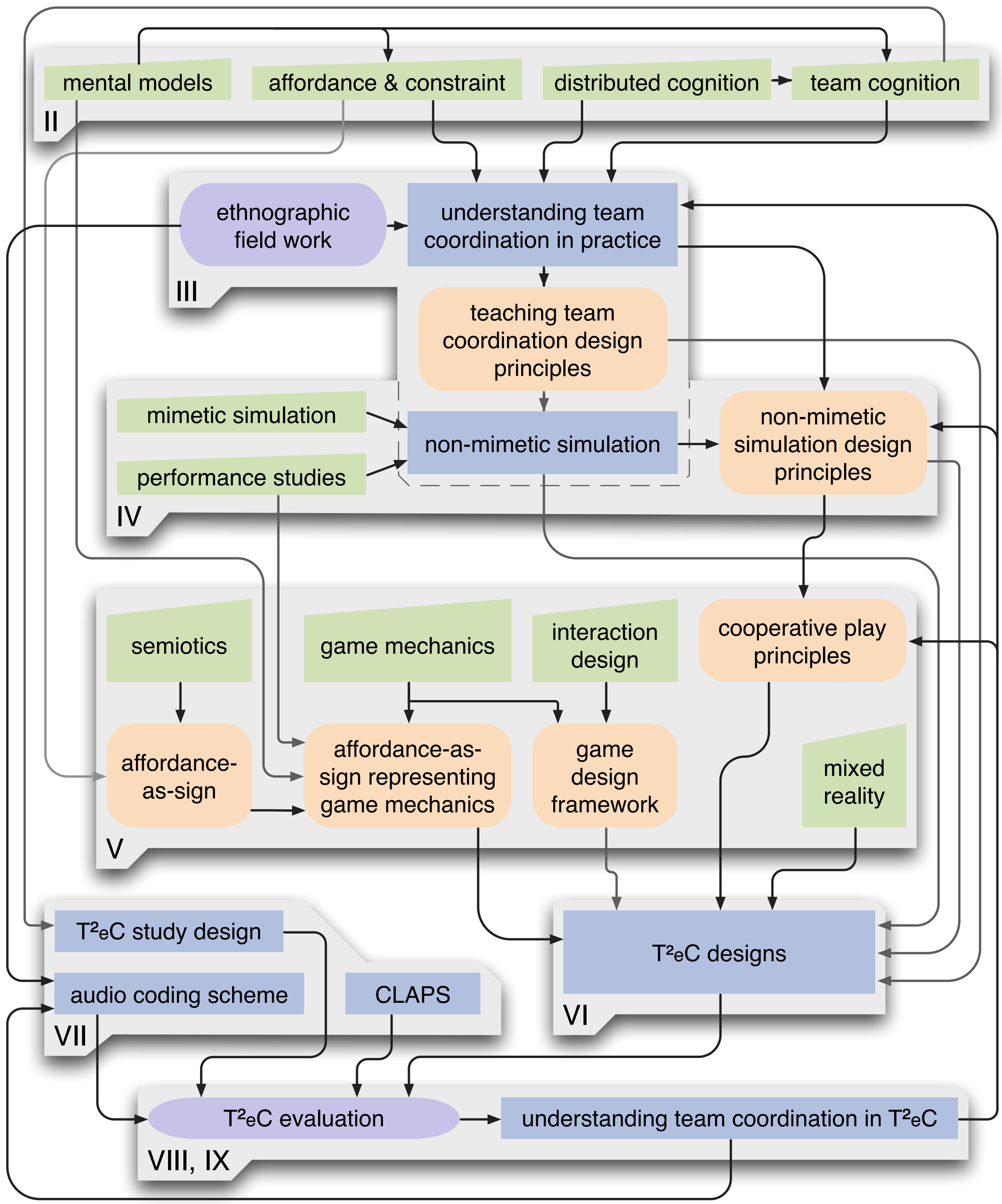


Fig. 1.: A map showing the relationships between concepts throughout the present research. The work is non-linear, but must be presented linearly. Many concepts influence their predecessors, creating strange loops [Hofstadter 1979]. This map will be revisited at each chapter.

CHAPTER II

BACKGROUND: COGNITION

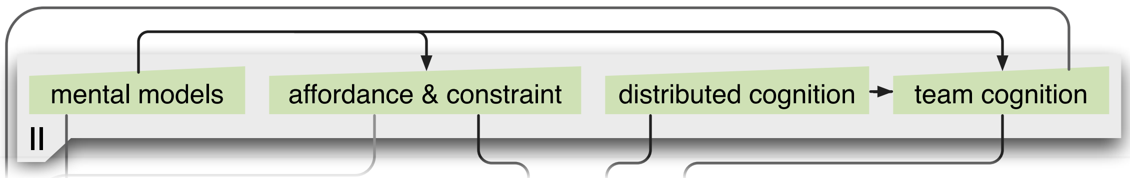


Fig. 2.: Component of the concept map (Figure 1) for background on cognition.

This chapter describes relevant background in the field of cognition (Figure 2); in later chapters, this background information will be incorporated into design principles for learning systems, simulations, game mechanics, and interfaces. The present research seeks to educate emergency responders; emergency response is a *distributed cognition* environment, wherein different team members have access to different pieces of information in different forms. These pieces must be selectively fit together, using the communication technologies, affordances, and constraints available in the environment, giving rise to *team cognition*. In this chapter, we start from the concept of mental model, which identifies the ways in which individuals simulate complex processes and phenomena from the real world in their heads. From mental models, we describe affordances and constraints, which identify the ways that environments communicate their actionable properties to an animal within them. We then incorporate background in distributed cognition and team cognition.

A. Mental Models

Mental models are the way in which individuals maintain and manipulate a representation of the functioning of an object or process in their heads [Gentner and Stevens

Fig. 3.: Neo-Gibsonian model of affordance. An affordance maps between an action to be taken by an animal and the form of an object, environment, substance, other animal, etc.

1983; Jonassen and Henning 1996]. The model is an internal form of simulation, based on past experiences. It enables high-level problem solving and an understanding of the dynamics of the physical world and can be used to predict future outcomes.

According to Lakoff and Johnson, mental models are *embodied* [1999]. They are directly connected to the human ability to manipulate and perceive the world. Animals understand elements of their environments in terms of what they can *do*: how an object or environment is manipulable, given the body. Thus, mental models exclude activities that are impossible for the individual to perform. My mental model of a chasm does not include its being "jumpable", but a bird's might include it being "fly-over-able". Mental models are runnable: they can be manipulated using body experience to simulate and predict.

B. Affordance and Constraint

Gibson's *affordance* is a mapping between an animal and an environment, substance, object, other animal, etc., such that the later supports an action for the former [1986]. Flat, rigid, open surfaces afford support to most animals: they can be laid, stood, walked, or run upon. The substance of the surface may afford digging for some animals (for example, a dirt floor and a mole), but most likely does not afford sinking for any (if it were quicksand, it would not afford support). For animals with legs, open surfaces afford walking and running. Figure 3 diagrams our neo-Gibsonian model of affordance. It incorporates a mapping between an object's form and the possible action, given the actor's abilities.

Affordances exist, regardless of whether or not they are *perceptible*. According to Gaver [1991] and Norman [1999; 2002], perceived affordances suggest action to the user through their design. Interactive objects are designed to match capabilities of the user, suggesting ranges of interaction possibility. Failure of the designer to make an affordance perceptible may obfuscate it, making the affordance difficult to identify and use.

Norman [2002] also identifies the concept of *constraint*. Constraints in a design limit scopes of use through physical characteristics or cultural conventions. A constraint in a design prevents its accidental or purposeful misuse. An example of a constraint is a hinge that prevents a door from opening in the wrong direction.

The perception and successful identification and use of an affordance relies on an animal being in the environment and intuitively knowing the abilities of its body [Gibson 1986]. Most humans easily discover the affordance of a well-designed doorknob: it is the right size for grasping, at the right level for a hand to reach it. Upon grasping it, it supports rotation, pulling, and pushing. Past experience and observation play a role. Embodied understanding of the world through mental models supports animals in discovering new affordances.

C. Distributed Cognition Theory

Distributed cognition theory takes a holistic view of a working environment, describing cognitive processes spread through individuals, artifacts, and time, while interacting with one another [Hollan et al. 2000; Hutchins 1995a; Hutchins 1995b]. This theory provides a framework for analyzing information processing within teams and modeling the way in which information flows among participants and artifacts over time.

Information relevant to a task is stored in multiple forms: mental models, embedded in the environment, written in books, or to be derived using formulae. Those working in the distributed cognition environment transform the pieces: they move them from an original form into other, workable forms, then apply them to the situation at hand. Workable forms may be communicated in a variety of media, enabling information transfer between individuals engaged in a cooperative task.

We use distributed cognition theory has the basis for understanding fire emergency response work practice. FERs constantly translate and communicate information. They filter and distribute to provide the right team members with the right information to make decisions and take action. Embodied sensory understanding, such as heat from a wall is noted, transformed into a description incorporating knowledge of the structure, perhaps communicated over radio, where it might be recorded by an incident commander on a map. In FER work, we see distributed cognition in action.

D. Team Cognition Theory

Team cognition theory considers a team as a fundamental cognitive unit [Salas and Fiore 2004].

> A *team* is a group of individuals working together toward a shared and valued goal, which will disband after the goal has been completed [Salas et al. 1992].

Team cognition theory posits implicit coordination as an efficient mode of work for teams. A number of training elements and theories contribute to a successful shift by a team from explicit to implicit coordination.

1. Implicit Coordination

In the *explicit coordination* mode, team members need to communicate a significant amount to synchronize action and communicate information. In many team environments, such as firefighting, wide-area communication bandwidth is limited: radios share a single channel and are half-duplex[1]. Further, those being communicated with must expend time and cognitive effort to hear and understand the speaker. Thus, the cognitive, time, and bandwidth costs of communicating within a team are known as *communication overhead* [MacMillan et al. 2004; Serfaty et al. 1993]. High-performance teams reduce communication overhead by communicating efficiently [Entin and Serfaty 1999]. They speak less and are able to act more; this is known as *implicit coordination*: the ability of team members to synchronize action and understanding with little communication.

The emergence of implicit coordination relies on shared mental models and situation awareness. When a mental model is *shared* between team members, it enables them to work together smoothly. Individuals can predict one another's actions and react accordingly, with lessened communication [Cannon-Bowers et al. 1993; Mathieu et al. 2000]. *Cross-training*, where team members learn not only their jobs, but the jobs of others on the team, is a means for fostering shared mental models [Cannon-Bowers and Salas 1998; Cannon-Bowers et al. 1998; Marks et al. 2002; Schaafstal et al. 2001]. FERs practice cross-training; they all know how to perform every basic job at an incident.

Situation awareness is a theory, developed in the context of aviation, that describes the level at which individuals are conscious of their environment, the status of

[1] A duplex communication device can send and receive data; a *full-duplex* device can send and receive simultaneously, a *half-duplex* device must switch between a send mode or a receive mode.

their team, and the events occurring around them, as well as their ability to predict future outcomes [Endsley 2000]. A component of situation awareness within a team may involve observing the activities of others and how they align with and differ from the norm [Heath and Luff 2000].

E. Conclusion

Cross-training in fire emergency response is essential, as it supports implicit coordination, enabling efficiency. As long as each team member is situationally aware, they can maintain a shared mental model of the fireground. By combining this mental model and their awareness with their understanding of their fellow team members' roles, they can predict the outcomes of other team members' actions, reducing communication overhead.

The present research seeks to teach team coordination to participants. Improving participants' implicit coordination capabilities is one measure of success. Our user studies are designed to cross-train players in alternative roles, encouraging mental model formation.

In the coming chapters, we will synthesize the background on cognition with a deep understanding of emergency response work practice to understand team coordination. From the synthesis, we will develop principles for teaching team coordination. The principles identify the essential human- and information-centric components of team coordination, such as the way information is distributed among team members. The principles suggest the method of non-mimetic simulation that abstracts out the concrete aspects of the working environment in favor of the abstract components that are important in team coordination.

CHAPTER III

FIRE EMERGENCY RESPONSE WORK PRACTICE

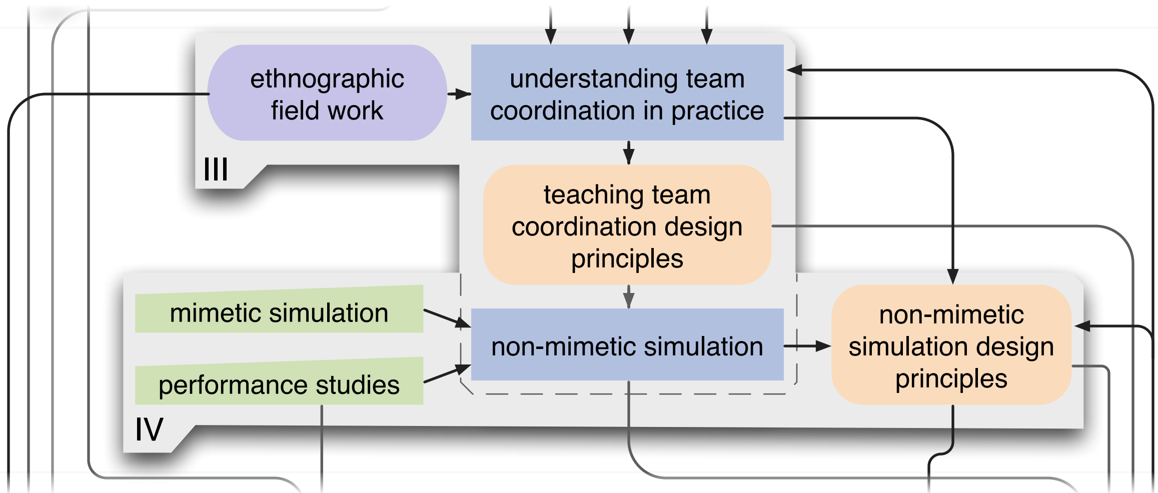


Fig. 4.: Component of the concept map (Figure 1) for fire emergency response work practice, including overlap with non-mimetic simulation.

Fire emergency responders (FERs) work with hard time constraints on action with life-or-death consequences. While fire emergency response involves intense team coordination, formal instruction places little emphasis on learning how to coordinate as a team. Team coordination skills are expected to be learned on the job. Fire emergency response work is an ideal target domain for the present research.

In this chapter, we describe ethnographic fieldwork undertaken to understand communication and coordination in fire emergency response work practice, including a description of the studied site, Brayton Fire Training Field. Field observation of work practice is primary data, which is combined with the work of other researchers in the related domains of emergency response and disaster recovery to build an integrated description of communication and coordination in the distributed cognition environment (Figure 4). From this understanding of communication and coordination, we develop design principles for teaching team coordination, which are synthesized with other principles around simulation and game design in later chapters for the design of the T_e^2C game. This chapter concludes with the translation of the design principles into the concept of *non-mimetic simulation*, which is described in greater detail in the next chapter.

Fire emergency response work practice, as presented in this chapter, is based on ethnographic investigation at the Texas Engineering Extension Service (TEEX) Emergency Services Training Institute (ESTI) Brayton Fire Training Field. The present work focuses primarily on firefighting in the United States in urban settings; other countries and settings, such as industrial, airport, rural, and wildland firefighting, may differ substantially.

A. Methods: Ethnographic Fieldwork at Brayton Fire Training Field

The present research involves an exploration of fire emergency response work practice. Ethnographic fieldwork began in late 2005 at the TEEX ESTI Brayton Fire Training Field, as summarized in Table I. The TEEX ESTI Brayton Fire Training Field is the largest firefighter training facility in the nation; in 2009, the Training Field provided education to over 195,000 responders, both domestic and international [Texas Engineering Extension Service 2009]. As a successful emergency services training school, it is an ideal site [Marshall and Rossman 1999] to learn about general fire emergency response work practice.

We used semi-structured interviews with six expert emergency responders on-site at Brayton (Table II) to understand the way FERs communicate and coordinate in practice (November 2005). The interviews began with a set of structured questions centered around team coordination and communication (see Appendix C for specific

Table I.: Summary of ethnographic investigations of fire emergency response work practice.

date	fieldwork undertaken
2005 Nov.–2010 May	consultation with FTA Program Coordinator
2005 Nov.	tour Brayton Firefighter Training Field
2005 Nov.	interviews with expert responders / instructors
2006 Mar.	exterior burn training observation (recruit class 118)
2006 Nov.	exterior burn training observation (RC 120)
2008 Jan.	participation observation of class on NIMS (RC 124)
2008 Sept.–Oct.	participatory design with FTA Program Coordinator
2009 Mar.	interior student burn training participant observation (RC 128)

interview questions), but interesting responses prompted probing questions into how FER work is undertaken. All interviews were audio recorded and later transcribed. Where participants are a primary source, they are referenced by a code (Table II).

Later, student burn training exercises were observed, both from the exterior (March 2006) and interior (March 2009), allowing me to see how firefighting teams operated in a realistic environment. Exterior burn training observations were video recorded with radio communication on the audio track; the audio was later transcribed. Where video recordings are a primary source of information, they are referenced by <V-#>, where # represents the observation (1, 2, or 3).

Participant observation of coursework on the National Incident Management System (NIMS) [U.S. Department of Homeland Security 2004] (January 2008) provided insight into the formal hierarchy and communication practices of FERs. We constantly communicated with the Firefighter Training Academy's (FTA) Program

Table II.: Interviewees at ESTI Brayton Field in November 2005. Summarizes job experience of interviewees, with reference codes.

	years*	jobs
<I-1>	6	firefighter
<I-2>	14	firefighter, engineer / driver, aircraft rescue instructor
<I-3>	18	firefighter, firefighting instructor
<I-4>	20	firefighter
<I-5>	30	firefighter
<I-6>	31	firefighter

* Number of years of accumulated experience at the time of interview.

Coordinator, Cary Roccaforte; he provided feedback on our interpretations of FER practice. We included him in participatory design sessions, where identified ways the game could be improved to engage players in nuanced aspects of response practice (November 2005–May 2010).

1. *Life at the Firefighter Training Academy*

Although Brayton Field hosts numerous training exercises for local, international, and corporate fire departments, it is primarily home to the Firefighter Training Academy (FTA). The FTA course of study is intense, teaching practical training in firefighting with firefighter gear and apparatus (firefighting vehicles). Learning takes place in the classroom and in the field. After students successfully complete the FTA, they take an exam and become certified firefighters. They may then go on to join fire departments and industrial crews.

Each FTA class consists of about 40 students who attend the school for 12 weeks. On arrival, students are divided into four-person crews to match the team structure used in emergency response. Each week, the leader of each crew changes. The leader is responsible for the other three members and reports to the FTA Program Coordinator, as their commanding officer.

2. Burn Training Exercises

Most of the FTA consists of classroom exercises, where students attend lectures, read books, and take tests. In the final few weeks of class, focus shifts from book learning to hands-on training. Students, working in their crews, take on the role of actual firefighters, using real equipment to fight real fires in a controlled simulation called *burn training* ("burns"). Elaborate, fireproof prop buildings, vehicles, and industrial structures are set on fire, using flammable liquid and/or hay bales (Figure 5). The students drive firefighting apparatus from the school's engine bay in full turnout gear. They set up command structures, organize teams, and fight the fire using hydrants and engines. In the first week of burns, instructors fill in the role of *incident commander* (IC), observing and directing (more detail later in this section); students perform the role later.

Burn training exercises provide valuable practical experience to the students. It is also the primary means by which they begin learning to communicate and coordinate. Burn training is not focused on team coordination, however, as the essentials of safety and fighting fire are emphasized.

B. Data: Coordinated Teams in Fire Emergency Response

FERs work within a hierarchy of specific roles. While their organizational structure superficially resembles that of military or other regimented organizations, FERs are

Fig. 5.: FTA students practice night burns on an industrial prop. Taken with permission TEEX ESTI.

highly autonomous and work interdependently around the *fireground*[1]. The chain of command is frequently inverted, as FERs engage in necessary situated actions [Suchman 1987] that may not always implement the plans of superiors, but advance the objectives of the team. Individuals rely on embodied skills to rescue victims and fight fires [Toups Dugas and Kerne 2007; U.S. Department of Homeland Security 2004; Wieder et al. 1993]. FERs respond to emergency *incidents*[2] in *companies* of a minimum of four individuals. Each company is associated with an *apparatus*, a special vehicle designed for fire emergency response (such as a fire engine (Figure 6) or ladder truck). At a minimum, each company consists of one *company officer*, who is in charge of directing the team and aiding when necessary; two *firefighters*, who

[1]*fireground*: The immediate area surrounding the fire at an emergency incident.

[2]*incident*: "An occurrence or event, natural or human-caused, that requires an emergency response to protect life or property." [U.S. Department of Homeland Security 2004]

Fig. 6.: A fire apparatus: fire engine used for transporting rescuers, water, and equipment. The vehicle is equipped with a water pump and water distribution system to run multiple hoses. Taken with permission TEEX ESTI.

search for victims, render aid, fight fire, etc.; and an *engineer / driver* who manages equipment and the apparatus. Multiple companies deploy to any incident, where they will work at the fireground from distributed locations [Jiang et al., "Ubiquitous computing for firefighters," 2004; Landgren 2006; Toups Dugas and Kerne 2007; U.S. Department of Homeland Security 2004; Wieder et al. 1993]. Figure 7 diagrams the team hierarchy, showing how the incident commander directs the company officers of the responding companies.

1. Roles

Roles at an emergency incident include administering medical aid, fighting fire, search and rescue, and ventilation. Each emergency responder is *cross-trained* [Cannon-Bowers et al. 1998; Marks et al. 2002; Volpe et al. 1996] in each role; consequently,

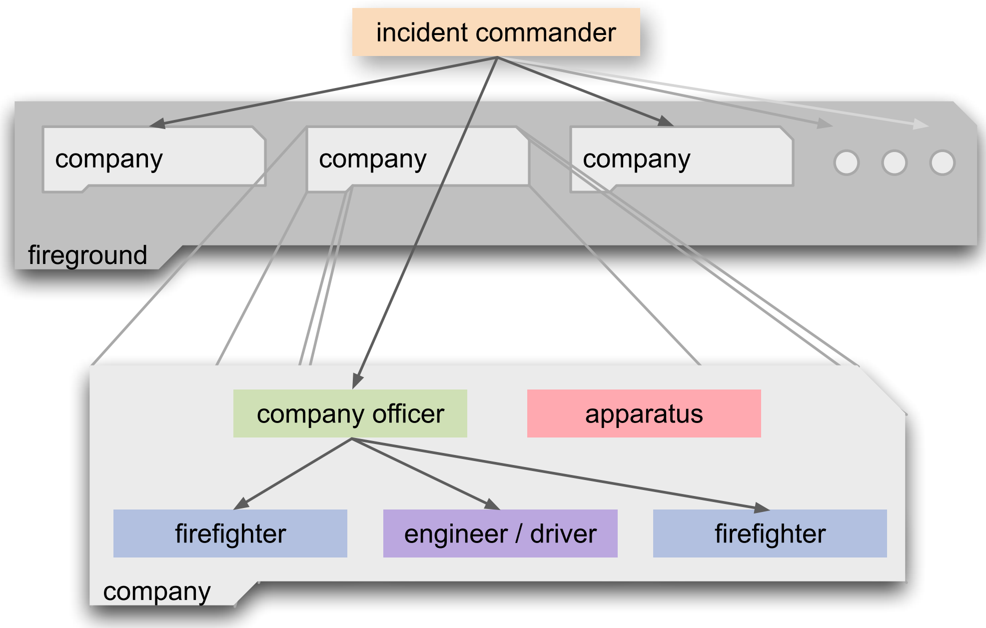


Fig. 7.: Team hierarchy in fire emergency response. Each company consists of a firefighter, engineer / driver, and company officer, which are associated with an apparatus. Each company with apparatus is involved at the fireground. The incident commander directs multiple companies from outside the fireground.

each FER can fulfill a variety of roles. Activity at the fireground is fluid, each FER's role may change to match the changing needs of the incident [<I-5>]. Initial role is determined by the team's apparatus. Fire engines (Figure 6), vehicles with water tanks, pumps, hoses, and/or water cannons, carry FERs who will fight the fire. Ladder trucks or rescue trucks (which transport FERs and a variety of equipment) often carry rescue crews, who will search for victims and pull them to safety. Ambulances are staffed by medics.

a. Incident Commander (IC)

Incident commander (IC) is a transitory role that exists only during an emergency incident. The role of IC is assigned to the highest ranking officer at the incident; it might transfer once, from the first-arriving company officer to the highest ranking officer dispatched to the incident, when he or she arrives[3].

The IC observes and directs from a distance, using a global, contextualized perspective [<I-1>; <I-3>; <I-4>; <I-5>]. The other FERs at the incident act as the IC's "eyes and ears." The IC coordinates with outside agencies to gather information and direct support.

Chief fire officer ("fire chief") is the highest rank within a firefighting organization. The fire chief typically has a separate vehicle, equipped with an array of information artifacts and communication equipment [Jiang et al., "Ubiquitous computing for firefighters," 2004]. For information artifacts, pre-planned attack strategies, blueprints, area maps, accountability forms, a laptop computer, and miscellaneous forms are common [<I-1>; Cary Roccaforte, personal communication; NIMS observation]. Information artifacts are used to record information about the incident and to track the location and status of subordinate FERs. When taking on the role of IC, these information artifacts are an essential benefit to coordination, supporting situation awareness.

2. Communication and Coordination

FERs work from multiple distributed perspectives, from which they must maintain situation awareness [Toups Dugas and Kerne 2007]. FERs at these perspectives need to collect, filter, and share information with one another. We learned that FERs prefer to speak to each other face-to-face, as this is a rich communication modality, through which information can be quickly shared. Because workers are distributed, however, face-to-face communication is frequently impossible. To contact remote

[3]If the new highest ranking officer determines that the current IC is in control of the situation, they may opt out of taking over the role.

team members, FERs make use of a single channel[4], half-duplex radio.

a. Radio

Half-duplex radios enable multi-way communication, but only a single party can use the channel at a time. FERs need to use turn-taking to avoid "walking on" each other (crosstalking) when communicating. Crosstalk occurs when two or more parties activate their radios at the same time: because the radios either transmit *or* receive, all of the parties are transmitting at the same time, and not receiving the others' communication. Those who are still receiving will either hear a single speaker, or, more likely, only noise. Crosstalk is dangerous because all of the information that speakers were attempting to communicate is lost, while the speakers are not necessarily aware that they failed to communicate.

Further complicating the problem of crosstalk is the fact that radios are laggy and noisy. FERs use radios in a push to talk (PTT) mode; they hold down a button to begin transmitting to all radios on the same channel in the area. Although the radio will start transmitting immediately, receiving radios may take as much as one second to begin receiving the transmission. The radio channel is noisy, full of static and interference. This can make it difficult to hear and understand the speaker.

To avoid the dangers of crosstalk, FERs use direct addressing and acknowledge communication; they repeat back acknowledgements to reduce information loss due to laggy and noisy connections. As an example of ideal communication, we present the transcript of an exchange between fire attack team 3 ("Attack 3") and the IC ("Command") at a burn training exercise:

[4]Very large incidents, such as multi-county forest fires, necessitate the use of multiple channels. In these circumstances, the groups on different channels may have little need to coordinate with each other directly; coordination may take place through a communication officer higher up in the chain of command.

Attack 3: “Attack 3, Command.”

Command: “Command go ahead.”

A3: “Command, Attack 3, we are ready on Charlie side.”

C: “Go ahead and advance up the stairs on the Charlie-Delta corner.”

A3: “Copy that. Advancing up stairs, Charlie-Delta corner.”

anonymous FTA students, Recruit Class 120 [<V-1>]
ESTI, Brayton Fire Training Facility
exterior student burn training observation
March 23, 2006

Notice that, in the exchange, the speaker for Attack 3 announces that he is speaking, then directly addresses the IC. The IC responds by acknowledging the incoming transmission and announcing himself. The speaker for Attack 3 then delivers the message, once again announcing himself as the speaker. After the IC gives his orders, Attack 3 repeats them back to ensure that he received the communication correctly. If they IC heard something different than he commanded, he would correct Attack 3.

Because FERs use a shared radio channel, this enables overhearing [<I-4>; <V-1>]. FERs can listen in on communication that is not directed to them, but that will be useful for maintaining situation awareness.

FERs make use of specific terminology and conventions, while speaking in plain english [U.S. Department of Homeland Security 2004]. FER-specific jargon covers vocabulary for equipment, maneuvers, etc. Firefighting has abandoned confusing conventions that require extra memorization.

In cases where the conventions are used incorrectly, the situation can become dangerous. We were told by an anonymous firefighter that during one incident, firefighting teams from two districts were unable to coordinate effectively. One team was using the now-ubiquitous designations for the sides of the buildings[5], while the other was using cardinal directions. This resulted in confusion between the two sets of teams, and the fire burned out of control.

C. Background: Related Research in Emergency / Disaster Response

Others' research exploring emergency response work practice worldwide informs the present research. Landay's group described information artifacts in fire emergency response work, which led to design implications for large scale displays for use by ICs [Jiang et al., "Ubiquitous computing for firefighters," 2004] and the design for a context-aware portable information display for firefighters [Jiang et al., "Siren," 2004]. The observations of Landay's team informs early design decisions in the present research, contributing to our understanding the role of the IC.

Landgren used ethnographic methods to examine the value of persisting fireground communications for accountability, with design implications [Landgren 2006]. His later work explored the use of mobile phones by emergency responders in Sweden [Landgren and Nulden 2007]. Landgren's ethnographies elucidate the rhythm of response practice and highlight similarities between our observations of U.S. FERs and those in Sweden. They highlight the value of the present research outside of the U.S.

Like the present research, the WearIT@Work project observed fire emergency response education practice, but in France [Denef et al. 2008; Klann 2007]. They developed test beds, in the form of a board game and a collaborative virtual environment (CVE), to discover needs and requirements for a wearable system and ran low-fidelity simulations to examine how new technologies might be adopted into existing practice. Through this process, they described the characteristics of information

[5] The main entrance to a building is the Alpha side; Bravo, Charlie, and Delta sides are designated clockwise.

flow that we call *information distribution* (see below) [Toups Dugas and Kerne 2007]. Later work described navigation and information exchange practices in FER practice [Denef et al. 2008] that is useful in designing game representations supporting coordinated navigation.

Turner and Turner [2002] considered use contexts for emergency simulators as part of the process of designing a CVE for maritime emergency response education. Palen's group looked at the ways communities self-organize, respond to, and recover from disasters, including how they exchange information through mobile devices [Palen and Liu 2007] and social networks [Palen and Vieweg 2008; Shklovski et al. 2008]. Palen's work is relevant to understanding how groups of people respond to and communicate around disasters when communication channels are uncertain.

D. Discussion: Design Principles for Teaching Team Coordination

From our ethnographic investigations at the Training Field, we constructed design principles for teaching team coordination [Toups Dugas and Kerne 2007]. In general, the design principles might be used for general education of teams; in the case of the present research, we apply the principles to the design of simulation games.

The principles center around ways in which firefighters gather, filter, and share information with one another. We highlight the value of *information distribution*, where each team member has access to an alternative perspective on the same information picture. *Mixing communication modalities* involves the timely selection between face-to-face communication and radio, based on the affordances and constraints of the local environment. Because FERs strongly rely on sounds in their environment and in radio communication, we advise the use of *audible cues*. These design implications are incorporated into the T^2_eC game designs, described in later chapters.

1. *Information Distribution*

FERs work from different vantages in and around the fireground: a firefighter engages directly with the fire, while the IC observes from a distance. The firefighter's experience is strongly sensory and local; it directly impacts the incident. The IC observes the big picture, but cannot directly act. The IC may also use information artifacts to aid in situation awareness; firefighters' reports from the inside may need to mapped onto a blueprint of the building. We call this apportioning of information access *information distribution*[6] [Toups Dugas and Kerne 2007; Toups Dugas et al., "Game design principles," 2009; Toups Dugas et al., "Emergent team coordination," 2009], recalling Hutchins' distributed cognition [Hollan et al. 2000; Hutchins 1995a; Hutchins 1995b] (II.C, page 11).

As in distributed cognition [Hutchins 1995b], information exists in a variety of representations that must be transformed to be communicated and used. An IC may transform reported locations of FERs to a building map [Denef et al. 2008]; fundamentally, this involves monitoring a combination of reports from deployed FERs, using a knowledge of their starting locations, and combining with information from the map to track them on the information artifact. The map is an alternative representation of the reality that the FERs are experiencing; it is flat and two dimensional, lacking the rich sensory experience of the fire.

The alternative perspectives of FERs are both a benefit and a burden. They allow the team, as a whole, to know about the situation at a variety of ever-changing

[6] Originally, we used the term *information differential* [Toups Dugas and Kerne 2007], but later revised it to *information distribution* [Toups Dugas et al., "Emergent team coordination," 2009].

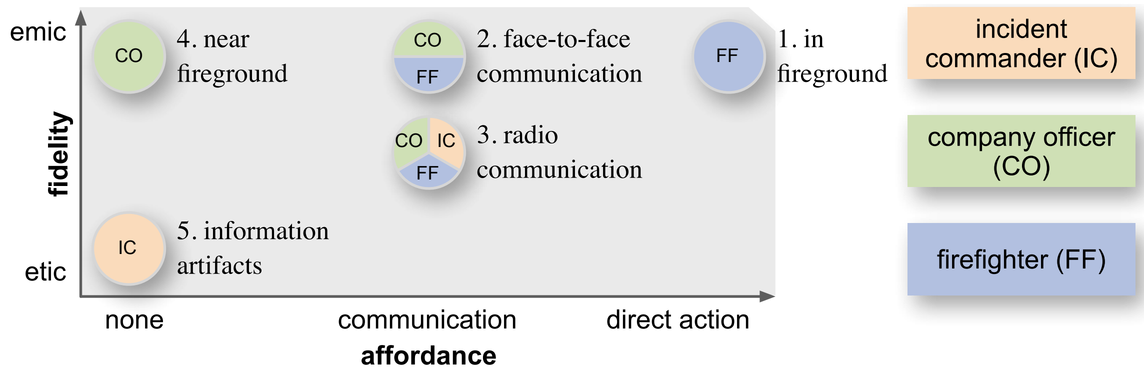


Fig. 8.: Bi-variate classification of information flows by information fidelity and action affordance. Each point is an information source at an emergency incident; points indicate if they are primarily attained by firefighters (FF), company officers (CO), or incident commander (IC).

locations: *team cognition* (II.D, page 12). This enables coordinated response to threats and completion of goals. However, each perspective must be synthesized and transformed to understand the situation, placing a cognitive burden on participants [MacMillan et al. 2004]. This requires each member of the team to carefully consider what information they have, and what information others' need. The cost of communication is very high and its outcome is uncertain.

We adapt Pike's cultural theory [1954] to classify the information flows of fire emergency response. According to Pike, an *emic* analytical standpoint is taken from within, while an *etic* standpoint is external. An emic approach is personal and includes the actor's understanding of the culture being studied. An etic approach is neutral; when taking an etic approach, select parts of the cultural understanding can be used for comparison and synthesis. Pike uses emic and etic to describe perspectives on understanding culture; we apply them here to classify information sources at an emergency incident. Later, we will apply the same framework to the design of the T^2_eC game.

We combine the concept of *affordance* (II.B, page 10) with Pike's cultural theory to create a classification scheme for information sources in fire emergency response. Affordances map *possible* actions onto *apparently available* actions in a creature-environment dyad.

Taken together, we have a bi-variate classification of information flows in fire emergency response work practice (Figure 8). On the Y-axis, we plot the fidelity of the information: how it is obtained. Emic information is acquired near the fireground and is directly sensory. Etic information is embodied in artifacts. On the X-axis, we plot how the emergency incident affords action. At the left, the actor cannot take action in the fireground, only observe. In the middle is communication: indirect action at the incident, commanding other team members and receiving information from them. To the right is direct action, such as putting out the fire or rescuing victims. Each point represents one or more FER roles at the fireground. In later chapters, this classification scheme will be applied to create information distribution in design.

2. Mixing Communication Modalities

FERs mix face-to-face and radio communication modalities. Each modality has advantages and disadvantages.

Face-to-face communication is preferred in fire emergency response work. Face-to-face communication is fast and the backchannel of body language and short utterances enables disambiguation. Deictic reference[7] can be used to indicate features of the environment, equipment, etc. without relying on complicated explanation.

The need for mixing communication modalities suggests the value of a mixed reality (MR) simulation. Because the choice of communication modality is driven by

[7] A deictic reference is one that can only be understood in an observed context, such as the phrase, "over there."

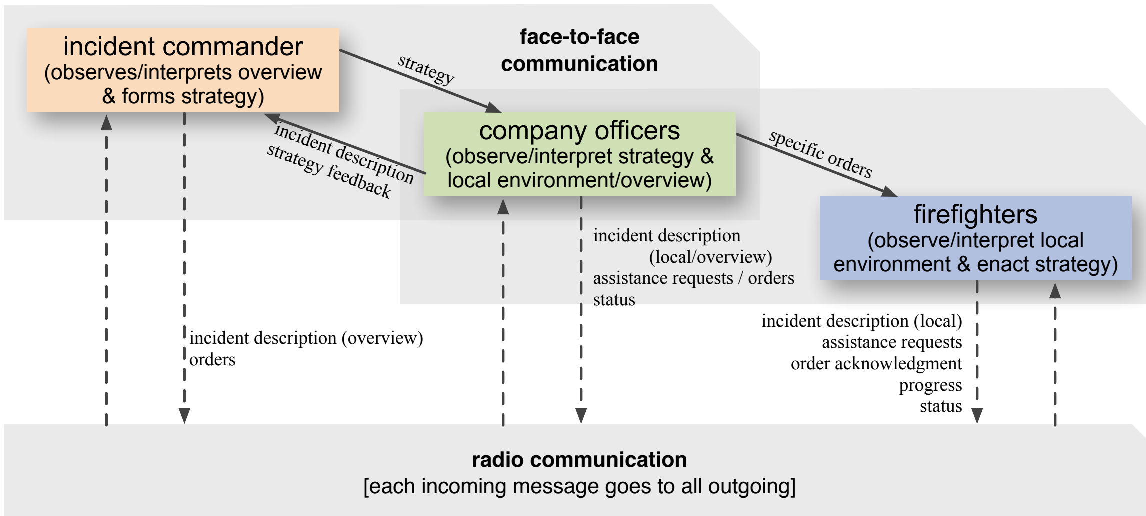


Fig. 9.: Information flows in fire emergency response work practice. Certain types of information are shared over face-to-face communication, while others go over radio. Communication follows the chain of command.

the affordances and constraints of the environment, participants need to find themselves in varied environments. In traditional CVEs, participants are confined to a desktop computer; this requires that the topology of the team be configured in advance: participants must be either co-located or distributed (in some combination). In an MR simulation, participants are free to move in a large environment. The simulation may drive them to split up and come back together. In these varied situations, participants make decisions about when to use the radio and when to come together to speak face-to-face.

The mixing of communication modalities is driven by the constraints of the radio technology with the affordances of the environment and information to be communicated (Figure 9). Long messages, such as an overall strategy, need to be communicated face-to-face; the radio is not suited to that level of understanding. Short reports of what is happening can, however, go over the radio. Relative position of workers is another consideration. When time is limited, it may be necessary to communicate using the radio, rather than face-to-face, as the receiver cannot otherwise be reached.

3. Audible Cues

We learned that FERs make extensive use of audio in their environment. It is difficult to hear in the fireground, due to ambient noise, headgear, and the sound of the self-contained breathing apparatus (SCBA) [interior student burn training participant observation]. Despite these challenges, FERs are attuned to the sounds of the fireground. They listen for characteristic environmental sounds in the local fireground, and how these change. They also listen for these characteristic sounds at the remote fireground, by monitoring the background sounds in radio transmissions. For example, a popping sound is indicative of timbers about to break and is a strong indicator that all teams should soon evacuate.

FER gear is designed to make use of the audio channel for signaling status. A call for evacuation is signaled through three blasts of the engine's horn. SCBA masks are equipped with a pressure gauge, but also include a loud ticker that sounds when air is running low; the ticker can be heard over the radio channel, and grows more rapid as air runs out.

Audible cues are advantageous, because they offer a way of multiplexing a single-channel radio. Additional, contextual information is supplied through the background environment and equipment sounds of other FERs. This has the beneficial effect of reducing the amount of communication necessary at the fireground.

E. Conclusion: Motivation for Non-mimetic Simulation

FERs employ skills that enable smooth team coordination. They benefit directly from implicit coordination that is learned on the job or indirectly through existing training.

Team coordination is essentially a human- and information-centric process. It is based on participants building situation awareness through observation, communication, and prior knowledge. FERs engage in a distributed cognition environment where they must transform and share information while under real-time stress.

We hypothesize that FERs can benefit from a simulation of the human- and information-centric aspects of their work. Such a simulation provides opportunities for participants to practice skills in transforming and sharing distributed information. It enables mixing communication modalities, so participants see when each mode is more or less useful for sharing. Further, these design principles do not specify a need to model fire and smoke, but rather scopes of information available to various roles and the need to perform effectively under stress. We hypothesize that the domain of teaching team coordination is general enough to omit such domain-specific representations.

We generalize this to the concept of *non-mimetic simulation*, operational environments that do not mimic concrete aspects of the target domain, but instead capture abstract, human- and information-centered aspects. Non-mimetic simulations must be grounded in practice to have value, supporting the *in situ* activities of workers. we discuss non-mimetic simulation in more detail in the next chapter.

Future work will develop MR non-mimetic simulations, based on the need to mix communication modalities. The freedom of movement afforded by the real world, augmented with wearable computers, enables participants to mix communication modalities naturally.

CHAPTER IV

NON-MIMETIC SIMULATION

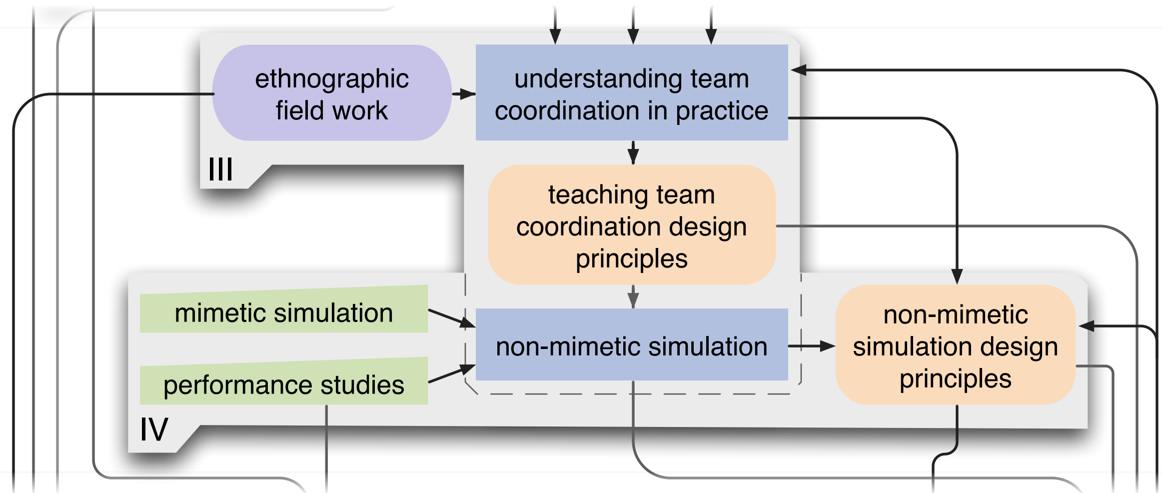


Fig. 10.: Component of the concept map (Figure 1) for non-mimetic simulation, including overlap with fire emergency response work practice.

We introduce the theory of *non-mimetic simulation*: operational environments in which participants learn practice-grounded skills in an alternative context without a mimesis of the concrete environment [Toups Dugas et al., “Emergent team coordination,” 2009]. Traditional simulations are *mimetic*, they capture as much of a real-life environment as possible. A central concern in the design of mimetic simulations is the level of fidelity: how close is the simulation to reality. The central principle of non-mimetic simulation is abstraction through a zero-fidelity environment.

Gagné suggests that *training devices* might be constructed to learn specific job skills, without a complete simulation [1954]. He identifies simulators as re-creations of the actual equipment used in the task. According to Hays and Singer [1989a], much simulation research ignores these findings. Prior work does not identify the value of such systems as *simulation*, but identifies them as training devices.

In non-mimetic simulation, there is no question of simulation fidelity. Fidelity is not a design consideration: the simulation is not of the concrete environment. Instead, non-mimetic simulations consider tasks and alternative means by which participants can learn to perform a task through an abstraction of reality. Participants learn to execute a suite of tasks in an alternate environment. The suite of learned abilities can then be applied back to the target domain; transferability of such skills is suggested in prior work [Gagné 1954; Reder and Klatzky 1994] and the field of performance studies [Schechner 1985]. Non-mimetic simulations are economical, focused, and potentially transferable across domains once developed.

Effective non-mimetic simulations are grounded in practice: the skills practiced are based upon those used in real life work (Figure 10). Practical grounding is essential for learning skills [Reder and Klatzky 1994]. Non-mimetic simulations take a place side-by-side with other forms of simulation training and fulfill a complementary role. When built into games, this training methodology is appealing: non-mimetic games are fun, providing intrinsic motivation to learn [Malone 1981; Salen and Zimmerman 2004f]. Combined with reward structures and a competitive environment, external motivation is added. Non-mimetic simulations can offer a constructive break from other forms of training, teaching critical skills to participants. When instantiated as games, non-mimetic simulations function as a form of *stealth learning* in which participants are not necessarily aware that they are practicing skills and learning concepts [Falstein 2005].

In this chapter, we begin by addressing background areas of performance studies and mimetic simulation. Grounding in performance studies, particularly the notion of restored behavior [Schechner 1985], is the basis of the theory of non-mimetic simulation. Mimetic simulation is contrasted with non-mimetic simulation. We consider *Chess* and *Hush* [Antonisse and Johnson 2008] as non-mimetic simulations, then move to an example of an existing mimetic simulation, which we contrast with a hypothetical non-mimetic simulation. We describe the advantages of non-mimetic simulation: economy, focus, and potential transferability. We conclude with team coordination non-mimetic simulation design principles motivated by studies described in Chapter VIII.

A. Background: Performance Studies

Schechner identifies *restored behaviors* as "strips" of action, like the strips of film used by a film editor, which are learned in one context and then recalled and reproduced in another [1985]. These behavior strips can be remixed, embellished, altered, and otherwise transformed in practice.

Restored behavior is the basis of non-mimetic simulation. Behaviors (skills) can be learned in a safe simulated environment, then recalled (applied) later in real-life environments. As with acting, these environments are not necessarily the same, suggesting that non-mimetic simulations can be transferred across domains.

B. Background: Mimetic Simulation

Simulation is a broad term encompassing a wide range of systems that imitate other systems for the purpose of learning or predicting. Simulations model the real world in a controlled way [Smith 2003]. Training simulations are designed to directly represent the world at some level of detail, omitting only the portions that are not directly relevant to the task to be learned; how much of the real world is omitted is the question of *fidelity* [Hays and Singer 1989b]. In this dissertation, we focus on *interactive education* simulations: operational environments in which participants safely practice skills in preparation for actual situations.

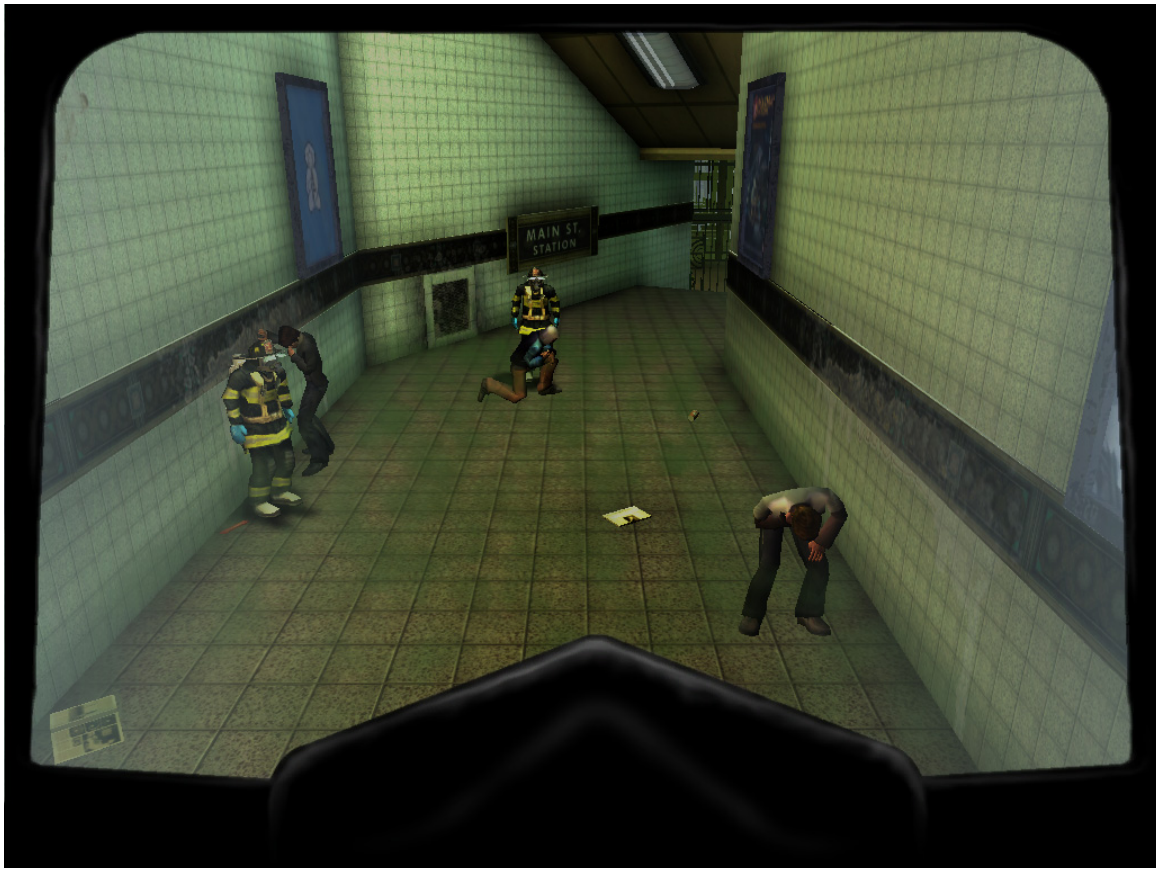


Fig. 11.: Screenshot from the mimetic virtual simulation *HazMat Hotzone* showing virtual firefighters responding to a biohazard [Entertainment Technology Center 2005]. The learner controls an avatar from a first-person perspective, and must respond to threats exactly as in real life.

1. Simulation Types

Non-mimetic simulations are based on the roles, activities, and information needs of work practitioners. These simulations stand in contrast to other forms of mimetic simulation: live, virtual, and constructive [Page and Smith 1998; Under Secretary of Defense for Acquisition Technology 1998]. Live, virtual, and constructive simulation are classifiers of *aspects* of simulation. Although they have been traditionally used to identify the *type* of a simulator, they are more effectively used to describe aspects of a simulation, as many systems are an amalgam of the three.

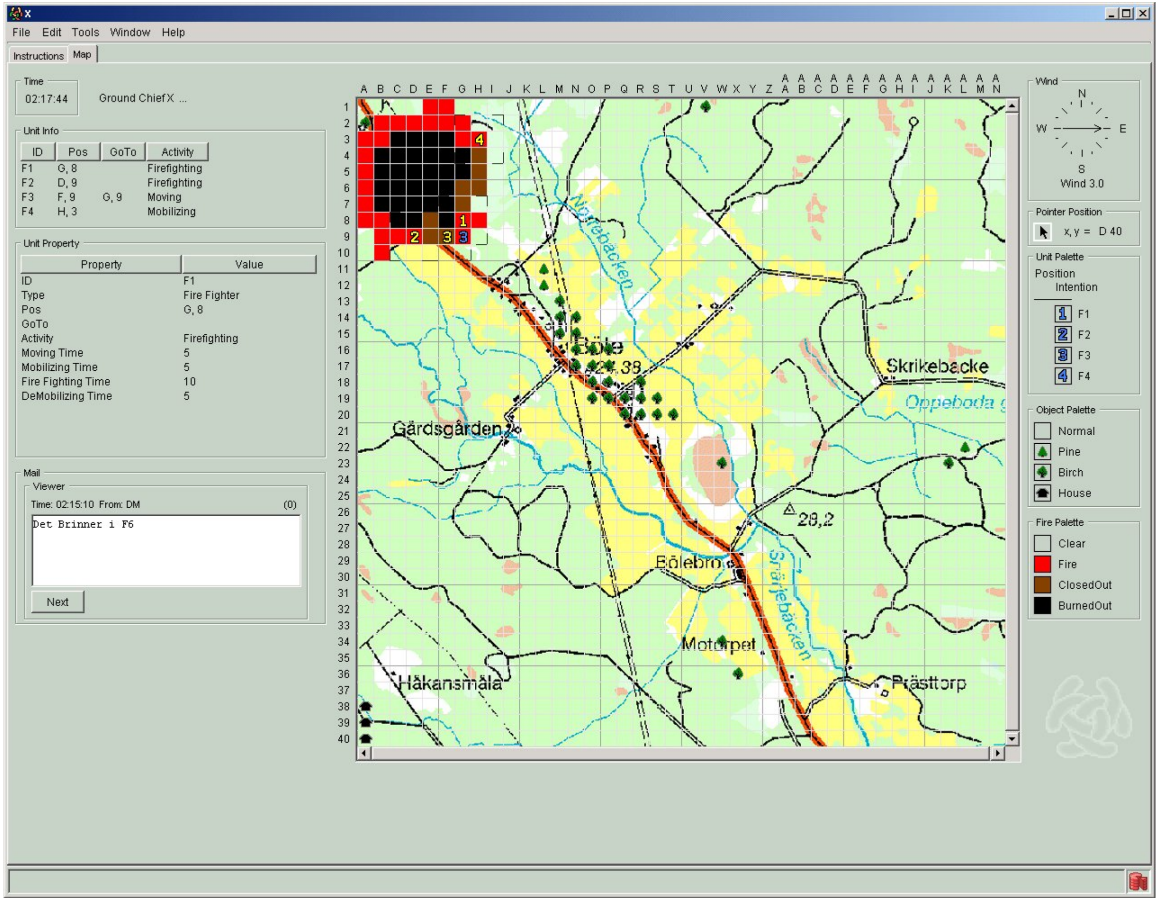


Fig. 12.: Screenshot from the mimetic constructive simulation *C3Fire* showing a fire spreading [C3Fire 2009]. Participants in the simulation direct simulated shared resources on the overhead map to combat the fire and protect property.

In *live simulations* participants rehearse actions using real equipment. Driving courses, where students take control of an automobile in which an instructor can stop the car at any time, are an example. Burn training is another example: students are using actual equipment to put out live, but contained, fires (Figure 5; chapter III, page 15).

Virtual simulation utilizes computer-controlled environments, typically 3D, designed to mimic, in high-fidelity, many aspects of a real-world situation. Virtual simulations are prolific and are used for emergency response (Figure 11) [Entertainment Technology Center 2005] and military training [U.S. Army 2002].

In *constructive simulation*, participants manipulate virtual-world entities that are based upon real-world entities, similar to tabletop war games or digital real-time strategy games (*StarCraft* [Metzen and Phinney 1998], *WarCraft* [Blizzard Entertainment 1994]). The *C3Fire* simulator, discussed in the next section (Figure 12) is a constructive simulator.

2. Prior Team Coordination Simulations

Some prior mimetic simulations specifically address teamwork in simulated stressful environments, including the Distributed Dynamic Decisionmaking simulation (DDD) [Kleinman and Serfaty 1989; Song and Kleinman 1994], *C3Fire* (Figure 12) [Granlund et al. 2001; Johansson and Branlund 2003; C3Fire 2009], and the MedTeams' Emergency Team Coordination Course [Small et al. 1999; Shapiro et al. 2004].

In the DDD simulator, participants collectively make decisions about how resources should be allocated to solve a problem that changes over time; for example, participants might need to allocate search teams to locate victims in a hostile environment. Over time, the virtual search teams will report back with findings, perhaps dependent on the equipment issued to them and the competence of the team members. In *C3Fire*, participants are presented with a map of terrain and direct virtual units to respond to emergencies. The MedTeams' Emergency Team Coordination Course [Small et al. 1999] provides a live and virtual high-fidelity simulation of medical emergencies for team training. Participants work with robotic dummies whose conditions are simulated through physical action within the dummy and computer equipment connected to medical "sensors", based in a realistic setting. Teams of students work together to deal with crises with the simulated patients.

C. Contrast between Mimetic and Non-mimetic Simulation

Non-mimetic simulations may combine aspects of all three mimetic simulation classifiers, but do not directly mimic real-world events. They are grounded in practice: the skills practiced are based upon those used in real life work. As a method of teaching, we intend non-mimetic simulations to fulfill a complementary role to existing learning environments. Such environments may be necessary to complete the transfer of skills from one context into another [Gagné 1954]. Traditional instruction is essential for them to be effective.

1. [Zero] Fidelity

In mimetic simulations, there is the question of simulation fidelity: how close does the simulation resemble the target environment, in terms of its stated educational goals [Hays and Singer 1989c]. There is a belief that higher fidelity will translate into more effective skill learning [Thorndike and Woodworth 1901; Hays and Singer 1989a]. Lave and Wenger go so far as to suggest that learning should be fully situated socially and operationally to be effective [1991].

Reder and Klatzky [1994], through an extensive overview of existing literature, conclude that fully situated learning is unnecessary in many cases. They note that social processes, such as the ones the present research targets, may be ignored in training. As such, the notion that learning should be socially situated [Lave and Wenger 1991] is essential in the present research.

In non-mimetic simulations, fidelity is not a question, they are essentially zero-fidelity. Non-mimetic simulations are task-focused and socially oriented, from findings in the field. Tasks are then executed in an alternate context, which may bear little resemblance to reality. Components of concrete reality may be incorporated, but are not focus. The behaviors learned in the environment can then be restored in practice.

2. Simulation and Games

Games function as a form of mimetic simulation [Ellington 1982; Salen and Zimmerman 2004d] in which physical and social processes are carried out. Narayanasamy et al. provide a classification of games and training simulators [2006][1]. In their framework, games are not primarily designed to teach skills, and simulations are not intended to be fun. Non-mimetic simulation games are intended to both teach skills and be entertaining, so that players are encouraged to train and improve. Gagné suggests that metrics within training devices can encourage cooperation or competition [1954]. Framing non-mimetic simulation as a game encourages players to compete and cooperate with each other, motivating participation.

D. Non-mimetic Simulation Examples

One example of a prior non-mimetic simulation is *Chess*. *Chess* was played as a simulation of war in sixth century Persia [Meri 2005]. It includes a variety of units, each with different maneuvering capabilities. Players need to plan moves in advance and consider what decisions their opponents might make; skills that can then be applied in alternate domains. *Chess*, however, does not take into consideration the effectiveness of certain units against one another, reinforcements, hidden units, or diplomatic solutions to conflict. It teaches the ability to think ahead and mentally model expected responses from an opponent.

A second example of non-mimetic simulation is the game *Hush* [Antonisse and Johnson 2008], in which the player takes on the role of a Tutsi mother during the

[1] Narayanasamy et al. also divide games from simulation games, but their framework does not meaningfully distinguish the two, so we omit simulation games [2006].

Rwandan genocide in 1994. The player's avatar is attempting to stay hidden from Hutu patrols seeking to kill her and her baby. To stay hidden, one must be quiet, but the avatar's baby begins to cry; to quiet the child, the mother must sing. Fundamentally, the core mechanic of the game is a rhythm game, in which the player times key presses to letters appearing on the screen. Visuals of photographs from the genocide, along with sounds of shouts, cries, and gunfire create tension. While *Hush* is not a mimetic simulation of a woman's experience hiding from Hutu patrols, it begins to capture the abstract tension experienced in this historical setting. The game play activities non-mimetically simulate keeping the child quiet while under stress.

1. Contrasting Mimetic and Non-mimetic Simulations

To contrast non-mimetic and mimetic simulation, first consider a mimetic flight simulator. Such software is designed to take into account atmospheric conditions, aerodynamics of a simulated aircraft, etc., to create as realistic an experience as possible. The user interface might include a dashboard, modeled closely on the gauges of the simulated aircraft. An ideal hardware setup may include a joystick or flight yoke and foot pedals. A mimetic flight simulation is an effective way to teach future pilots to control aircraft and respond to emergent conditions, without endangering themselves or valuable equipment.

If there were a training need to focus on aircraft landing procedure, including the socio-technical aspects, a non-mimetic simulation might be more effective. It might eschew accurate cockpit design and aircraft physics to focus on information translation and exchange between co-pilots. Specifically considering Hutchins' "How a cockpit remembers its speeds" [1995b] as an example, co-pilots need to look up information about the aircraft on tables, and enter relevant transformations into dashboard instruments while communicating with the pilot. This enables the pilot to maintain situation awareness and plan how to land the aircraft.

The non-mimetic socio-technical flight simulation might center around fast lookup of information in tables and entering it into a variety of controls quickly while under real-time stress, abstracting the tasks performed by a co-pilot in real life. A game might be set up where it is essential to announce to a co-player what controls are being modified and how. The co-player, in this case, might be engaged in some other cognition-intensive task. This kind of simulation would be useful for pilots who need to learn these skills, and is less expensive to conduct than a full mimetic flight simulator.

E. Advantages of Non-mimetic Simulation

Non-mimetic simulations have three advantages over mimetic simulations: economy, focus, and transferability. Non-mimetic simulations are *economical* because they are simpler to produce and abstract out details that would be expensive to replicate. The present research investigates *focus*, determining the effectiveness of non-mimetic simulations for teaching specific set of skills. Future work will investigate *transferability*, by taking game designs produced in the present research and applying them in alternative domains.

1. Economy

Non-mimetic simulations omit actual reality for conceptual learning. Cost is a consideration in simulators and training devices that leads designers to reduce simulation fidelity [Gagné 1954; Hays and Singer 1989a]. Removing fidelity as a consideration allows non-mimetic simulations to be economically produced and executed.

If, for example, we were to mimetically simulate fire emergency response work practice, we might need to create algorithms for fire and smoke, as well as representations. Such work is the subject of intense research across a variety of domains. The hardware needed to run such physical simulations and displaying realistic graphics would be expensive. Instead, the present research is run on inexpensive, off-the-shelf hardware with relatively low system requirements.

2. Focus

Non-mimetic simulations are specific to a subset of tasks within a domain. Focusing simulation resources is part of how non-mimetic simulations are economical. Focus enables learning without distraction. While mimetic simulations may capture a variety of working conditions, non-mimetic simulations extract particular aspects. Which aspects are selected depends on the purpose of the educational program.

If we consider the example of burn training, participants are engaged in communication and coordination, but this is confounded with a need to learn to maneuver in closed environments, manipulating hoses and other equipment, and learning the physics of fire. Because there is a need for team coordination education, the simulation is targeted to that aspect of work practice. While focus is a primary benefit, the original task environment cannot be entirely overlooked. Continuing the example of fire emergency response work, participants must make timely decisions while under stress, so this must also be a part of the non-mimetic simulation.

3. Transferability

We hypothesize that non-mimetic simulations will be transferrable. Aspects of work in one domain are just as essential in another. In the present research, we focus on team coordination: the need to transform and share information while under real time stress, enabling multiple individuals to function together effectively. Team coordination in abstract is necessary in a variety of domains beyond emergency response: teams of programmers, air traffic control, etc. We hypothesize that non-mimetic simulations of the intense team coordination of fire emergency response work practice will be valuable to domains that also rely team coordination.

F. Designing Non-mimetic Simulations

As with designing mimetic simulations, a fundamental question is "what should be included and what should be omitted?" We argue that the answer to this question is discovered through deep knowledge of the practices of experts in the domain combined with iterative development and testing of designs. The process, used successfully in the present research, involved learning about effective team practices through field experts and observing training exercises, identifying a gap in training, and developing a game centering on the skills in the gap.

Through the design process, we identified a set of skills necessary within the domain that were not explicitly practiced through the traditional mimetic simulation. Once the skills are identified, the design problem is one of crafting a context in which such skills are practiced. The alternate context is then tested with a variety of users and iterated. Evaluation centers on improvement in the target skills.

Through evaluating T^2_eC (Chapter VIII), we have refined a set of non-mimetic simulation design principles presented originally in Toups Dugas et al. ["Emergent team coordination," 2009]. These principles are based on fire emergency response work practice, and are meant for non-mimetic simulations for team coordination, as the present research constructs. Although the actual user study is discussed later, we present the findings here to aid in understanding non-mimetic simulation in the context of developing T^2_eC.

Our principles for non-mimetic simulation focus on abstract human- and information-centered aspects of practice. Fire emergency response work is carried out safely and efficiently by sharing and integrating rich, multi-way flows of information. Information access is an essential difference in the roles of firefighters and ICs. Real-time stress impacts the way that FERs select and share information. In capturing these aspects of work practice, we develop a simulation in which non-FERs learn to coordinate effectively. Their emerging practices reflect the long-standing work practices of expert responders.

1. Information Distribution [Simulation Design]

Information in varied forms and content is available to different members of a fire emergency responder (FER) team [Toups Dugas et al. 2009]. Information distribution makes explicit the essential role of distributed cognition as team members assemble complementary pieces of the situated information puzzle. Designing information distribution consists of supplying information to team members in such a way that members have alternative perspectives on the overall situation that are characterized by the modality of information (e.g., directly sensory, versus artifact-mediated), in addition to its content. Information distribution creates an environment where relevant data is dispersed among team members who gather, filter, transform, and share it with one another to make sense of the whole incident.

Simulation designers must *create interdependencies*, so that each individual's task requires communication from other team members. Creating such interdependencies involves crafting constraints such that team members are reliant on one another: a distributed cognition environment. In such an environment, the smooth interaction of participants creates more than the sum of the parts.

Also essential to practicing distributed cognition is the need to transform information from alternate modalities. For example, each firefighter in a building needs to make sense of his/her location within a structure to communicate about it. Such communication accounts for the path taken through the building, observable characteristics nearby, and a shared referencing scheme. In communicating, those listening need to make sense of the firefighter's account of the situation, in order to locate him/her within the fireground. The incident commander (IC), for example, may have a blueprint and will need to integrate an understanding of how the blueprint is transformed from a two-dimensional representation on paper to a three-dimensional building, in which the firefighter is situated. Successfully crafting information distribution involves creating multi-modal forms of the same information, which participants then transform and communicate with each other.

2. Roles

The axis of information distribution is another consideration in team coordination non-mimetic simulation design. One effective way of distributing information is through the creation of roles. A role within the simulation has access to individualized information, a set of available actions, and an array of tasks to be performed.

FERs use differentiated roles to accomplish specific tasks [Jiang et al., "Siren," 2004; Toups Dugas et al., "Emergent team coordination," 2009; U.S. Department of Homeland Security 2004]. For example, firefighters search for victims and put out fires, while an IC directs teams from a distant vantage, possibly consulting information artifacts. Each role carries access to a different piece of the information picture and enables a specific set of actions at the incident.

Role, task, and environmental constraints at the incident drive the choice of communication modality. Because the IC is often far away from the fireground, s/he must use the radio to keep up with those in the fireground. Firefighters located near one another can communicate face-to-face. Through constraints on each role, the designer can manipulate what actions participants can take, driving them to make decisions about how to act.

3. Real-Time Stress

Real world team environments are often characterized by stress with high stakes. There are hard time limits on action and the situation changes continuously. Real-time stress impacts choice of communication modality and actions taken. If participants are free to spend as much time as possible, without consequence, they will not learn to practice quick decision making skills.

There are hard limits on the amount of time FERs can spend in and around a fireground. Not only must they consider dangers of heat and visibility, but also air supply. Audible cues from the environment and equipment are one way in which FERs monitor their remaining time. Using sound effects helps create urgency in the real-time stress of the simulation environment.

G. Conclusion

The central design principle of non-mimetic simulation is abstraction. Contrary to prior mimetic simulations, non-mimetic simulations are operational environments in which participants learn practice-grounded skills in an alternative context without a mimesis of the concrete environment. Non-mimetic simulations are economical, focused, and potentially transferable to other domains. Carefully crafted from work practice, they build a set of skills used in the target domain and allow participants to employ them in an alternative context. Skills learned in the non-mimetic simulation context are then restored in the original.

The present work investigates a non-mimetic simulation game for teaching team coordination: T^2_eC. The next chapter discusses game design with an emphasis on cooperative play; the one that follows describes the design of T^2_eC, incorporating the design principles for non-mimetic simulation.

CHAPTER V

GAME DESIGN

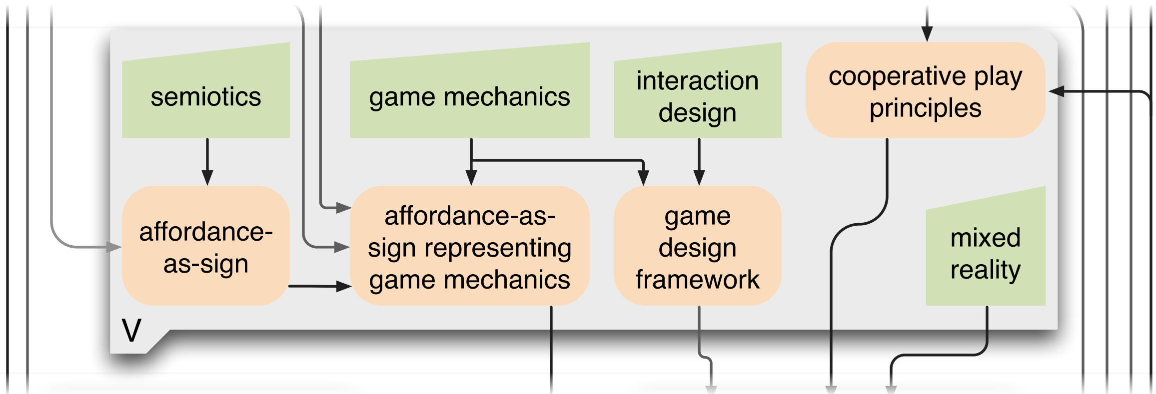


Fig. 13.: Component of the concept map (Figure 1) for game design and game mechanics.

This section begins by covering relevant elements of interaction design, including visualization and sonification (Figure 13). We provide background on semiotics, then merge the concept of sign with affordance as a new theory. We then discuss background on game design, including game mechanics and the use of score for motivation. What follows is our game design framework and design principles for engaging cooperative play developed from observations of FER work practice and user studies with the T_e^2C games. Future work will address mixed reality versions of the T_e^2C game, which we hypothesize will be more effective for teaching team coordination. Because the stationary version of T_e^2C discussed here is designed anticipating the needs of MRT_e^2C, we conclude with a brief discussion of mixed reality systems and games.

A. Background: Interaction Design

Interfaces are border zones between humans and machines [Kerne 2005]. Through interfaces, the machine provides information to the user. It provides a basis for experience. The user makes him/herself known to the machine through sensors (keyboards, mice, global positioning, etc.). This section is primarily concerned with software interfaces; the complex sensors and pattern recognizers of hardware interfaces will be essential to later work in mixed reality.

Interfaces provide information and feedback to the user. Effective use of color is essential to convey meaning [Tufte 1990a; Ware 2004], balance cognitive load [Tufte 1990b; Ware 2004], and enable visibility [Itten 1997; Thomas et al. 2002]. Bright, saturated color can be used to call attention to important details, while muted tones should dominate for less-important information. Layering is a compositional technique used to enable visual parsing of a scene through depth [Tufte 1990c]. Each layer of information can be taken individually, or in concert with the layers above and below it. Overviews of information can be explored through details on demand to enable the user to quickly and enjoyably process large datasets [Shneiderman 1996].

Information in interfaces may change rapidly, especially in games. It is essential to signal to the user what is changing and how. Animation enables understanding context, so that users do not get "lost" in the interface and can observe causality [Bederson and Boltman 1999; Ware 2004]. Sound provides context through audible cues, enabling multi-sensory interfaces [Blattner et al. 1989; Brewster 2002; Toups Dugas and Kerne 2007].

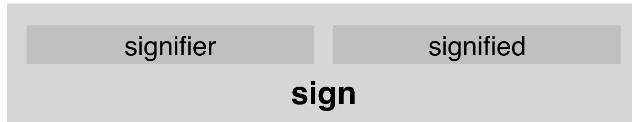


Fig. 14.: Barthes' model of sign, built from de Saussure [Barthes 1991; Kerne 2001]. Signs represent meaning through the intertwining of signifiers (that which is perceived) and signifieds (to which signifiers refer).

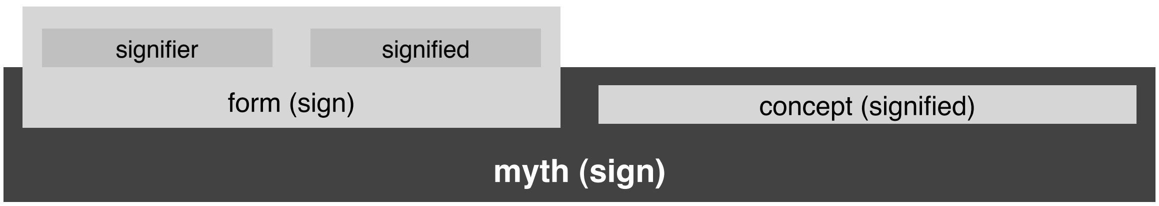


Fig. 15.: Barthes' model of myth [Barthes 1991; Kerne 2001]. Myths are built on signs; they take a sign as the signifier to create an additional layer of meaning.

B. Background: Semiotics

Semiotics is the study of signs and the way they create and communicate meaning. Building on de Saussure's science of semiology [1959], Barthes describes signs as the combination of a signifier and its signified [1991]. The signifier is that which is perceived, while the signified is the object or action in the environment to which the signifier refers. The signifier and signified are inexorably linked as the sign, the fundamental unit of meaning. Figure 14 diagrams Barthes' concept of sign.

For example, consider a corporate logo. The image itself is the signifier; it stands in for the company. When one observes a recognized logo, it brings to mind the meaning, the company represented, or perhaps even a specific product.

Barthes nests his model of sign to develop what he calls "myth" (Figure 15). Myths are second-order signs in which a complete sign becomes the signifier for an additional layer of meaning.

Barthes gives the example of the cover image of a French magazine: an African soldier salutes with eyes uplifted [presumably toward the French flag]. The analysis of the second-order sign addresses how this is not just a person, a soldier, but that in the second-order signification, the ability of France to incorporate and embrace multiculturalism, including people from its former colonies, in a respectful and orderly way.

C. Theory: Affordance-as-Sign

We synthesize affordances (II.B, page 10) and signs to form a new theory. Perceptible affordances create a mapping between the observable characteristics of an environment and the action an animal may take. In this new theory, affordance, itself, functions as sign. The observable characteristics of an affordance (form) is its signifier. Its meaning, the signified, is the possible action. We refer to this unity as an *affordance-as-sign*.

The perceiver of the affordance-as-sign uses a mental model (II.A, page 9) to decipher the meaning of its form-signifier, resulting in the possible action-signified. We combine Figure 3 and Figure 14 in Figure 16, diagramming the affordance-as-sign. The concept of affordance-as-sign has value in designing game interfaces and game mechanics, suggesting ways in which the game designer can craft meaningful and comprehendible play. Later, we apply this theory to designing games.

D. Background: Game Design

Salen and Zimmerman [2004g] develop an understanding of game design through a multi-part schema of rules and play. *Rules* encompass the mechanical and mathematical properties that constrain and enable operation in a game. *Play* describes

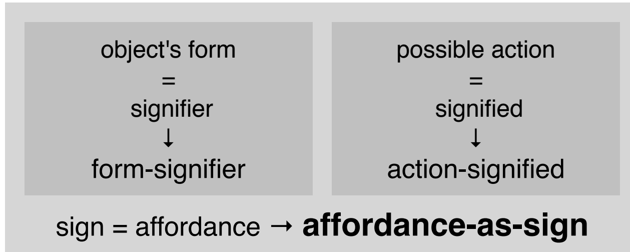


Fig. 16.: The affordance-as-sign diagrammed. Combines the concept of affordance with that of sign. The form-signifier indicates to the perceiver the action-signified. The action-signified must be a part of the perceiver's mental model to be usable.

how game participants interact with each other and the rules to craft a meaningful experience. Game design fundamentally involves developing rules to constrain play, making it meaningful. *Game mechanics* are the combination of rules and play; they are the set of actions available to a player, and the outcomes of those actions. We take our operational definition of *game* from Salen and Zimmerman:

> A *game* is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome. [2004a]

1. Rules

According to Salen and Zimmerman, there are three types of rules: operational, constituent, and implicit [2004h]. To exemplify the three types, we use the board game *Settlers of Catan* by Teuber [1995][1] as a case study.

a. Operational Rules

Operational rules define game constructs, their behaviors, and the means by which players manipulate those constructs. Operational rules create mappings between the real world and the game world. They describe actions that players take.

[1]A complete description of the rules and play of *Catan* are not included here. An operational understanding of the game will be helpful, but not necessary.

In *Catan*, players have a chance of acquiring a randomly-determined (dice roll), differentiated resource (bricks, stone, wheat, wood, or wool, in the form of cards) each turn. Throughout the game, players claim territory on the board; each territory has a number and a type of resource associated with it. On a player's turn, s/he takes the dice and rolls them. Players who have, on previous turns, claimed territory with the number rolled gain the resource associated with the territory. This is an operational rule: it is written in the game's manual and describes how one plays the game. It defines what actions players are required to take in order to acquire resources.

b. Constituent Rules

Constituent rules are intrinsic to the play of games and are invisible to players. Constituent rules are the inherent sub-systems that materialize through play, relationships that are dependent on play to appear that are not otherwise specified. Through the behavioral specifications, affordances (II.B, page 10), and constraints of the game, these rules make up the internal logic of the game system.

Trading acquired resources is an essential component of play in *Settlers of Catan*; supplementing the standard acquisition methods described above. Players have as many as four options when making a trade: they may always trade with the bank, trade with a generic port (if they have one), trade with a resource-specific port (if they have one), or trade with another player (if they successfully negotiate a mutually-beneficial trade).

In trading with the bank, the player trades away four of any same kind of resource (for example, four wood cards) in exchange for a single resource of another type (a single wool card): a 4 : 1 ratio. If the player is in possession of a generic port (another characteristic of some of the territories claimed through play), they may use that port to trade three of any single resource type to the bank for another resource of their choice: a superior 3 : 1 ratio. As with the generic port, a player might be in possession of a resource-specific port. Resource-specific ports enable the player to trade a specific resource at a 2 : 1 ratio for any other resource; superior to the 3 : 1 ratio supplied by the generic port, but more restricted. For example, a player with the wood port could trade 2 wood cards for one card of any other kind. Finally, players may negotiate with the other players in the game to make arbitrary trades. Trades need only be agreed upon, their ratio is not specified (although a minimum of 1 : 1 is required, you cannot *give* a resource).

A set of constituent rules materialize around player-player trades in *Catan*. These trades lack operational rules outside of their inclusion as one potential action on a turn. There is no ratio for the trade specified (outside the lower bound), but the existing operational rules give a clue as to what is appropriate. As players' states change in the game (access to ports, availability of resources, etc.), new ratios suggest themselves. Early on, Bill might have a large supply of brick cards, and desperately be in need of other resources; the other players could take advantage of this to acquire bricks they need from Bill at a favorable ratio. The ratio, of course, must be better than trading with the bank, so 3 : 1 is the upper bound. If Bill acquires territory with a brick resource-specific port (allowing him to trade bricks at a 2 : 1 ratio), the other players must change tack. They will need to offer him something better than a single resource of his choosing for two brick cards; only a 1 : 1 ratio is now reasonable[2].

[2]This assumes Bill is a rational player working only for himself. It is possible that Bill might try to bolster one of his opponents to make him/her more successful against a rival; in that case, he might take an unfavorable ratio to advance that player.

c. Implicit Rules

Finally, *implicit rules* are not formally specified and take into account complex social and cultural protocols and interactions between players and their engagement with the system [Salen and Zimmerman 2004h; Sniderman 1999]. Implicit rules form between players, and may be group specific. Players who do not know each other may use operational rules as a kind of universal language, but implicit rules may be left open, following basic decorum. In most cases, it is inappropriate to use the threat of physical violence as a means to encourage trades in *Catan*, but it is not expressly forbidden; in some groups, it is inappropriate to use the promise of future favors for bargaining, but that, too, is not specified (and is not uncommon, in practice).

2. Game Mechanics

Rules and play are intimately connected to the experiential building block of game mechanic. *Game mechanics* are the instances of player choice and the outcomes associated with that choice [Juul 2005a; Salen and Zimmerman 2004b]. The *core mechanics* of a game are the suite of game mechanics that are repeated during play. Some of the core mechanics of *Catan* include those described above: rolling dice to acquire resources and trading resources with the bank and the other players.

Game mechanics are structures of play: information is presented, a player decides and acts within the scope of rules, the system responds, and the cycle repeats. For example, one game mechanic in the digital game *Super Mario Bros.* is jumping [Miyamoto and Tezuka 1986]: the player makes the choice to have his avatar jump, the resulting action is constrained by simulated physics.

The set of actions available to a player at any given time are defined by game mechanics [Salen and Zimmerman 2004b]. The game's interface mediates experience of the mechanics [Toups Dugas et al., "Game design principles," 2009]. It is necessary for the game designer to make visible affordances in the game to the player, taking into account the rules that apply to the player's agency in the game system. This allows a player to perceive the set of choices that are available, making design of the interface a component of game rules.

While the goal in most non-games is to use the interface quickly, easily, and effectively; part of playing a game involves going about a task inefficiently [Salen and Zimmerman 2004a]. Games are specifically about challenge; as Salen and Zimmerman note, racers do not just run the shortest distance from start to finish, they follow the prescribed course.

It should be noted that although players may apply existing, embodied mental models, in many cases, play itself is disembodied or is connected to embodied interaction in a way that is non-isomorphic [Bayliss 2007; Gregersen and Grodal 2009]. Players engage in *primitive actions* (*p-actions*) [Gregersen and Grodal 2009], such as moving an analog stick, pushing a button, or performing a gesture. Through play, game actions are connected to p-actions: they are learned and incorporated into mental models. In-game p-actions function as a form of restored behavior (IV.A, page 36). P-actions are parameterized and restored in a variety of contexts for a variety of purposes.

3. Score

Score rewards players for accomplishing tasks within a game. In theory, it is an arbitrary, abstract construct; in practice, score externally motivates players. Score gauges progress, allowing comparison and competition over time and between or within individuals and teams. While games themselves are engaging, score motivates play and directs action.

Score determines the winner in athletics and board games. In many digital games, score has no direct impact on play, it is a *reward of glory* [Salen and Zimmerman 2004c]. In some cases, this is because there is no way to "win" the game [Rouse 2006]; in others, it is a way to compare the degree to which the player has won. Unlike other types of rewards, which may improve the player's ability to progress or achieve (e.g. free games, extra lives), score rewards the player.

Pinball and digital games have used scoring mechanics since their inception [Rouse 2006]. A high-score list logs the greatest scores achieved, often with attribution (e.g. initials). High-score lists were common in arcade games, where the data was public. Players could compete even if they did not know one another, earning "bragging rights". The Twin Galaxies organization [Twin Galaxies International Inc. 2010] was formed to maintain and publicize top arcade scores.

As gaming transitioned from the arcade to the home, the value of high-score lists diminished. Individual games tracked high scores, but, unlike arcades, these were not public. Gaming magazines solicited photographs of subscribers' high scores in games; these were published in an effort to increase access.

Global networks restored the value of high-score lists, making scores public and re-enabling competition. Online gaming communities, such as Microsoft's Xbox LIVE (XBL) [Microsoft Corporation 2010], Sony's PlayStation Network (PSN) [Sony Computer Entertainment America LLC 2010], Valve's Steam [Valve Corporation 2010], and Kongregate [Kongregate 2010] support competition though score. These services reward players with *achievements* ("*trophies*" on PSN): digital badges for in-game accomplishments. Achievements are displayed on a player's online profile and contribute points to the player's aggregate score.

Some games integrate networked high-score lists directly into the games themselves, motivating play. For example, *Geometry Wars: Retro Evolved*[2] displays a score for a player to beat: the current top score of one of the player's friends [Cakebread 2008]. Other games use score to motivate real-life activities. In *Chore Wars*, players create a character that gains experience for self-reported house work [Davis 2007]. In *The Nethernet*, players earn points for visiting web pages and can go on "missions" by navigating hyperlink trails that other players create, rewarding players for traversing the web [GameLayers, Inc. 2010].

E. Game Design Framework

We develop three schemas, derived from Salen and Zimmerman's work, for use in game design: operational elements, functional semantics, and representations. The framework expands on the concept of rules and play, and direct them in terms of digital game design, such as the T^2_eC game.

1. Operational Elements

Operational elements are a combination of all types of rules that are not directly contained in the game's written mechanics. They are play constraints derived from the social relationships that develop or are imposed by play within the game, as well as the affordances and constraints of the technologies used. Operational elements may include roles played by participants or the seams [Chalmers and Galani 2004] of the game environment.

2. Functional Semantics

Functional semantics describe entities and terrain within a game, the entities' ranges of action, and the inter-relationships (which make up the operational and constituent rules [Salen and Zimmerman 2004h]).

Entities are game objects, such as players' embodiments in the game world (avatars), computer-controlled opponents (threats), and objects that the players seek out (goals). Entities interact with each other. *Terrain* is the environment of play, representing space in which entities act.

Operational and constituent rules become the actions and relationships of entities to each other, within the terrain. These might describe, for example, the speed at which a player's embodiment (avatar) can move over a type of terrain or the method by which a computer-controlled opponent (threat) attacks an avatar. The relationships between terrain, avatars, threats, and goals direct the outcome of play.

3. Representations [Interfaces]

Representations are game interfaces. They are visual and aural ways in which entities and terrain are presented to the player, as well as the means through which the player interacts. Because they enable information to flow between the human and the game, issues in developing representations revolve around creating meaningful iconography and sounds for game events, as well as recognizers for sensor data.

In addition to providing representations of the game to the players, it is necessary to provide representations of the players to the game. Support for sensors (mouse, keyboard, GPS) is accomplished through recognizers, which translate raw data into something meaningful in the context of the game system (GPS to avatar location).

Color, animation, and sound are important for building interface representations for the game. These help players understand the affordances and constraints of play, make sense of information, and have meaningful experiences.

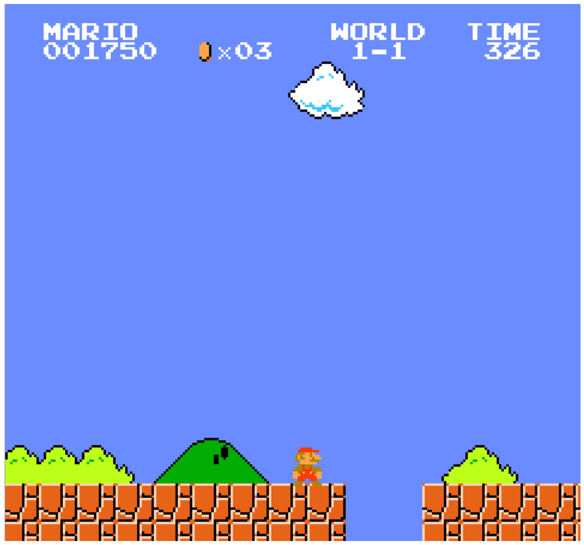


Fig. 17.: Mario encounters a pit in *Super Mario Bros.* [Miyamoto and Tezuka 1986]. Mario may jump the pit, or fall into it. The pit is an affordance-as-sign, the form-signifier is the pit itself and the actions-signified are jump or fall.

F. Theory: Augmenting Affordances-as-Signs to Represent Game Mechanics

In this section, we apply the theory of affordance-as-sign to game mechanic design and suggest how it can be augmented. The theory implies appropriate designs for communicating with the player about affordances [functional semantics] through representations. The context of the theory is movement and advancement through games. We present two levels of sign: first-order *affordance-as-signs* and second-order *augmented affordances-as-signs.*

1. First-Order: Affordance-as-Sign

Mental models enable humans to understand and simulate complex phenomena. In playing games, players use existing mental models to understand and successfully execute actions in play. As long as the existing mental models can account for the game mechanics, affordances-as-signs are sufficient as game interface design components.

As an example, consider *Super Mario Bros.* [Miyamoto and Tezuka 1986], in which the goal is to move Mario from the left end of the stage to the right, without dying, before time runs out, maximizing score along the way by collecting coins and defeating enemies. One type of obstacle the player encounters is a pit (Figure 17). The player may engage in the game mechanic of falling into a pit, but this does not advance the player's goals. Further, while falling is included in most players' mental models of the real world, one frequently avoids the falling affordance of real-life pits.

Jumping is another game mechanic in which the player may engage. Jumping is also present in most humans' set of mental models and is another means of navigating pits. That pits afford jumping is a way of understanding how to play, engaging in the game mechanic and advancing toward the goal. The pit is the form-signifier, indicating that one should jump, the action-signified. The form-signifier of the pit, the desired action-signified of jumping, and the feared action-signified of falling are composed in this first-order affordance-as-sign.

Players may learn to adapt their mental models without in-game design components through explanation or exploration. Many games supply a manual or reference sheet describing the mappings from p-actions to game actions. When the set of p-actions is limited or simple, experimentation supports the player in expanding his/her mental model. Exploration enables players to determine the functions of the environment experimentally and experientially.

When the game designer directly uses the design of an object [the pit] as a signifier for the action the player should take [jumping], we refer to this as a first-order affordance-as-sign. Such a sign is first-order because, as Barthes does with myth, we nest the affordance-as-sign to create an additional layer of meaning to aid players learning game mechanics outside of their existing mental models.

a. Case Studies: Affordances-as-Signs

In this section, we consider a variety of games in which environments are structured to support engagement of existing player mental models. It is possible to design game objects so that, inasmuch as the player's mental model includes the capabilities of the avatar, or the avatar's capabilities are sufficiently similar to the player, the affordances are clear (Figure 18). This choice may hinder the player, requiring role playing, with which players may be unfamiliar.

Signifiers are created through the design of objects. Affordances-as-signs in *Mirror's Edge* may be optionally augmented (described later); un-augmented, low blocks afford vaulting over high obstacles (Figure 18, top left) [EA Digital Illusions CE 2008].

In the *Legend of Zelda* series of games, the main character uses bombs to clear cracked walls, accessing new areas: the action of creating an explosion is signified by the perceived instability of the wall (Figure 18, bottom left) [Tezuka and Miyamoto 1992]. Although somewhat inconsistent, some secret areas in Zelda are accessed by using bombs on apparently sound walls. Once the mechanic of blowing up walls is learned, the player can reenact this restored behavior in different contexts.

Window frames, ledges, beams, and other protrusions afford climbing for the avatars in the *Assassin's Creed* series (Figure 18, right) [Dasilets and Raymond 2007]. Affordances in these games have natural signifiers that match up to the expected physics of physical reality.

b. Case Study: Affordance-as-Sign in Need of Augmentation

Criterion Games supplies an illustrative example, which we revisit later. In *Burnout Paradise*, an open-world stunt racing game [Ward 2008], the player operates a simulated vehicle in city streets. The goals of the game are to complete driving challenges

Fig. 18.: Examples of making affordances visible by structuring the environment.
Top left: Blocks in *Mirror's Edge* [EA Digital Illusions CE 2008] afford vaulting to the avatar, enabling a high, fast jump to clear obstacles.
Bottom left: The avatar in *Legend of Zelda* [Tezuka and Miyamoto 1992] waits for his bomb to break down a cracked wall. When the bomb goes off, a new passage to a secret area will be open.
Right: The avatar in Assassin's Creed [Dasilets and Raymond 2007] scales a wall using the window frame: any protrusion that appears to afford climbing does.

(street racing, time trials, stunt driving, etc.), and to discover locations to perform stunts and find shortcuts.

One type of shortcut/stunt is the *super jump*, where the player drives her/his car as fast as possible over a ramp, clearing a large distance. TheTeam@Criterion observed that players were having difficulty identifying locations where they could super jump [2009]. Although there were locations in the game world that afforded

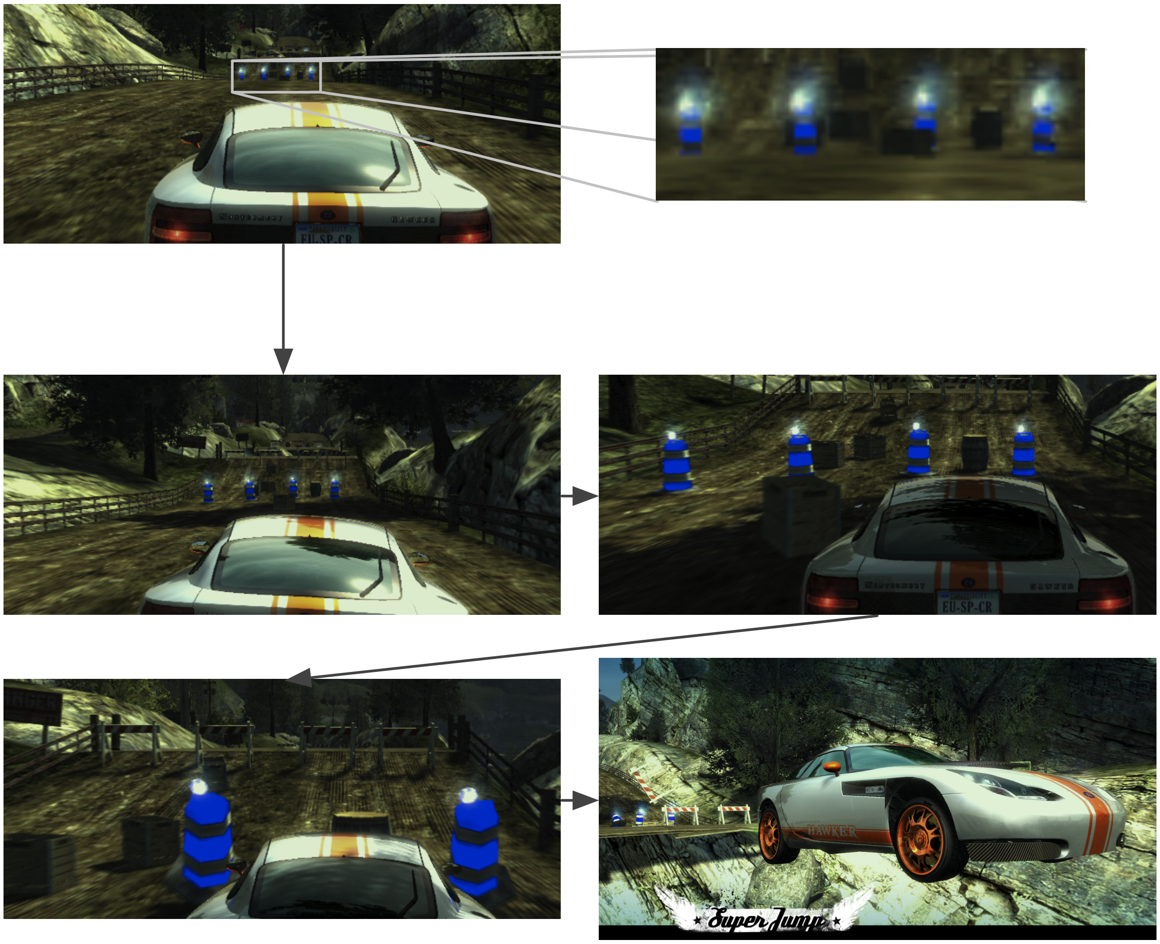


Fig. 19.: The approach to a super jump in *Burnout Paradise* showing augmented signifiers, flashing blue lights. The player spots the lights and guides the automobile toward them, making a successful jump.

super jumping, players could not find them. Many players' mental models of the real world do not include driving cars off ramps over chasms.

The solution was to update the game design, by patching all existing versions, to make the super jump ramps more visible. TheTeam@Criterion augmented them with bright, flashing blue lights (Figure 19). A voice (in the avatar-car's radio) informs the player of this during play, using an affordance-as-sign to add the augmented signifier to the player's mental model.

Fig. 20.: The second-order augmented affordance-as-sign. An augmented signifier pairs with an affordance as signified, forming a second-order sign.

2. Second-Order: Augmented Affordance-as-Sign

The game player does not live in the same world as the game's avatar, and the avatar may possess abilities beyond those of the player, activated by p-action. The player must perceive a mapping between the game environment and the avatar's abilities. Further, unlike real, embodied experience, games are not always capable of representing all nuances of what may be perceived within the game environment. In these cases, existing mental models may be insufficient for understanding game mechanics. Players may have difficulty knowing what to do, a common problem in game design [Salen and Zimmerman 2004e].

To teach the user and enable play, the designer may add an *augmented signifier* to make the game mechanic explicit, stimulating mental model formation. Augmented signifiers add to the game interface in a way that may or may not be in line with the game's narrative [Juul 2005b]. The augmentation layer provides additional information to the player, so that he or she can determine what actions may be taken.

We nest affordance as the signified in a new level of signification: the second-order *augmented affordance-as-sign* (Figure 20). In the augmented affordance, the augmented signifier refers to the entire first-order affordance-as-sign as signified.

Like explanation and exploration, tutorials are supported by augmented affordances-as-signs. Tutorials, usually in the game engine, walk players through the game mechanics, so they experience play while the game provides augmented signifiers describing what to do. Once the player has completed the tutorial, s/he is better able to map p-actions to game actions. Her/his repertoire of mental models expands, providing building blocks for subsequent spontaneous enactment and remix of restored behavior.

A variety of techniques can be employed for augmented signifiers. The most primitive include the use of text, iconography, and speech to tell the use what to do or how to do it. Coloration or texture may be employed, but must be mapped to an action. Sound can also indicate the affordance of an object.

a. Case Studies: Text and Iconography

In some games, the player is told what they need to know to interact with the environment (Figure 21). This augmented signifier takes the form of messages that appear on the screen, sometimes only in an early tutorial (e.g. [Guyot 2008]), and sometimes throughout the entire game (e.g. [Bungie Studios 2001; Hellquist and Levine 2007]). Messages indicate when an affordance is available that the player may not realize or may not be able to see. In the *Halo* series, when a player is standing on top of a weapon that may be picked up and used, or an object that can be thrown, a message appears indicating which button to hold and what action will be taken [Bungie Studios 2001]. Iconography is used for describing the button presses.

While not deeply immersive and potentially disruptive to the player's suspension of disbelief [Juul 2005b], text and iconography can clearly disambiguate the available actions to the player.

Fig. 21.: An example of using text and iconography to indicate affordances in *Halo*. The text tells the player to hold the X button to make the avatar throw the object in front of him.

b. Case Studies: Coloration and Texture

Affordances can be made visible through coloration and texture. Highlights can indicate interact-able objects. Color can provide clues about the functions of the environment.

Some games *highlight* affordances (e.g., [Pardo et al. 2004; Brevik et al. 2000; Schaefer et al. 1997; Toups Dugas et al., "Emergent team coordination," 2009]). In many cases, the use of highlighting includes details-on-demand [Shneiderman 1996]. For some games, this means displaying a tooltip with more information about the highlighted object (e.g. [Pardo et al. 2004; Brevik et al. 2000; Schaefer et al. 1997]). In others, secondary displays may show additional details (e.g. [Toups Dugas et al., "Emergent team coordination," 2009]). We present a number of examples as case studies.

***Mirror's Edge*: Optional Color Signifiers.** Use of contrasting color [Itten 1997; Tufte 1990a] is another method of augmenting affordances in an environment.

Fig. 22.: An example of making visible using color: runner vision in *Mirror's Edge*. The avatar has just burst through the red door (doors that cannot be opened are white) and spots a red block directly ahead. Jumping from the block will enable the avatar to reach the black zip-line hanging from the ceiling, escaping the guard in the distance. Note that, were runner vision augmented signifiers activated in Figure 18 (top), those blocks would also have appeared red.

Mirror's Edge [EA Digital Illusions CE 2008] overcomes the problem of making structures in the environment clear to the player by using bright, contrasting color (Figure 22). The game uses an otherwise muted color palette, and thematically associates the color red with *runners*, the protagonist group of messengers skilled in leaping, climbing, and running (*parkour*). The player takes on the role of a runner who is expert at sizing up the environment for ways to use her abilities. Players need a way to tap into the character's ability to perceive the virtual environment in order to traverse terrain efficiently.

To make the avatar's ability to perceive the environment's affordances clear to the player, designers introduced an augmented signifier, *runner vision*. Runner vision highlights, in red, portions of the environment that can be interacted with, or that provide clear routes for escape from danger. Locations where the character can leap from one building to another, balance along a narrow path over a gap, or break through a door are highlighted. Red doors afford opening; white doors do not. Spots of bright red are used sparingly, serving to draw the eye to runner-vision-highlighted objects [Tufte 1990a], marking out one of several efficient paths through large, overwhelming landscapes.

Runner vision makes visible the opportunities for in-game action. Salen and Zimmerman [2004e] cite “not knowing what to do next” as a common problem in game play. Runner vision addresses this neatly by guiding the player to places where they can interact and advance through the level. It has the further advantage of maintaining complete consistency with the fiction of the game [Juul 2005b].

Mirror’s Edge exemplifies a fluid method for intertwining game mechanics and interface design by augmenting affordances-as-signs. The player has the option of playing *Mirror’s Edge* with or without runner vision enabled, independent of difficulty setting[3]. With runner vision enabled, *Mirror’s Edge* is a game about speedily traversing a (mostly) linear path through an environment, while evading threats. Once the player disables runner vision, s/he is left with un-augmented affordances-as-signs. Players must make decisions about which objects to try to vault. Play is enabled by mental models that encompass the terrain characteristics that afford vaulting and memory of whether or not particular places on the game map can be vaulted. The route through the level is essentially the same. But now, the player invokes a superset of the previous restored behaviors to play at a higher level of complexity. Game play grows to involve plotting courses, evaluating routes, and making

[3]On the hardest setting, runner vision cannot be enabled.

judgment calls, while speedily traversing a linear path through an environment and evading threats.

***Prince of Persia*: Signifying through Texture.** The eponymous Prince of Persia [Guyot 2008] uses a clawed gauntlet to run along and climb walls, traversing terrain to reach his goal. Texture is used as augmented signifier: slash marks on walls indicate spaces where wall runs and climbs will be effective. Over time, the player learns to move quickly through the environment, automatically identifying many traversable locations. During lulls in action, the augmented signifier helps the player to identify where to go next.

The purpose of the wall slashes is never described explicitly, nor do they match the game's narrative[4]. However, the correlation between slashed walls and wall running quickly becomes clear, as every runnable wall and climbable area is thusly demarked.

Burnout Paradise. Returning to the study of *Burnout Paradise* [Ward 2008], the game developer iterated the game design, post-release, to include more augmented signifiers [TheTeam@Criterion 2009]. Flashing lights on parts of the terrain signify affordances-as-signs. Red, pulsing billboards and flashing yellow caution gates afford crashing through and blue flashing barricades were placed in front of signifier ramps that afford signified super jumps (Figure 19). The bright illumination stands in sharp contrast to the background, making it easier to spot at a high (virtual) speed.

All of these destructive driving acts are rarely practiced in the real world, but in the *Burnout* world, engaging with them is the goal of play. The signifiers indicate

[4] Has another character traversed the same terrain in the past, using the same set of equipment, leaving the signifier traces behind?

where the player needs to incorporate game mechanics into their mental model of (virtual) driving.

3. Discussion

We have developed a theory of first-order affordances-as-signs and second-order augmented affordances-as-signs using examples of game design practice. The theory abstracts play experience to produce principles for game design. In its present form, the theory is primarily concerned with game mechanics for traversing terrain and interacting with game objects. Other mechanics, such as monitoring status, may not fit as neatly, because communication of status from game engine to players is more of a direct usability design pattern, as in tools. The theory can be directly extended to non-game design contexts, such as virtual reality, where spatial terrain traversal is also a primary interface metaphor.

Player and Unique Affordances. As Gibson notes [Gibson 1986], affordances exist uniquely between each animal and actionable objects (e.g., environment, other animal). This is no less true in games for the *player*[5]. Each player brings with her/him an existing set of mental models, a different experience of real and virtual worlds. Each player has unique motor and perception skills. Signifiers in one game may mean nothing to one player, and everything to another.

Embodied Understanding. The problem with structuring objects to make affordances visible is that even if they are visible, they may not be understandable to the player [Forlizzi and Battarbee 2004; Norman 2002]. The player, lacking the knowledge

[5]It is also trivially true across different games: a textured affordance-signifier in *Prince of Persia* will mean nothing to Mario. Still, lessons learned in one game are often applicable to others when mechanics are compatible.

and experience of the fictional character, may not realize the proper interpretation. Essential to the nature of affordance is the notion of *being-in-the-world* [Heidegger 1967]. Because the player is *not in-the-world*, a fictional character *is*, players may not understand the affordances of fictional objects.

An object, *ready-to-hand* [Heidegger 1967] for the avatar may be only *present-at-hand* for the player. Game avatars are adept at skillfully handling complex weapons and vehicles with which the player is unfamiliar. While the avatar "knows" exactly how to use an item, without thinking and without analysis, this is untrue for the player. A convolution, through p-actions [Gregersen and Grodal 2009], is necessary for the player to engage with the game mechanic supplied by the avatar-ready-to-hand object.

Returning to the red and white doors of *Mirror's Edge*, red doors afford kicking open while white doors are essentially decorative walls. In the real world, most doors do not afford kicking down and many afford opening through grasping and turning their handles.

Scaffolding and Tutorial. Augmented affordances can act as a form of scaffolding [Guzdial 1994], where the designer provides the augmentation temporarily for the purpose of teaching. In scaffolding, support is provided to the learner while she performs a new task. The student is taught how to perform the task, coached while performing it, and asked to articulate process. Many in-game tutorials take exactly this form, providing augmented affordances-as-signs at critical junctions when new mechanics are to be employed.

Automated tutorials may assist the user in troubleshooting failure to grasp the game mechanic. Such games (e.g., [Aonuma and Miyamoto 2006; Q-Games 2009]) detect when the user is having trouble progressing, and suggest the next course of action through augmented signifiers. This allows the player to incorporate the new mechanics into her or his mental model, constructing a rich set of behaviors for the player to later restore and remix. Once learned, the p-action sequences for activating the affordance-as-sign to engage the game mechanic attain embodied ready-to-hand status and function as restored behavior. At this point, depending on the game design, the augmented signifier may be discarded automatically, discarded by a player's choice, or, without such options, disregarded by the player. The range of mechanisms used for tutorial deactivation is an area for future research.

Dangers and Hackability of Augmented Signifiers. When augmented signifiers are retained, they may act as a meta-game signal to the player, indicating more than the game should reveal. In such cases, the *player* knows the mechanic is designed to come into play in a certain area, and *has not deduced this independently nor why*. Rather, s/he identifies the designer's intention that the ability be used.

Discovery is frequently a core mechanic in games (e.g., [Pardo et al. 2004; Ward 2008; Hellquist and Levine 2007; Aonuma and Miyamoto 2006; Tezuka and Miyamoto 1992; Guyot 2008]), so players' meta-gaming augmented signifiers as a means of learning may run counter to the game designer's intention. It may be interpreted as an acceptable side effect, a *design for hackability* [Galloway et al. 2004], or such avenues may be closed in design iteration by automatically removing the scaffolding when the player reaches a certain level of proficiency.

Another issue may arise when the augmented signifier becomes a nuisance to the player. An example is Twilight Princess [Aonuma and Miyamoto 2006], in which a secondary character nags the player when s/he runs off track. While the sarcastic commentary is helpful, it can become grating over time. This is analogous to Microsoft's Clippy character, who appears and talks to the user whenever it believes they are having difficulty in some versions of *Office*; the help is frequently unwanted. Designers must be aware of the affect of their augmented signifiers when creating them.

G. Design Principles for Engaging Cooperative Play

The core mechanics of team games differ from those of single-player games. Human-human interaction is essential, adding communication and coordination to the array of options already available. *Communication is a core mechanic.* Design implications for teaching team coordination, uncovered from the ethnographic field work (III.D, page 27), shape interface components that contribute to engagement in the core mechanics, grounding T$^{2}_{e}$C game design in practice. Non-mimetic simulation principles further guide game mechanic design (IV.F, page 45). Essential to practicing team coordination skills in the non-mimetic simulation game is the information distribution among roles and players, which requires players to engage in distributed cognition (II.C, page 11) by perceiving, integrating, transforming, and sharing information in order to make sense of the game environment.

The principles developed in this section are derived from a series of user studies with various versions of the T$^{2}_{e}$C game, which are described in more detail in Chapter VI. The principles were previously published in Toups Dugas et al. [“Game design principles,” 2009].

1. Information Distribution [Game Mechanics]

In addition to its role in teaching team coordination (III.D.1, page 15) and in non-mimetic simulation (IV.F.1, page 46), information distribution is an essential component of game interfaces supporting cooperation. Information is shared between players through their interfaces, often modulating visibility. It impacts the way they play the game, becoming a game mechanic itself.

Creating information distribution involves determining the information necessary to play the game and effectively sharing it between participants, so that each player has access to a different piece of the information picture. Information distribution is accomplished through varied participant roles (IV.F.2, page 47). Players must be reliant on each other to complete the game. Information distribution encourages engagement with the core mechanic of team communication. It requires modes of play in which participants in different roles gather and integrate different types of information in different representations.

2. Modulating Visibility

Despite the interaction design mantra of "making visible" [Gaver 1991; Norman 1999; Norman 2002], we find that making *invisible* can be just as important when designing cooperative game interfaces. As part of information distribution, some information is withheld from players and provided to others. Throughout the design process, we find that developing the proper balance of visible/invisible information in team members' interfaces is important, as it impacts their sources of information (the interface versus other players).

The timing of information is essential in the selection of whether information should be made visible or invisible. Slow- or un-changing information is a good candidate for making invisible. In games where communication is a core mechanic, team members must have something to communicate about. Creating deficiencies in one interface that are fulfilled by another player is one way of accomplishing this.

3. Information Timing

Part of creating information distribution and real-time stress (IV.F.3, page 48) involves rapid information change. Information in games may be ephemeral. The temporality of information must be considered when players need to communicate about it. Rapidly changing and short-lived information that must be acted upon quickly should not have to be communicated using slow channels, such as radio. Players will be unable to react in time and may perceive the game mechanics as unfair. The user interface must provide the right information at the right time [Do 1996].

4. Making Predictable

Mental models enable players to understand and manipulate the game in their heads (II.A, page 9). When mental models are shared, players are able to cooperate more effectively, because their mental models predict things in the same way (II.D.1, page 13). Game mechanics must be consistent [Salen and Zimmerman 2004f], they must provide some level of predictability, to enable mental model formation.

5. Communicable Representations

Representations in a game's interface impact the way players cognitively engage with the game. For players to engage in team processes of distributed cognition, they must be able to construct a shared understanding of the game system and be able to communicate about it. Essential to building effective interfaces for team coordination games is creating representations that are easily understood and referenced while under the real-time stress of game play. Information to be shared should be easy to communicate, in order to reduce communication overhead.

H. Background: Mixed Reality

The next stages of the present research project will construct a *mixed reality* non-mimetic simulation game for teaching team coordination. While this work presents the stationary T_e^2C game, it incorporates a simulation of the mixed reality environment as part of the game design.

Humans experience the world directly through the body [Dourish 2001; Lakoff and Johnson 1999]. The physicality of experience is lost in traditional desktop computing. Low-cost, lightweight sensors make it possible to blend digital and physical artifacts to create an embodied experience. Location-aware systems, which track the user's position, allow a computer to react to acting in the world. Mixed reality takes this one step further by enhancing the user's experience of the world with information, building a digital experience around real world action [Milgram and Kishino 1994]. Mixed reality games transform real-life action into game action.

Prior work has developed location-aware games and systems for the purposes of entertainment (e.g. [Björk et al. 2001; Cheok et al. 2004; Thomas et al. 2002]), exploration (e.g. [Ballagas et al. 2007; Bedwell et al. 2009; Benford et al. 2004]), social interaction (e.g. [Barkhuus et al. 2005; Björk et al. 2001; Brown et al. 2003; Cheok et al. 2004]), education (e.g. [Benford et al. 2005]), and tourism (e.g. [Brown et al. 2003; Feiner et al. 1997]). These projects have raised a variety of issues that arise from building location aware systems, including the need for seamful design [Barkhuus et al. 2005; Bell et al. 2006; Benford et al. 2006; Chalmers and Galani 2004], ergonomics of wearable computing systems [Cheok et al. 2004; Feiner et al. 1997; Thomas et al. 2002], and the ways that technology inhibits and promotes social interaction of participants [Barkhuus et al. 2005; Björk et al. 2001; Chalmers and Galani 2004; Mansley et al. 2004].

1. Seamful Design

Computation on mobile devices creates the need for *seamful design* [Barkhuus et al. 2005; Bell et al. 2006; Benford et al. 2006; Chalmers and Galani 2004]. Sensors and networks have a level of inaccuracy or unreliability, for example, global positioning system sensors (GPS) are only accurate to within a few meters at best [Hightower and Borriello 2001; Zogg 2007] and WiFi signal strength drops off over distance and across obstacles [Borriello et al. 2005]. These problems are seams in an otherwise smooth experience, and impact the ways in which mobile computing can provide services to the user.

Seamful design moves beyond exposing these to the user and uses seams as an aspect of design. In games, for example, they can be used to enhance the experience, providing strategic opportunities to players [Benford et al. 2006]. Seager et al. have shown that indicating to users their possible location, based on the inaccuracy of positioning sensor data, aids users in understanding the nature of the sensor [Seager and Fraser 2007]. Barkhuus et al. suggest that color-coded patches on a map enable an understanding of the level of wireless network saturation, affecting player strategy [Barkhuus et al. 2005]. *Can You See Me Now?* pits live location-tracked players against Internet player-controlled avatars in a game of tag in an urban setting, utilizing seamful design to expose technology failures and allow players to use them to their advantage [Benford et al. 2006]. *Uncle Roy All Around You*, provides a location-based experience without a location sensor by using self-reported positioning [Benford et al. 2004]. In *Savannah*, players experienced difficulty engaging in collaborative action due to the inaccuracy of the GPS sensor and inconsistencies between each players' device [Benford et al. 2005].

2. Ergonomics

Several mixed reality projects (e.g. [Chalmers and Galani 2004; Feiner et al. 1997; Thomas et al. 2002]), showcase issues relating to the ergonomics of wearable computers. These systems were bulky and heavy, requiring participants to wear backpacks carrying laptop computers, boom antennas for sensors, and large power packs. Advances in miniaturization make this less of a problem. *Real Tournament* is an example of an ergonomic design: players teaming up to hunt down virtual enemies with toy guns that are equipped with location-sensing and communication gear [Mitchell et al. 2003].

3. Human-Human Interaction

Technological and gameplay issues can impact the way that participants socialize within a mixed reality system. The game *Pirates!* was specifically created to encourage social interaction between players [Björk et al. 2001]. Participants carried personal digital assistants (PDAs) that simulated a pirate ship, and moved through an environment to move the ship. Players were disinclined to socialize with each other, because the game only allowed confrontations, which would put one of the two players out of the game. Other games used full binocular head mounted displays (HMDs), which inhibited social interaction [Chalmers and Galani 2004]. Barkhuus et al. noted that participants often did not notice each other while playing, because they were sometimes too busy monitoring the game on a handheld device; however, game actions that required collaboration between participants encouraged them to work together [2005]. Thomas et al. found that players cooperated on a team better if only a few players have access to information about the game; it became necessary for them to share information when there were fewer devices in play [2002]; this is an example of effective information distribution that gives rise to player roles.

I. Conclusion

This chapter presented relevant background on game design for the present T^2_eC game. We construct T^2_eC in terms of operational elements, functional semantics, and representations.

Operational elements incorporate the human-human aspects of the team game, including communication modalities, such as those from fire emergency response work. They address the need for seamful design that accounts for issues that cannot be controlled within the game environment. Roles will be constructed for players to engage in; information is distributed through the varied representations in the roles' interfaces. Functional semantics must take into account that aspects of the interplay between terrain and avatars will be created by the real-world environment in which the mixed reality version of the T^2_eC game is played. Functional semantics will be used to describe the entities within the game and the terrain within which they operate. The speed at which entities change impacts how they can be rendered visible or invisible within the game interfaces of the player roles. The terrain, again, incorporates seamful design from mixed reality. Representations are how information is distributed between players, and the way in which affordances-as-signs are augmented within the game.

CHAPTER VI

DESIGN OF A NON-MIMETIC SIMULATION TEACHING TEAM COORDINATION GAME ($\mathrm{T}^2_\mathrm{e}\mathrm{C}$)

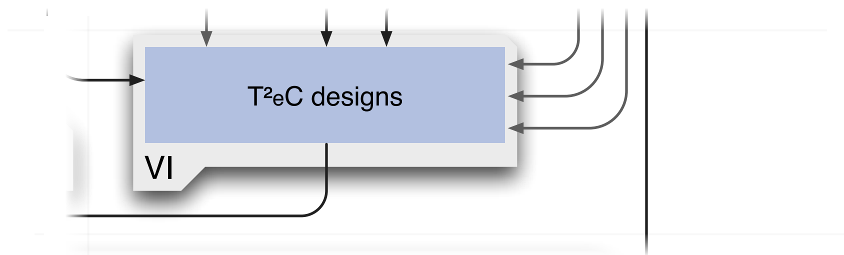


Fig. 23.: Component of the concept map (Figure 1) for design of $\mathrm{T}^2_\mathrm{e}\mathrm{C}$, based on a number of concepts from earlier chapters.

One of the most essential aspects of fire emergency response practice is sharing information at an incident. Firefighters in the fireground have to act as the eyes and ears of the incident commander (IC) outside. The IC must make sense of the information from the firefighters and combine it with a contextualized overview that includes observing the fireground from a distance and consulting and maintaining information artifacts. Situation awareness enables the IC to formulate the best strategy and communicate orders for firefighters to accomplish it. Communication in fire emergency response is rich and multi-way.

In the Teaching Team Coordination non-mimetic simulation game ($\mathrm{T}^2_\mathrm{e}\mathrm{C}$), players take on roles that reflect FER practice in terms of information availability and action opportunities. Seekers take an active role, searching and avoiding danger in a virtual reality, while a coordinator observes the virtual reality and communicates with them (as in the figure on page 88). The seekers collect goals and avoid threats to improve their team's score.

Just as communication is essential between the firefighters and IC and among firefighters in work practice, communication between coordinator and seekers and among the seekers is a core mechanic of the non-mimetic simulation game. Players need to share information about goals, walls, bases, threats, and each other to coordinate their actions, form shared mental models, and engage in distributed cognition. Communication is stimulated by information distribution. Representations must be designed to support shared mental models.

Essential pieces of an emerging information picture are distributed between players and across roles (IV.F.2, page 47), creating interdependency (IV.F.1, page 46). The pieces vary in perspective and representation, requiring players to engage in processes of distributed cognition (II.C, page 11) to share information and understand the game. Players communicate with each other either face-to-face or over radio, depending on role and experimental condition, creating opportunities for them to mix communication modalities (III.D.2, page 30). Figure 23 shows how the T^2_eC design is dependent on a number of concepts discussed in earlier chapters.

This chapter presents version 2.0 of T^2_eC, as constructed through iterative design. Version 2.0 was used for the T^2_eC with FERs user study, presented in Chapter IX (page 156). We develop the core mechanics of T^2_eC, considering the operational elements, functional semantics, and representations (V.E, page 60). We then describe affordances-as-signs (V.C, page 53) in T^2_eC. The end of this chapter discusses the iterations that led to version 2.0, based on data collected from pilot studies and the non-FER study presented in Chapter VIII (page 143).

A. Operational Elements

The operational elements (V.E.1, page 60) of T_e^2C consist of the roles of players within a human team, the communication modalities between the players, and considerations for seamful design (anticipating the mixed reality version of T_e^2C).

1. Player Roles

Players take on alternate roles with different capabilities and information access that reflect FER practice. The human team consists of four players: three seekers and one coordinator. *Seeker* players move an avatar in the virtual reality terrain, searching for goals while avoiding threats (Figure 24). A *coordinator* observes the virtual world with limited detail. S/he communicates with the seekers to direct them and acquire detailed information.

a. Seeker

A seeker is the combination of a *seeker player* with an *avatar* in the virtual world. Seekers have agency in the virtual world through their avatars. They are able to interact with game entities and terrain. Seeker players move their avatars in the virtual world using the keyboard. They have a limited, local perspective that provides rich detail about the game at their location (as in the figure on page 96). Seekers are like firefighters in FER work practice (III.B.1, page 21). They accomplish tasks in dangerous environments and feed information back to the coordinator.

b. Coordinator

The coordinator observes and communicates, like an IC (III.B.1.a, page 22). The coordinator can only interact with the virtual world through the seekers by communicating with them. The coordinator's view lacks the detail of the seekers', providing an overview that shows the locations of all online seekers (demonstrated by the figure on page 97).

2. Communication

Communication is a core mechanic (V.D.2, page 57). Coordination around goals, collaborative navigation, and threat avoidance all require communication. An essential design goal is to encourage participants to engage in two-way communication, like the kind of communication found in fire emergency response.

To support the design principle of mixing communication modalities (III.D.2, page 30), T^2_eC may be played in one of two team configuration conditions that impact how team members are able to communicate with each other. In the *co-located condition*, all of the seeker players are seated around a table with individual computers in front of them, while the coordinator is isolated. Seeker players can communicate with each other by speaking face-to-face, but must use the radio to contact the coordinator. In the *distributed condition*, all players are isolated and must use the radio to speak.

Face-to-face communication is fast and easily disambiguated. Participants can use expression, gesture, and short verbalizations to communicate rapidly. In some cases (seeker-coordinator communication and seeker-seeker in the distributed condition), players need to use a half-duplex radio, like those used in fire emergency response. This component of the design is mimetic, using equipment found in work practice. The qualities of the radio that must be overcome in practice are unique. The radio only allows one participant to speak at a time. Radios are controlled using push-to-talk (PTT) and are activated in the game by holding down a key. The radios used for T^2_eC, like those used by FERs, have a delay between when a radio begins transmitting and when another begins receiving.

3. Seamful Design

T^2_eC was designed anticipating the seams in a mixed reality environment in which location and/or data services are likely to fail at times (V.H.1, page 80). Regions of simulated connectivity are a part of the game terrain. Players' avatars may go *offline* based on the simulated connectivity. Handling of these cases is built into the functional semantics. When an avatar is offline, s/he is unable to see or collect goals. Offline seekers cannot be attacked by threats and cannot be seen by the coordinator.

B. Functional Semantics

Functional semantics (V.E.2, page 60) incorporate entities and terrain with their interrelationships. Figure 24 describes the functional semantics.

1. Entities

A set of entities, with complex relationships, interact in T^2_eC (Figure 24). Seeker players drive *avatars* in the virtual world to find *goals* and avoid *threats*. To win the game and earn score, players collect goals. Threats move through the game environment, defending the goals from seekers by chasing them down to take them out of play.

a. Seeker Avatars

Seeker avatars transition through a set of bi-variate states: safe / in / out and online / offline. Figure 25 shows the representations for each state and the functional semantics that determine state, which are detailed in this section.

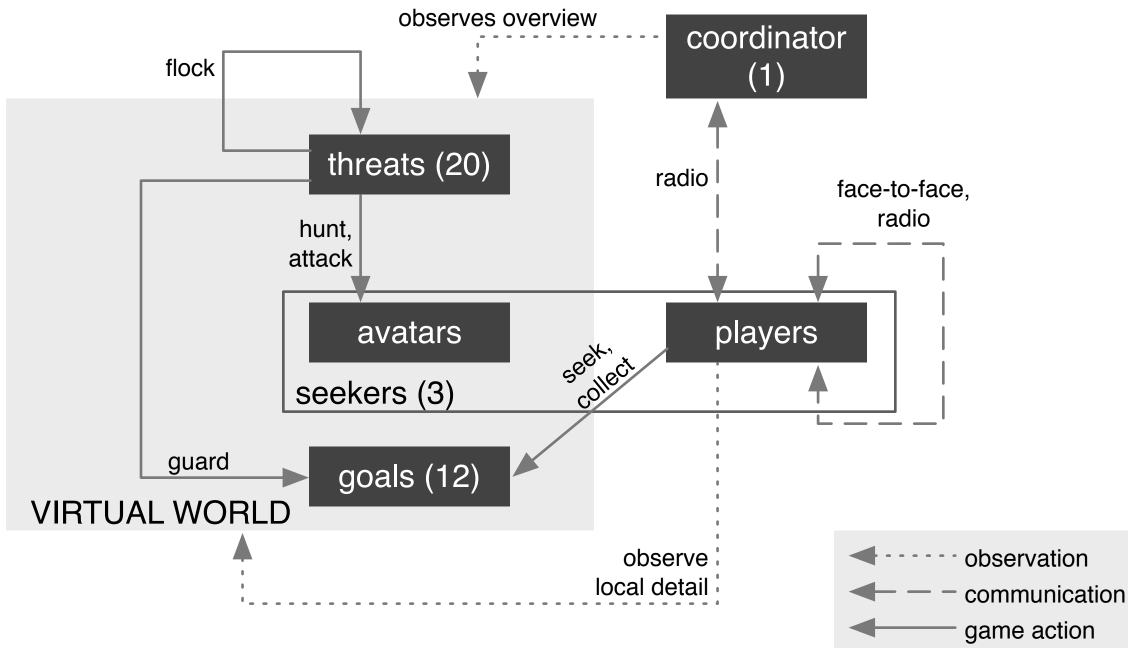


Fig. 24.: The operational elements and functional semantics of T^2_eC. Functional semantics are entities and their game mechanics: observation, communication, and action.

Each seeker has a limited amount of hit points (HP) which are reduced each time the seeker comes into contact with a threat[1]. As long as HP are greater than zero, the seeker is *in*, and able to participate in the game. Once an avatar has no more HP, the seeker avatar's state changes to *out*. Certain parts of the terrain contain bases, where seekers are *safe*. While safe, a seeker regenerates HP and cannot be attacked.

T^2_eC was designed anticipating the seams in a mixed reality environment (V.H.1, page 80). Two signal levels are simulated, one for location status (global positioning sensor, GPS) and one for data access status (wireless network, WiFi). Avatars go *offline* based on the avatar's simulated connectivity; if either signal drops to zero, the seeker is offline. When a seeker is offline, s/he is unable to see or collect goals. Offline seekers cannot be attacked by threats and cannot be seen by the coordinator.

[1] "Coming into contact" with a threat is the same as "being attacked by" a threat.

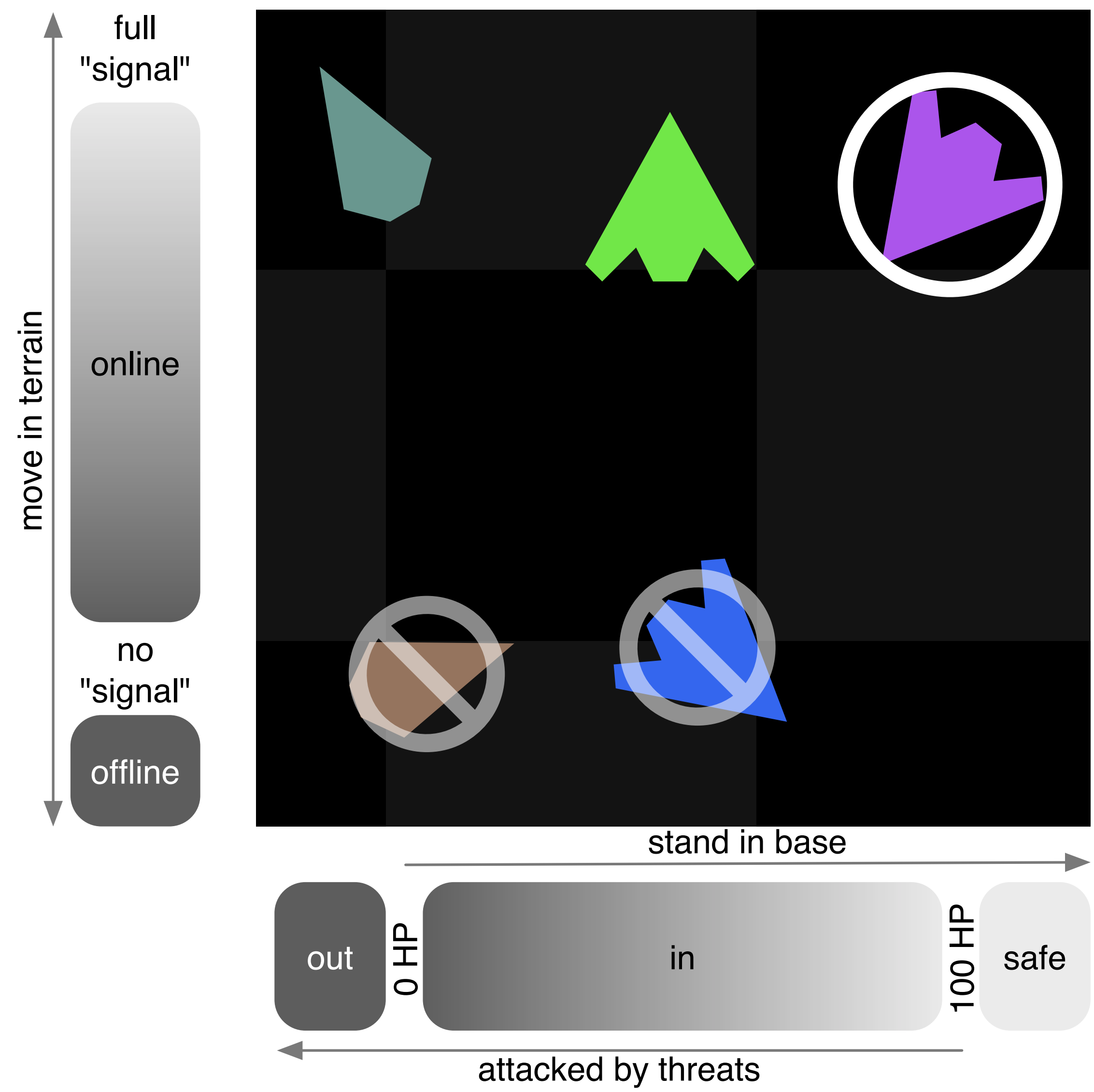


Fig. 25.: Bi-variate range of seeker avatar states in T^2_eC. X-axis range is safe / in / out; in / out are determined by number of hit points (HP), while safe is determined by whether or not the seeker is located in a base. Standing in a base restores HP, while being attacked by threats reduces HP. Y-axis shows combined level of simulated location and/or data network signal. If either simulated signal drops to zero, the seeker's avatar goes offline. Offline seekers cannot be safe, because they are not able to detect the location of a base.

Seeker avatars can move at different speeds: walk, run, and sneak. Walking is the default mode for seekers and is slower than the speed of threats. Running allows faster movement, but may only be performed for a limited time before the avatar must recharge *stamina*. While seekers run faster than threats, running draws attention. Sneaking is very slow movement that does not draw attention from threats. Seekers can recharge stamina by sneaking (slow recharge rate) or standing still (fast recharge rate).

b. Threats

Threats are automated computer-controlled opponents that are a source of real-time stress for the human players. Threats guard goals from seekers by chasing and attacking them. Otherwise, threats exhibit three ambient behavior modes: generic flocking, guarding, and patrolling. Each ambient behavior is overridden by chase behavior when a threat *spots* a seeker.

Threats chase and attack any seeker they spot. They spot avatars at different distances, based on speed: faster seekers are spotted from farther away. A seeker collecting a goal is spotted by threats as if that seeker were running. Seekers are only pursued when the nearby threats outnumber the nearby seekers[2]. Threats that attack seekers (chase and catch up to them) take seekers out of the game by reducing their HP.

As part of the functional semantics of threats, we use physically based modeling, computer simulations of Newtonian physics [Baraff and Witkin 1999]. A physically based modeling engine drives and constrains behavior of threats in reaction to the terrain. Particles [Reeves 1983] are used as a model for threats, giving them masses, velocities, and the ability to accelerate. Flocking [Reynolds 1987] and particle choreography [Sims 1990] techniques, combined with simple artificial intelligence, create

[2]Because games include a maximum of three seekers and a minimum of 20 threats, threats frequently outnumber the seekers.

interesting and challenging behaviors for computer-controlled opponents that encourage players to work together [Toups Dugas et al., "Game design principles," 2009]. The functional semantics of threat flocking around goals and walls are described later in this chapter.

Generic flocking threats move in a straight line until they find another set of threats with which to flock. Guarding threats select a goal and stay near it. They flock with other nearby threats unless they move outside the area around the goal, in which case they turn back. Once a goal is collected, threats switch to another un-collected goal. Patrolling threats move from one un-collected goal to another, making a circuit around the map.

c. Goals

The objective of play in T^2_eC is to collect all of the goals before time runs out. Goals are hidden throughout the game terrain and come in three varieties. A basic goal requires a single seeker to collect and is not valuable in terms of score. Cooperative goals require two or three seekers to collect and are worth more points (three-seeker cooperative goals are the most valuable). Seekers can work in parallel on non-cooperative goals, speeding the process. The table on page 94 summarizes the score values of goals and illustrates their representations.

Seekers collect goals by standing on or near them; the seeker must stand still for a period of time. Seekers can only collect goals if they are safe / in and online. Collecting a goal attracts the attention of nearby threats, creating danger and inducing real-time stress.

Goals are incorporated into the flocking choreography of threats. Goals push threats away and to one side, causing a threat that approaches to smoothly orbit around the goal. This has the effect of splitting up large groups of flocking threats, helping to keep them distributed around the map. A collected goal ceases to have this effect on threats.

Fig. 26.: Sample terrain used in T_e^2C with FERs study. Highlighted red regions indicate areas where seekers are online, blue regions are walls, orange circles are bases (bases are online, but are not highlighted for visibility). Goals and threats are procedurally placed. Walls were placed using a Google Earth [Google 2010] map of the south side dorms on the Texas A&M University campus. This map and procedural placement seed that resulted in this layout of threats and goals were used in the T_e^2C with FERs study (Chapter IX).

2. Terrain

Game terrain is derived from existing campus maps; it includes the seamful elements described above, walls, and bases. Figure 26 shows a detailed sample of terrain.

The seamful elements of the game terrain create sections of the map where seeker avatars are online or offline, mediating how they can participate in play. Seamful elements can only be detected at the current location (through WiFi and GPS readouts on the seeker and coordinator interfaces, such as those in Figures 27 and 28). The information does not persist.

Walls are impassible for seekers, requiring that players circumnavigate them. Threats are unaffected by most walls; they may freely pass through. The edges of the terrain are surrounded by walls, preventing seekers (and threats) from leaving the play area. Other walls are based on a portion of the Texas A&M University campus: each building in the simulated portion of campus is a wall.

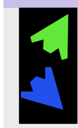
Bases are locations where seekers can quickly restore lost hit points. While in a base, a seeker is *safe*. A safe seeker cannot be attacked by threats and is also invisible to them (i.e. excluded from the flocking algorithm). Safe status persists briefly after leaving the base, to allow the seeker time to act. Threat flocking is impacted by bases in the same way that it is impacted by goals, preventing threats from entering a base.

Bases are visible to the coordinator, but not the seekers, as a part of information distribution. They can be detected by a seeker only when safe, because the seeker's interface indicates the safe status (as demonstrated in the figure on page 96).

3. Time and Scoring

To create real-time stress, games are timed. Players have set amount of time to collect all of the goals in the terrain. If players collect all of the goals before time runs out,

Table III.: Scoring rubric for T^2_eC, showing representations of entities and seeker states.

	entity (state)	summary	score rate
	seeker (in; online)	HP $>$ 0; *can* collect goals; *tracked* in coordinator view	+3.3 points / second / seeker in state
	seeker (*safe*; in; online)	restoring HP; *can* collect goals; immune to threats; *tracked* in coordinator view	+0 points / second / seeker in state
	seeker (*offline*; in)	*cannot* collect goals; immune to threats; *not tracked* in coordinator view	+0 points / second / seeker in state
	seeker (*out*)	HP = 0; *cannot* collect goals; immune to threats; *tracked* in coordinator view (while online)	−25 points / out
	one-seeker goal		+100 / collected
	two-seeker goal		+400 / collected
	three-seeker goal		+900 / collected

the game ends prematurely, giving the players bonus score. Table III outlines the scoring rubric for play.

Score provides motivation and is a gauge of performance (V.D.3, page 58). We provide a score for each team, but not individual team members, to discourage competition within the team. Players primarily gain score through collecting goals. Basic goals (requiring one seeker) contribute the least to the score, while cooperative goals (requiring two or three seekers) are worth considerably more. The functions for computing the value of collected goals is described below, where $numReqSkrs$ is the number of seekers required to collect the goal and $pointValue$ is the number of points collecting the goal is worth:

$$pointValue = (numReqSkrs^2) * 100 \tag{6.1}$$

Seekers additionally contribute to score by staying in and in danger (online and not safe). As long as a seeker is either out, offline, or safe, they are not contributing to the team score. The bonus for completing the game early is computed as if all seekers were in and in danger for the remaining (unused) time. Finally, seekers are penalized if they are captured by threats.

C. Representations [Interface]

Representations (V.E.3, page 61) compose the interface of T_e^2C. Representations are an essential component in creating information distribution (III.D.1, page 15; IV.F.1, page 46; V.G.1, page 76). Information is distributed among the seekers and the coordinator: seekers have detailed, local information, while the coordinator has a broad overview with limited detail. Interdependencies exist between roles (IV.F.2, page 47), creating a need for players to communicate in order to find goals, navigate, and stay safe.

1. Seeker

Each seeker observes a local view in a high level of detail, limited to an arc in front of their avatar. Seekers can see their local space: walls, threats, goals, and other seekers

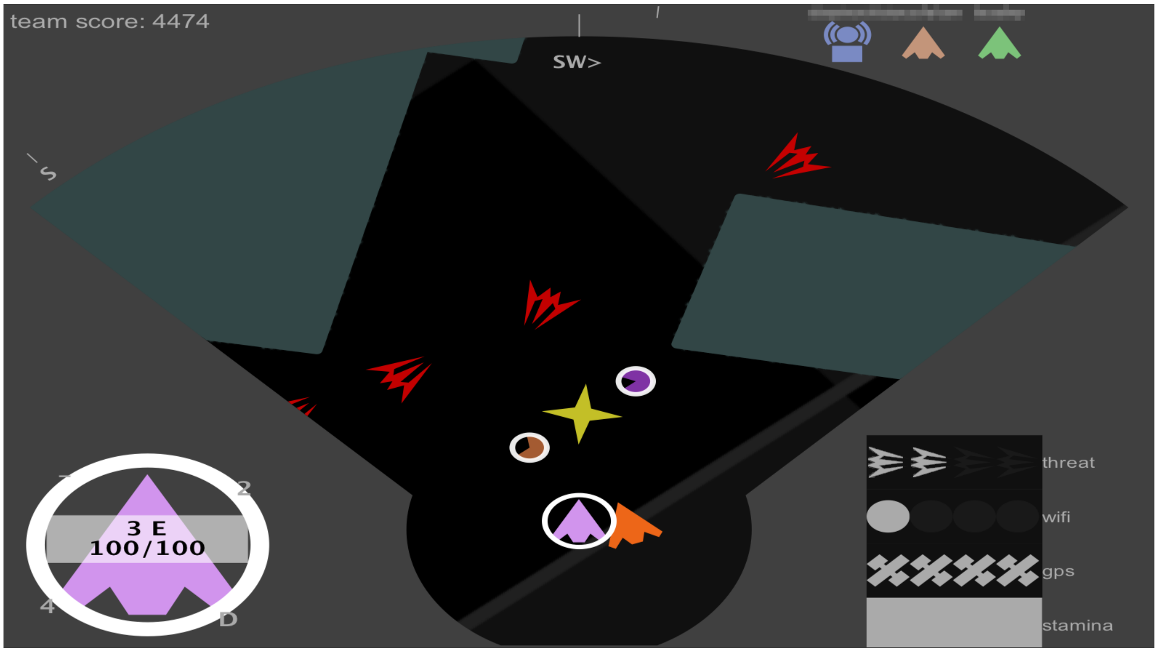


Fig. 27.: Screenshot of seeker view in T^2_eC (Team 5, session 4, game 8, 5'15"). The purple and orange players collect a two-player cooperative goal while standing inside a base. Image taken from T^2_eC with FERs study (Chapter IX, page 156); same moment as the coordinator's view in Figure 28. The purple player knows s/he is in a base, because the white shield around the avatar indicates safe status; the purple player cannot detect any information about the orange player's status. Threats are near the base. Graphs in the lower right show that at least one threat is getting close, weak simulated WiFi, strong simulated GPS, and full simulated stamina. The visualization in the lower left shows that the avatar is located in terrain region (3, E), the direction of other regions are shown on the periphery. It also indicates the seeker has 100 out of possible 100 HP. Team score is indicated in the upper left. Other team members' colors and names (blurred for anonymity) are shown in the upper right.

are visible to them. While each seeker can see the others, s/he cannot see the other seekers' statuses (safe / in / out, online / offline). To learn of another seeker's status, that seeker must be asked, encouraging communication. Seekers cannot see bases, but when they enter a base, it is visualized as part of their avatar's representation. Figure 27 shows the seeker interface in play.

The seeker head-up display (HUD), arranged around the viewing arc, includes

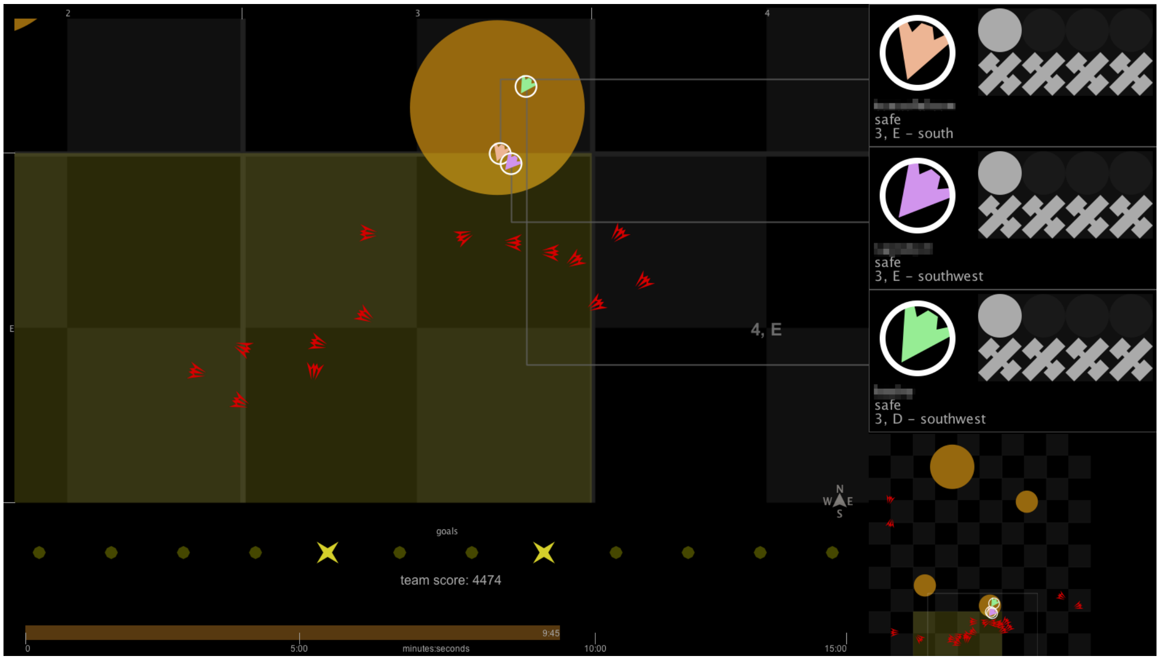


Fig. 28.: Screenshot of coordinator view in T^2_eC (Team 5, session 4, game 8, 5'15"). The purple and orange players collect a two-player cooperative goal while standing inside a base. Image taken from T^2_eC with FERs study (Chapter IX, page 156); same moment as the seeker's view in Figure 27. The main view shows the terrain with all entities in it; highlighted yellow regions contain goals. Walls (visible in the seeker interface) cannot be seen. The right column shows status information for each seeker; a mini-map at the bottom shows all of the terrain. Below the main view is the list of goals (two remain un-collected) and the time remaining in bar graph and text form (the team has more than half the time remaining: 9'45").

information about location and orientation, distance to nearby threats, HP remaining, and the colors and names of teammates.

The number of seekers required for a goal is visualized on the goal (Figures 27, 29, 32). Goals have collection circles around them that indicate the number of seekers to required to collect that particular goal. As a seeker collects a goal, a collection circle fills up with that seeker avatar's color to indicate that the seeker is successfully collecting the goal. If any seeker stops collecting a goal before all circles are filled, the group must start again. This visual feedback eliminates confusion about which seekers are actively collecting a goal, a problem discovered in early designs (VI.D.2.c, page 111).

Sonifications are used in the seeker interface. Sounds indicate when HP are low and when the seeker goes out. A different tone is used to convey when a seeker has transitioned from offline to online and vice versa. A radio PTT tone plays for one second to help prevent the player from speaking before the radio has connected (Figure 33; VI.D.2.d, page 112).

Sonifications are played through each individual player's headset. In addition, if the player is transmitting radio, the sounds appear in the background. This supports overhearing through the radio, so that one player can gain situational awareness from the background sounds of another's transmission.

2. Coordinator

The low-detail coordinator overview contrasts the detailed, local view of the seekers. The coordinator can see the location of all threats and seekers on the map, as well as the location of all bases.

Goal locations are obfuscated to encourage two-way communication between coordinator and seekers. Goals appear as highlighted regions of the terrain, which must be searched by seekers to discover exact locations and the number of necessary seekers (Figure 30; VI.D.1.a, page 103). Walls are likewise invisible, meaning the coordinator is reliant on the seekers to do their own wayfinding and/or report on local terrain. The coordinator is the only player aware of the time remaining in the game and the number of collected / un-collected goals.

3. Augmented Affordances-as-Signs

We incorporate augmented affordances-as-signs into the design of $\mathrm{T}^2_e\mathrm{C}$, supporting the development of mental models for play. A tutorial mode, use of color in the game interfaces, the collection rings on goals, and sonifications are all forms of augmented affordances-as-signs.

A tutorial mode, introduced in later user studies to help players understand how to play, makes extensive use of augmented affordances-as-signs. As players move avatars in the virtual world in the tutorial game, a running text monologue describes the various interface components and controls, helping players form the mental models needed for play. In the tutorial interface, *all* players take on the role of seeker, but can see the coordinator interface simultaneously. The monologue calls attention to the way information is distributed between the two roles.

Color indicates how a player may interact with the environment through the *collection arc mechanic* (Figure 29). A seeker's avatar can only collect goals that are located in a narrow arc in front of it, and only while safe / in and online. As long as the conditions are met, an arc-shaped region in front of the avatar, which supports interaction, is signified by white illumination, contrasting with the dark background.

Cooperative goals require aligned positioning of multiple avatars to collect, engaging players in teamwork. *Goal rings* indicate how many team members are required to collect the goal (Table III; Figures 27, 29, 32). These augmented signifiers fill in with the colors of the players involved in the collection. They signify whether it is necessary for a player to collect a goal, and when it has been fully collected.

Simulated GPS and WiFi signal strengths are directly signified to the player through a graph in the interface. However, because the classification of online or offline is bi-variate, this could be complex for the player. To aid the player, we use a

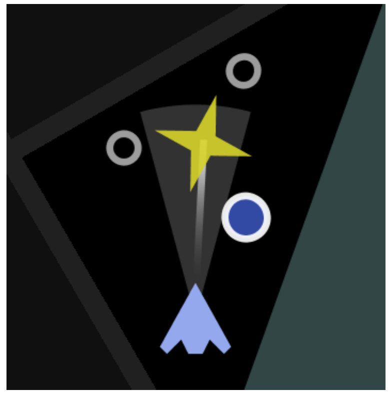


Fig. 29.: Screenshot of a single seeker attempting to collect a three-seeker cooperative goal, showing the collection arc mechanic and goal ring augmented affordance-assigns. The highlighted region in front of the seeker's avatar affords collecting goals. This particular goal requires three seekers to collect, because it has three rings.

sonification to indicate when the player has changed state. The augmented signifier sound indicates when a space in the terrain affords safety or danger.

D. Design Iterations

The design of $\mathrm{T}^2_e\mathrm{C}$ was iterated considerably, incorporating observations and feedback from users. This chapter has so far discussed version 2.0, as used for the $\mathrm{T}^2_e\mathrm{C}$ with FERs user study (Chapter IX, page 156). This section will address the design iterations that led to the final form: we start with changes made to a series of functional prototypes used in pilot studies, move to version 1.0 used for $\mathrm{T}^2_e\mathrm{C}$ with non-FERs (Chapter VIII, page 143), and conclude with the changes that led to the final version. Many of these findings were originally presented in Toups Dugas et al. ["Game design principles," 2009]. Table IV briefly outlines the changes discussed in this section along with the studies that led to the changes.

The data that inform the core mechanics and interface design principles come from a series of studies and iterative designs that span four years. Early pilot studies

Table IV.: Summary of evaluations and resulting changes to T^2_eC. Each session is a set of two games (one with seekers co-located, the other distributed), played by four participants. Resulting changes appear in the version that follows. Prototypes changed rapidly. Version 1.0 was used for the T^2_eC with non-FERs user study (Chapter VIII, page 143). Version 2.0 incorporates all resulting changes and is used in the FER user study (Chapter IX, page 156).

version	evaluation	sessions	participants	resulting changes
prototypes	early pilot studies	12	8	cooperative goal mechanic; HP mechanic; block-and-grid coordinates
prototypes	later pilot studies	3	12	making goals invisible in the coordinator interface; discernible patterns for threats; add scoring; introduce tutorial
1.0	T^2_eC with non-FERs	36	36	goal collection status indicator; PTT status indicator; update scoring rubric
1.0	FER expert participatory design	4	4	making threats visible to seekers; seeker location context indicator; PTT status audio
2.0	T^2_eC with FERs	28	28	–

rapidly iterated the game design, with later pilot studies continuing refinement. The T^2_eC with non-FERs study, in which 36 unique participants played eight games each over the course of four weeks followed. Integrating feedback from the T^2_eC with non-FERs study, we conducted a participatory design phase, in which we played the game with an expert FER who has 30 years of experience.

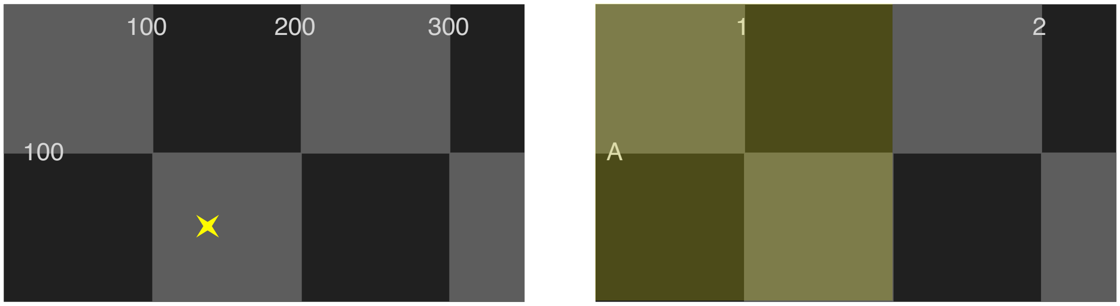
In all of the user studies, participants play the game on a set of laptop computers with the ability to communicate remotely, activated by key press (PTT). In the early pilot studies, players communicated using voice over internet protocol (VoIP) with wireless headsets. VoIP became problematic due to voice lag and an inability to record the players' utterances. In later games, hardware was developed to route handheld radio voice through the computer while recording it. Seeker players use the keyboard to move their avatars, while the coordinator uses a mouse and keyboard to explore and manipulate the coordinator map view.

In the early pilot studies, three conditions were used: all players sitting around a room and able to speak to each other freely; coordinator in a separate room, reachable only by VoIP with seekers co-located; and all players in separate rooms, communicating by VoIP.

In subsequent studies, games were played in one of two conditions, with both conditions forming a single session: seekers co-located with coordinator separate; and all players isolated. In the seekers co-located condition, seekers are seated around a table and able to speak to one another face-to-face. They may use the radio to contact the coordinator. In the other configuration, all players must use the radio to communicate. The configurations reflect the design principle of mixing communication modalities (III.D.2, page 30).

In the non-FER and FER user studies, participants play a set of four sessions (eight games) on the same team over the course of a month. These sustained user studies introduce a tutorial game in which all players are co-located for the first session that explains how to play and indicates the information distribution between the coordinator and seekers. The role of coordinator rotates each session, so all players have the opportunity to experience the role. This decision was made at the direction of our FER expert, as each student in fire school has the opportunity to experience IC roles (III.A.1, page 18).

The design process is iterative, incorporating feedback and observations from previous game versions into the new. Newer designs improve in their ability to encourage



(a.) precise goal locations and coordinates (prototypes); the goal is located near (150, 150)

(b.) fuzzy goal locations and block and grid coordinates (version 1.0, 2.0); a goal is located somewhere in the region A, 1

Fig. 30.: Goals and coordinate systems in prototype and version 1.0, 2.0 T^2_eC coordinator interfaces. Originally, goal locations are clearly marked and coordinates are specified in decimal numbers. This interface reduces communication and diminishes the role of seekers in the team. In the current version, information is made invisible in the coordinator's interface and moved to the seeker interface. Yellow highlighted regions contain goals; a block and grid coordinate system replaces the decimal system.

participants to cooperate and engage team coordination skills.

1. *Prototypes*

In early game designs, the seekers did not communicate or collaborate; there was no need to. There were no cooperative goals and the coordinator knew the exact location of every goal and exactly how many players were needed to collect each (a single seeker). Players had difficulty understanding how the radio worked, and thus shunned its use. This did not reflect fire emergency response practice. Further, the game was frustrating, because seekers could not avoid threats.

a. Goals and Visibility

Originally, the exact location of each goal was visible in the coordinator's view (Figure 30, a.). The result, observed in a series of pilot studies, was that the coordinator and seekers did not need to collaborate to gather information. The coordinator had access to all information necessary, and could share with the team. Typically, this took the form of top-down orders, directing seekers exactly where to go.

The use of basic single-seeker goals meant that the team did not need to come together to accomplish cooperative tasks. Each seeker could be sent on an individual mission by the coordinator. The most effective strategies involved the coordinator simply directing each seeker individually, monitoring their status, then re-directing them when they were finished.

Based on the need for seekers to engage in gathering information about the environment as part of distributed cognition, we altered how information about goals is distributed among team members. Instead of allowing the coordinator to see the exact location of each goal, goal locations are made fuzzy (Figure 28; Figure 30, b.). The coordinator can only see map *regions* that contain goals, so that it is possible to direct the seekers in general, but not tell them exactly what to do. To balance information distribution and stimulate communication, we made information *invisible* in the coordinator's interface.

The goal mechanic design was iterated, along with the game's interfaces. Originally, all goals required only a single seeker to collect. We added cooperative goals (Table III). Through further iterations, a piece of information was removed from the coordinator's interface: the number of seekers required to collect a goal. This instance of making invisible again drives initiative from the seekers in the distributed cognition process.

To further distribute information among team members, the seekers have a detailed view when they get near a goal. They are able to see how many players are necessary to collect the goal (Figure 27; Figure 29: the goal requires three seekers, as indicated by the three white rings around it). This information is hidden from the coordinator (Figure 28; Figure 30, b.), who may need to assist the seekers in grouping together. In the sustained non-FER and FER student user studies, this led to players developing strategies for scouting out goals. The modifications are examples of information distribution (V.G.1, page 76) and modulating visibility (V.G.2, page 77). In this instance, we *make information visible.*

b. Communication Difficulty

Location was initially difficult to communicate within the team because locations were given as a pair of detailed coordinates in the xy-plane (e.g. 123.83, 475.20; Figure 30, a.). As seekers moved, the numbers changed rapidly. We observed the coordinator directing seekers using the blocks drawn on the background of the map ("move two blocks east, one block north") instead of the coordinates.

Based on this observation and the need for locations to be easily referenced, we introduced a block-and-grid interface. We divided the terrain into five columns and five rows. Each column is numbered (1–5) and each row is lettered (A–E) so that coordinates consist of letter, number combinations (Figure 30, b.). In later user studies, this was observed to improve participants' ability to communicate location with each other, as the letter-number combinations were used extensively. Further, in the participatory design sessions, the FER expert commented that the block-and-grid coordinate system was similar to the one used by wildland firefighters to locate fires in rural areas. The block-and-grid coordinate system makes it easier for players to communicate about location in a way that is meaningful and satisfices[3] [Simon 1996] for the situation; it is an example of using communicable representations (V.G.5, page 78).

[3]Simon [1996] combines the terms "satisfy" and "suffice" into "satisfice" to describe how humans make decisions about tradeoffs. While it is frequently impossible to make a truly optimum choice (satisfy), it is also not necessary for decisions to be optimal (suffice).

c. Real-Time Stress from Threats

Threats provide real-time stress (IV.F.3, page 48). One problem with early game designs is that threats were too difficult to avoid. Seekers were out when a threat came into contact with them. Threats were faster than seekers, and once they targeted a seeker, a threat would pursue until the seeker was out.

From the early pilot studies, we addressed the problem of threats being too dangerous. We introduced the HP mechanic. This allowed seekers to sustain several hits from a threat, making it easier to stay in the game. This iteration enabled us to add more interesting behaviors to threats, as we could include more threats in each game. After the late pilot studies, we applied particle physics to the threats, and used flocking and particle choreography techniques to give them behaviors. This creates varied challenges for the seekers to overcome, and assists players in predicting what threats will do, increasing the player's ability to predict future outcomes using mental models.

Threat behaviors were introduced to make the threats predictable (V.G.4, page 78). Flocks are clear as the threats move around the playing field, although the patterns that the flocks follow may not be. Despite the complexity, players know that threats move together, and that they will react to seekers in a certain way. This allows the coordinator to predict when threats will be a problem for seekers, and warn them accordingly.

d. Motivation

Prototype game designs did not have a scoring system. Without an evaluation system, participants could not gauge their performance. We found participants were not motivated to play. This led to the introduction of a scoring system, as described on

Table V. The original scoring rubric used the following function for the point value of goals, using the same variables as Equation 6.1 (page 95):

$$pointValue = numReqSkrs * 100 \tag{6.2}$$

Table V.: Original scoring rubric for T_e^2C, version 1.0. Entity state entries match those on Table III.

entity (state)	score rate
seeker (in; online)	+3.3 points / second / seeker in state
seeker (*safe*; in; online)	+0 points / second / seeker in state
seeker (*offline*; in)	+0 points / second / seeker in state
seeker (*out*)	−10 points / out
one-seeker goal	+100 / collected
two-seeker goal	+200 / collected
three-seeker goal	+300 / collected

e. Learning to Play

It was observed that participants had significant issues in learning how to play T_e^2C; in particular, information distribution was hard to understand. Players were confused about what one another could see and would spend time discussing the interfaces or arguing about ground truth in the game world. To aid in understanding how to play in a collaborative learning environment, a tutorial mode was developed. In the tutorial mode, each player acts a seeker, but can observe the coordinator's interface simultaneously. A text box describes how to play the game, advancing through steps describing how to play. The tutorial mode is played as the first game in any user

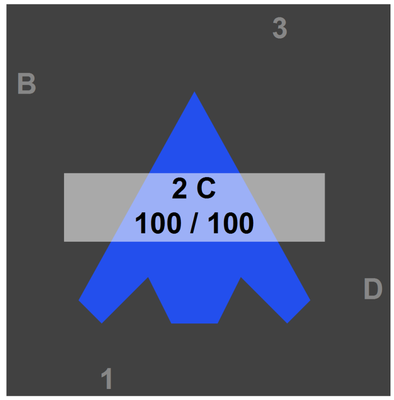


Fig. 31.: Seeker location and status indicator. The seeker avatar icon in the background shows the current state of the seeker; overlaid is location and hit points. Letters and numbers around the edge indicate nearby locations.

study; study administrators are available to answer questions by players.

2. Version 1.0

Version 1.0 of T^2_eC included numerous updates from the prototypes. While the game became a more effective tool for engaging players in processes of team coordination, communication patterns and player strategies were not yet similar enough to FER work practice. Further, certain interface and game play issues arose. Design iterations from version 1.0 improve players' ability to navigate the virtual world and their ability to communicate about and within the game. Representations are modified to support players in building a mental model of how the radio works, so they can use it more effectively. The scoring rubric was modified to encourage cooperation.

a. Navigation

In the non-FER user studies and participatory re-design, it became clear that seekers had difficulty navigating to block-and-grid locations specified by the coordinator. While the coordinator could provide directions, this was often a cumbersome process, made more difficult by seekers moving constantly. To make matters worse, seekers had difficulty determining what blocks were located nearby and in what direction.

During a series of participatory re-design sessions with an FER expert, we augmented the status / compass HUD element in the seeker interface. Instead of showing the seeker avatar icon rotating to indicate direction, the icon is held facing forward. Around the edges of the icon, the next nearest block and grid locations are displayed (Figures 27, 31). If a player needed to move from location 2, C to location 2, B, the player needs only rotate until the "B" is in front of the avatar icon and move forward. To enhance understanding of this interface element, we also clearly demark the edges of the blocks on the map, so as seekers move, they can see the boundaries.

b. Making Threats Visible

Information timing (V.G.3, page 78) must be tuned to promote distributed cognition. In our non-FER user studies and participatory design sessions, we observed seekers having difficulty avoiding threats, despite the HP mechanic and making threats predictable (V.G.4, page 78) through discernible patterns. Threats were invisible to seekers. The seeker HUD includes a proximity display to indicate when a threat was getting close, by filling up a meter with threat symbols (Figure 27) corresponding to the inverse of the distance to the nearest threat. The intention of this design decision was to make the coordinator direct seekers around threats, distributing information. However, because seekers could not directly see threats, attacks felt random. In most cases, the coordinator could not communicate to seekers about threats fast enough. They were overwhelmed by the rapid onslaught of information. In some groups, the coordinator simply gave up on communicating to the team about threats.

In this integrated design of core mechanic and interface, the timing of the information distribution did not, in practice, result in successful game play. The desired mechanic, that the coordinator would tell the seekers where the threats were and seekers would avoid them, rarely materialized.

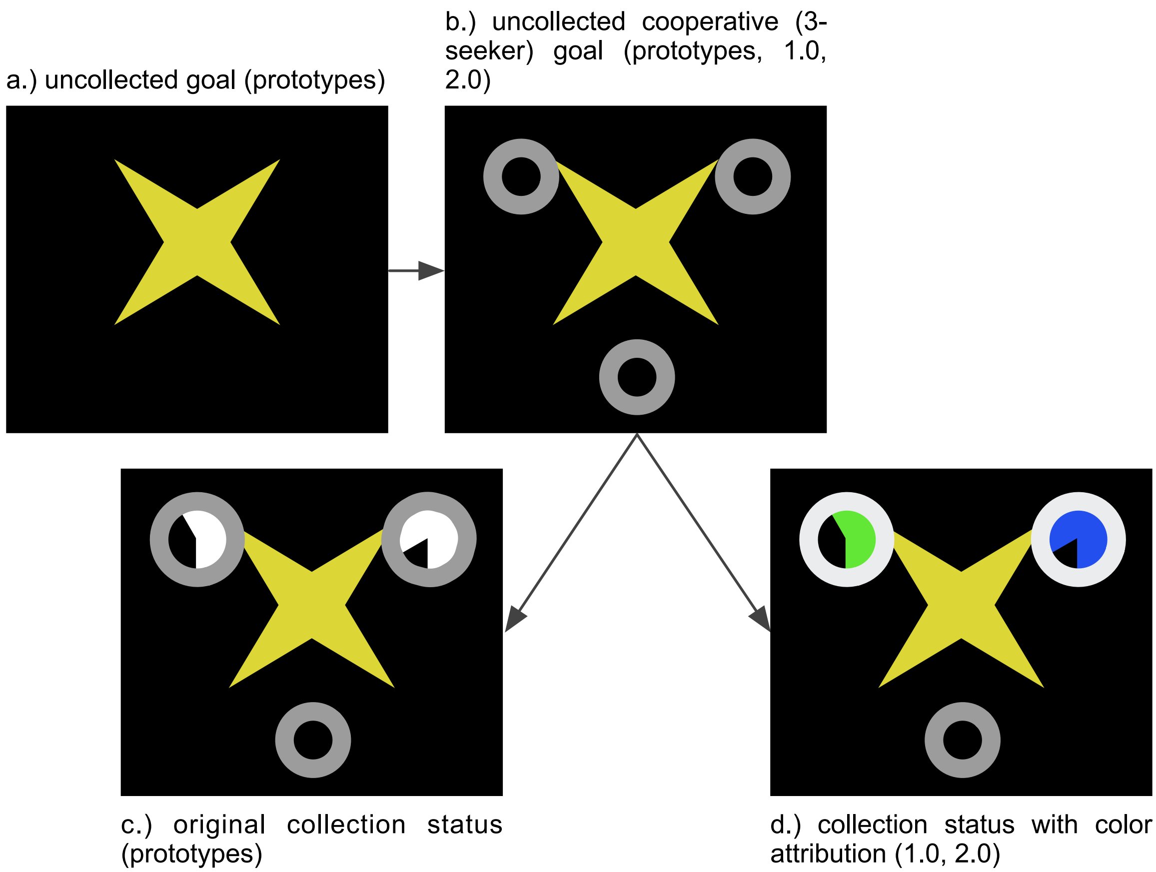


Fig. 32.: Goal collection status indicator iterations. Originally, all goals required only one seeker and had no collection rings (a.). Un-collected cooperative goal (b.) shows three empty rings, one for each seeker necessary to collect the goal. Original collection status indicators (c.) do not show who is collecting the goal. Current collection status indicators (d.) indicate how much each seeker has contributed to the collection of the goal through color.

To improve seekers' ability to evade the fast-moving threats, and make the game experience less random, we made the threats visible in the seeker interface. In the T^2_eC with FERs study, this improved play. Seeker players do not feel like they were taken out of the game randomly; they have more control to make decisions, engaging with game mechanics. Because seekers cannot see behind them and cannot move faster than the threats, they still challenge players. By providing the seekers with the right information at the right time, we reduce the ephemeral information burden on coordinators. This makes coordination less cumbersome and frustrating for both coordinators and seekers.

Another design choice might have been to slow the threats down. We did not choose this design because FERs in practice must respond to rapidly changing fire condition threats. Fast, dangerous threats promote real-time stress (IV.F.3, page 48).

c. Attributing Goal Collection

Once the cooperative goal mechanic was introduced (Figure 32, a. transitioned to b.), players had difficulty understanding *who* was currently collecting a goal. Goal collection is signified through a set of rings that indicate the goal's status, and the number of seekers required to collect it (Figure 32, b.). In the original design, each ring filled in white as each seeker contributed to collecting it (Figure 32, c.). This created confusion, as some players would incorrectly position their avatars around the goal. The goal would indicate that two seekers had collected part of the goal. A third seeker would be positioned incorrectly, but would incorrectly believe s/he was contributing and that another seeker was not. Problems appeared in the non-FER user study, after cooperative goals were introduced.

To correct players' confusion about who was contributing to a goal's collection, we color the collection status according to a seeker's color (Figure 32, d.). In addition, we draw a line from each collecting seeker to the goal, linking that player to the goal to indicate their action (Figure 29). This feedback is a change to *making visible* (V.G.2, page 77), and in the T^2_eC with FER user studies, no further confusion occurred.

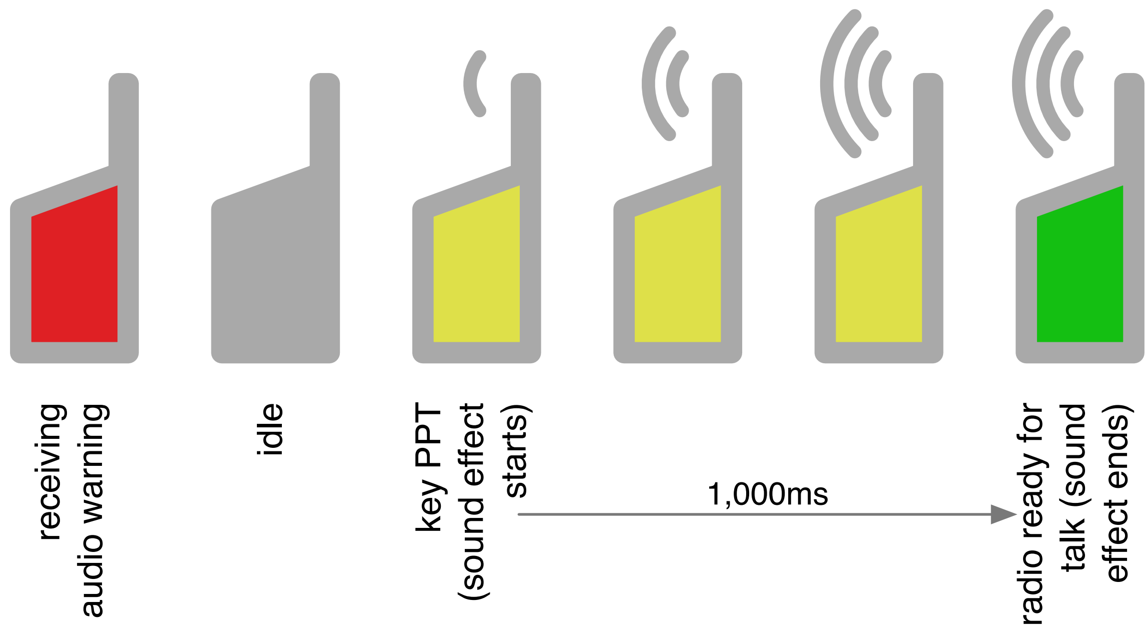


Fig. 33.: Radio status indicator animation and sound. The animation and sound help participants understand that the radio takes about a second to connect to the radios of other players.

d. Building a Mental Model of the Radio

Players had difficulty developing a mental model of how the radio worked. Because the radio is half-duplex, only one player can communicate at a time. Players would cross-talk (a common problem in real-life teams), and thus have difficulty understanding each other.

Another issue faced by teams when using the radio is connection lag when using PTT. There is a 500 millisecond (ms)–1,500ms lag between when the PTT button is keyed, and when receiving radios pick up the transmission. The result was that players would frequently fail to get the first parts of their messages to their teammates, who would either misunderstand or be unable to understand the communication at all.

To address these issues, we introduced a radio status augmented affordance-as-sign to all of the game interfaces (Figure 33). The status augmented affordance-as-sign depicts an icon of a radio. Whenever there is voice communication on the line, the status visualization lights up in red, indicating it is unsafe to talk. Whenever a player keys her/his radio, the visualization turns yellow for 1,000ms, then turns green. In addition, a set of waves animate from the antenna on the radio to indicate it is transmitting. This mechanism makes the otherwise unintelligible status of the radio visible to the player.

An aural augmented affordance-as-sign also helps delay players briefly before they start talking. The sonification lasts for approximately one second and stops early if the player releases the PTT key. This modification was made based on the suggestion of an expert FER, who indicated that radios used in the field work in this way. The change makes this component of the design mimetic, because the correspondence to reality enables participants to build a more functional mental model of the radio.

e. Encouraging Cooperation through Score

While the original scoring system (Table V) encouraged teams of players to compete with one another and strive harder, it did not motivate teams to cooperate as well as was intended. Participants noted that acquiring three single-seeker goals was the equivalent of collecting a single three-seeker goal and believed this was easier: $3 * 100$ points $= 1{*}300$ points (Equation 6.2, page 107). To motivate more cooperation within the team, the scoring rubric was iterated, placing heavier emphasis on cooperative goals (Equation 6.1, page 95; Table III, page 94).

E. Discussion

The present T^2_eC game incorporates the design principles discussed in the previous chapters. Through iteration, we develop the right distribution of information across player roles. Interface and game mechanic iterations selectively balance what information is distributed to whom through making visible and invisible. Communicable representations are crafted, reducing cognitive load. Threats are made predictable, through flocking behaviors. Game conditions create environments in which players mix communication modalities, by choosing between face-to-face and radio communication. Audible cues in the form of augmented affordances-as-signs support players in building mental models of equipment as well as understanding state. Cues are played over the radio, so that players can practice overhearing.

In terms of the traditional simulation types (IV.B.1, page 37), the present T^2_eC game is both virtual and constructive. The seekers' perspective is virtual, they move simulated avatars through a game environment. The coordinator's perspective is constructive, s/he directs resources (seekers) to accomplish tasks. In the planned mixed reality game, seekers will take on a hybrid live/virtual simulation. They will be moving in the real world and encountering real obstacles, while accomplishing tasks in a virtual world.

T^2_eC, as a non-mimetic simulation, is intended to have as little theme as possible; it is meant to be an alternate context in which to practice. The names selected for entities and roles specifically do not invoke the domain of emergency response, nor any fiction. The representations of the entities are likewise not meant to correspond to any existing real or fictional world. How players construct and appropriate meanings within the game is their own invention. This design decision will support the transfer of T^2_eC from the domain of firefighting to others in future work.

The following chapter addresses the evaluation methods used for T_e^2C, including measures of performance in the game and a speech coding scheme for measuring team coordination. The two chapters that follow evaluate T_e^2C with two subject groups: non-FERs and FER students.

CHAPTER VII

METHODOLOGY FOR EVALUATING TEAM COORDINATION GAMES

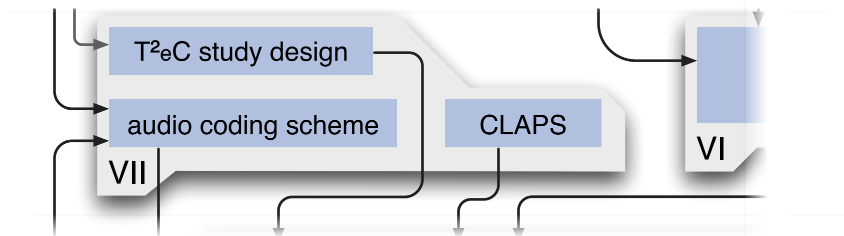


Fig. 34.: Component of the concept map (Figure 1) for the evaluation methodology.

As the designs of T_e^2C have changed through prototypes and two complete versions, so, too, has the evaluation methodology. Evaluation is of team coordination, as determined by measuring aspects of cooperative game play and communication. In this chapter, we begin by describing the experiment methodology used in the two T_e^2C user studies; each study's chapter describes any deviations from the pattern, as well as the subjects involved. Experiment methodology includes the experiment apparatus, study sequence, and data collection (Figure 34). We then present the Coordinated Log + Audio Playback System (CLAPS) that enables researchers to examine audio and gameplay records and some components of the game log analysis. We conclude with the iterated utterance coding scheme, on which metrics are based, and describe quantitative analysis methods that will be used throughout.

A. Experimental Methods

The team performance literature informs this research through the game and user study designs. Time for strategic planning [Stout et al. 1999] and reflection [Gurtner et al. 2007; Schön 1984] are important for teams to work together effectively and creatively. Hackman and Wageman suggest that teams need a level of familiarity with their task before reflection will be effective [2005]. Groups change over time, so it is essential to study them using *longitudinal methods* [Arrow et al. 2005] where the same participants are evaluated repeatedly over a long time period. This suggests that the studies need to be long term, and evaluate the same participants repeatedly.

1. Apparatus

In all user studies, the apparatus was the T^2_eC game deployed on four notebook computers. Each laptop was connected to custom audio hardware, allowing an audio feed to and from a two-way, half-duplex radio, as well as push-to-talk (PTT) control. Each laptop was also equipped with a Bluetooth monaural headset with microphone. Figure 35 diagrams the flow of data through the technology in the apparatus. Figure 37 shows a group of FER students using the T^2_eC apparatus to play a tutorial game.

A custom Pure Data (Pd) [Puckette 2009] patch mixed audio from the radio and the headset. PTT was enabled through T^2_eC Java software and the radio hardware interconnect. The result is that players can hear the radio communication, along with game sonifications, through their headsets. They can transmit to teammates by holding a PTT key and talking through the headset. The Pd patch also enabled recording audio data for later analysis.

The T^2_eC games were run in three different conditions: tutorial, seekers co-located (coordinator isolated), and all players distributed, as shown in Figure 36. In the tutorial condition (Figure 36, a.), all players were seated around a table with laptops and played a tutorial game (as described in the next section and in Section VI.D.1.e, page 107). When seekers were co-located, and coordinator isolated, seeker players were seated around a table, while the coordinator played from a separate room (Fig-

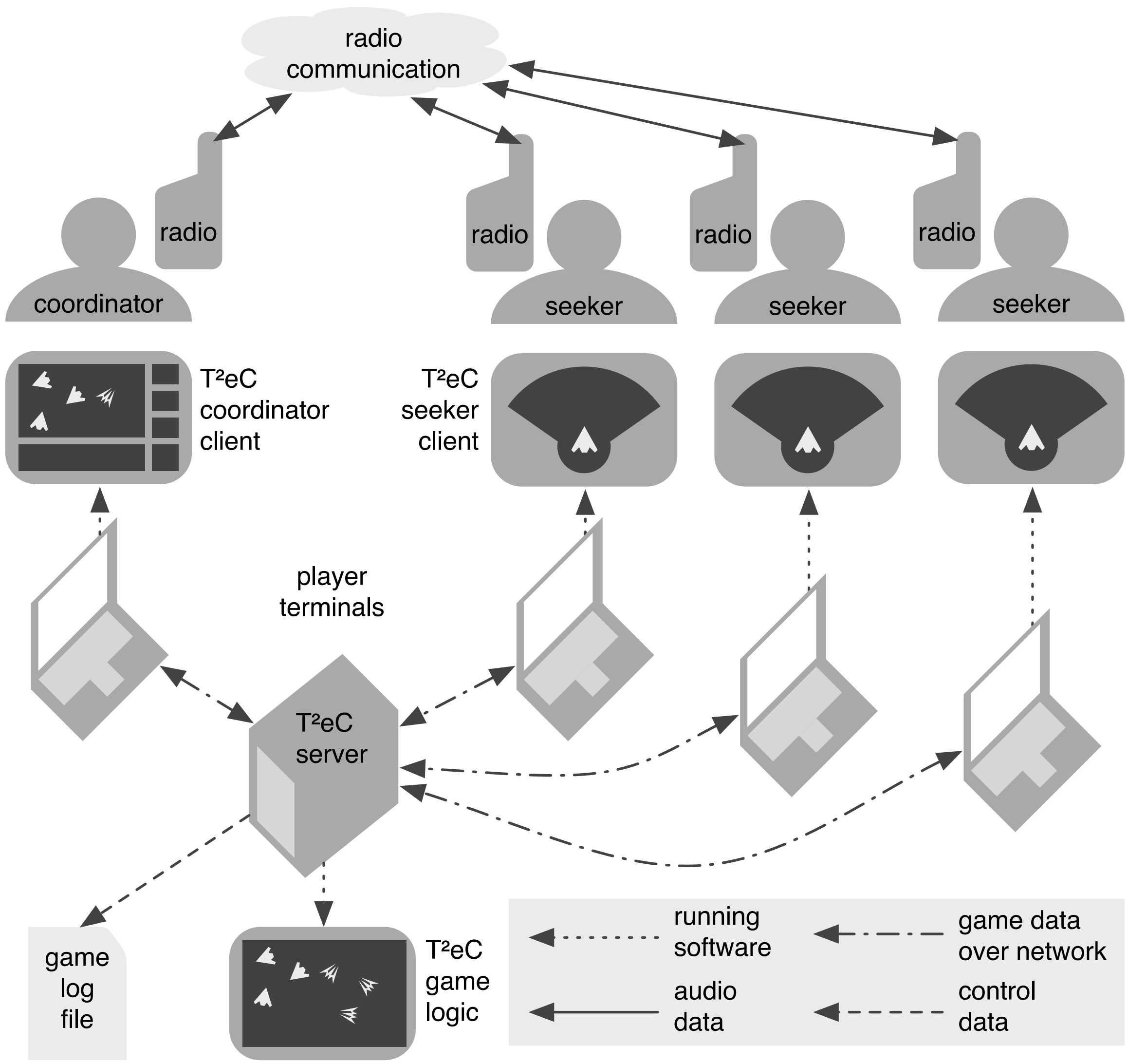


Fig. 35.: Technological data flow in the T_e^2C apparatus. Four players (one coordinator and three seekers) communicate over radio (details of the audio setup appear in Figure 38) while playing with the T_e^2C client software on their player terminals (notebook computers). The player terminals are networked to the T_e^2C server, which runs the T_e^2C game logic and records a log of the game.

ure 36, b.). The co-located players could communicate with each other face-to-face, while the radio was necessary to reach the coordinator. In the all players distributed condition (Figure 36, c.), each player was in a separate room. To communicate, each player had to use the radio. The varied conditions require the participants to practice

Table VI.: T_e^2C studies execution sequence, showing counterbalanced conditions. Each player is represented by a letter (W–Z).

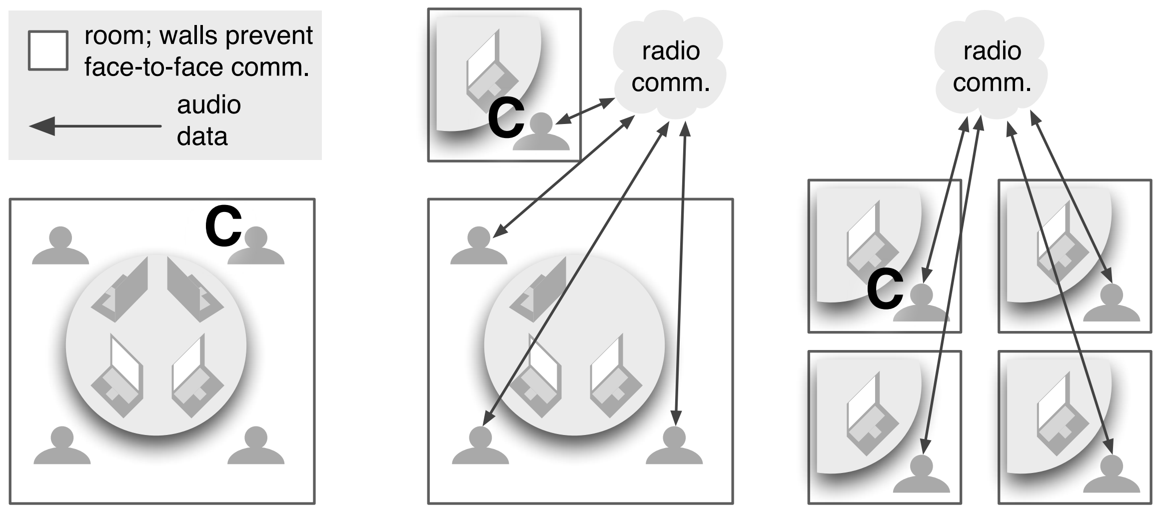
session (Ses)	sequence (Seq)	condition (Cnd)	coordinator	seekers
1	0	tutorial	–	W, X, Y, Z
1	1	co-located	W	X, Y, Z
1	2	distributed	W	X, Y, Z
2	3	distributed	X	W, Y, Z
2	4	co-located	X	W, Y, Z
3	5	co-located	Y	W, X, Z
3	6	distributed	Y	W, X, Z
4	7	distributed	Z	W, X, Y
4	8	co-located	Z	W, X, Y

with the radio, which they might otherwise avoid doing, because of its problems and limitations.

2. Study Sequence

Each team participated in four game sessions (Table VI), typically a week apart. The break between sessions gave participants time to consider their performance and develop new strategies, supporting incubation of new ideas [Smith 1994]. This longitudinal design allows us to evaluate changes in the team's coordination capabilities over time.

During each of the sessions, participants played two games. Before, after, and between games, participants were given 10 minutes to reflect and discuss, planning strategy and diagnosing problems they encountered. This reflection period is an essential component of developing effective strategy and team coordination [Gurtner



(a.) tutorial condition: all players in the same room; communicate face-to-face

(b.) co-located condition (C): all seekers in the same room, coordinator isolated; seekers communicate face-to-face, coordinator by radio

(c.) distributed condition (D): all players isolated; communication by radio

Fig. 36.: Study conditions for T^2_eC. The team's coordinator is identified by a label "C". Walls indicate where face-to-face communication cannot be used.

et al. 2007; Schön 1984; Smith 1994], giving practitioners time to make plans and develop shared mental models (II.D.1, page 13).

In the first session, a tutorial game was played, in which all players acted as a seeker, but could observe and interact with the coordinator's view. Cross-training by experiencing multiple roles within a team promotes shared mental model formation (II.D, page 12). The tutorial is a form of cross-training, like the kind undertaken by FERs, enabling players to formulate mental models of each others' perspectives and capabilities. The tutorial game walks each player through the game controls and demonstrates all of the game mechanics. It calls attention to the information distribution between the two interfaces. Study administrators were on hand to guide

Fig. 37.: A crew of FER students at Brayton Fire Training Field play a tutorial game of T$_e^2$C.

participants who had difficulty and to answer any questions.

As described above, there are two team configuration conditions (*Cnd*): co-located (C) and distributed (D). Conditions are counterbalanced, alternating order each week (Table VI). To more directly emulate FER education practice, each player takes on the coordinator role for one session (two games). For each session, a coordinator is randomly selected from among the players that have not yet played the role. The list below describes the study sequence. Components that occur only in the first of a team's four sessions are marked with an open bullet (○), while components that occur in every session are marked with a closed bullet (●):

○ Informed consent obtained from participants.

○ Participants fill out a pre-questionnaire, establishing prior experience with teams, sports, and video games, as well as demographic information.

○ Participants play a tutorial game, in which they are presented with the seeker and coordinator interfaces side-by-side, and given a series of instructions on how to perform both roles. The side-by-side design enables understanding information distribution.

- The team is informed of the coordinator's identity for the session and given a minimum of 10 minutes reflection time, where it is suggested they discuss strategy and make plans before the first game of the session.
- Participants play the first game of the session (see Table VI for condition ordering), and answer a short questionnaire about the experience.
- Players are given a minimum of 10 minutes reflection time, where it is suggested they discuss strategy and make plans for their second game.
- The team plays the final game of the session, in the opposite condition, and follows up with a questionnaire about the game itself, and the session as a whole. The final session includes extra questions reflecting on the study as a whole.
- The team is given a minimum of 10 minutes to reflect.

3. Data Collection

Data from the user studies consisted of audio records, game logs, and questionnaires. Audio was recorded by the testing apparatus during game play, using a four channel system through the Pd patch. A portable audio recorder with powered condenser microphone was used to record all participant interactions during the reflective sessions (before, after, and between games). The game logger captured the T^2_eC server's state at each game update. Pre-questionnaires recorded self-report data on experience with game play, firefighting, and attitude toward multiplayer games. Questionnaires during the user study recorded participants' impressions of the game immediately after play, asking about communication during play and perceived performance of teammates. Post-questionnaires recorded participants' impressions of the game and asked them to describe their experiences.

a. Game Log Recording

Game logs record the entire game state when the game server executes its simulation loop, incorporating all data from the player clients. The game log can then be used to reconstruct each player's experience on their individual client computers, using CLAPS. The game log records the terrain and the status of all entities for every cycle of game play. Game logs are recorded on the server in XML format.

The server always has the most current version of the T^2_eC game state. Game state components are either static or dynamic. Static components, such as the locations of goals, players' names, and the terrain are recorded once, at the beginning of the log. Dynamic game state consists of the states of all entities (location, status, etc. of threats and seeker avatars, state of goals). Dynamic game state is recorded repeatedly. While T^2_eC is designed seamfully, the lack of a simulated WiFi signal does not prevent clients from sending data to the server. The server simply runs the game mechanics as if the data were not present (but continues to record it).

b. Audio Recording

Audio is recorded from all players. Audio recording is thorough, capturing a variety of channels during play. Each T^2_eC terminal's audio setup includes a wireless Bluetooth headset (microphone and speaker), the terminal's sound card, custom audio interconnect hardware, and a handheld radio. Audio is mixed using a custom Pd patch. The Pd patch enables audio recording, in addition to audio mixing. For each player in a game, four channels are recorded to a WAV audio file during play at 8,000

Hertz (Hz): speech, incoming radio, game sounds, and a synch track. This results in a total of 16 audio tracks for a whole game (4 tracks per player with 4 players). Figure 38 diagrams the flows of audio and control data in the T^2_eC setup, including the audio recorder component.

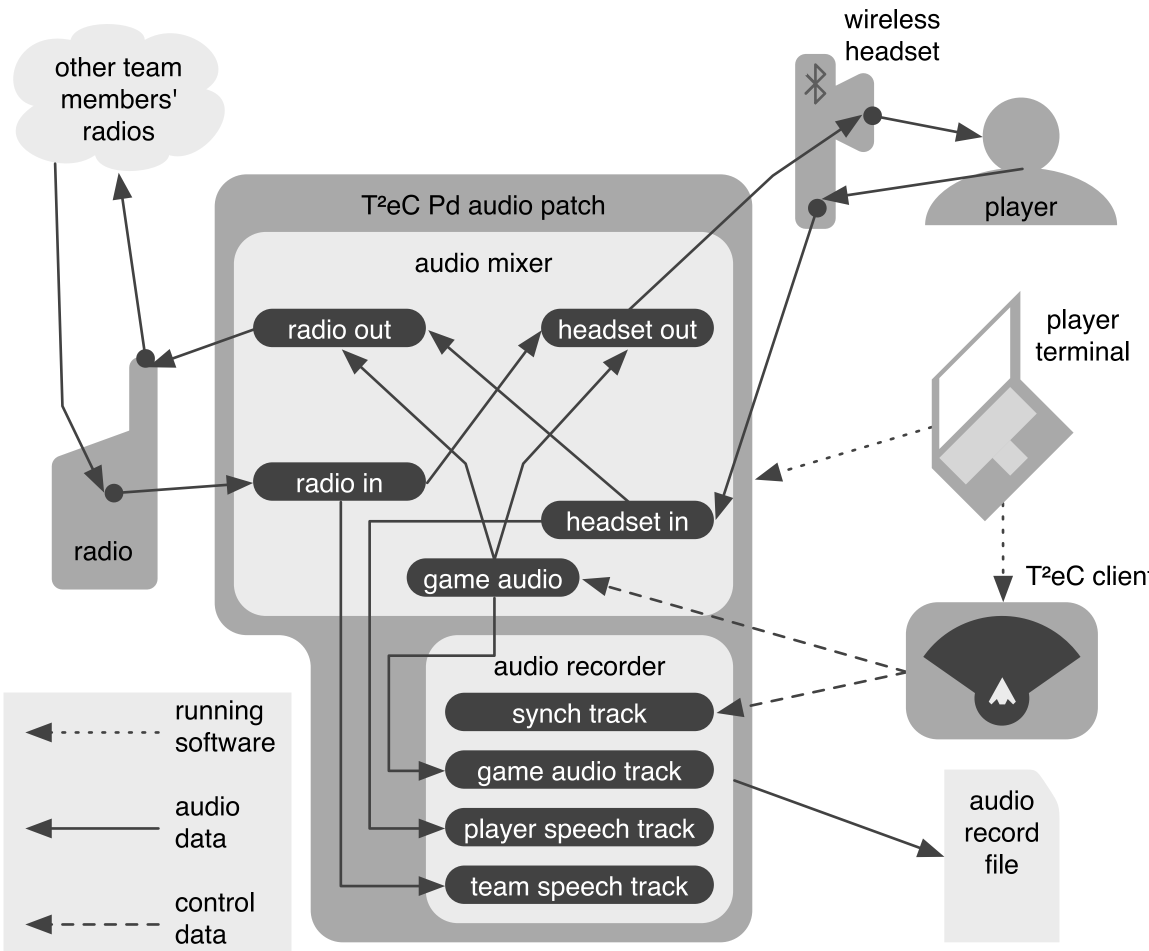


Fig. 38.: Audio setup in T^2_eC. Each player's terminal runs the T^2_eC client and the Pd audio patch. The audio patch handles mixing the audio streams from the player's wireless (Bluetooth) headset, the radio, and the game audio. Game audio is controlled by data from the T^2_eC client. The Pd audio patch also includes the audio recorder, which writes a four track audio file: a synch track (controlled by the T^2_eC client), a game audio track, a player speech track (all utterances by the player), and a team speech track (all utterances from the radio). This setup is repeated for each individual player.

The player speech track records all audio received by the microphone on the player's Bluetooth headset. This allows researchers to analyze what the player said during play. Speech data is useful for evaluating how effectively the team is coordinating, for measures like anticipation ratio.

The team speech track records all audio heard by the player through his/her radio. Because the radios are half-duplex, the incoming radio track will be silent when the player keys PTT on his/her own radio. The incoming radio track allows researchers to hear requests to which the player is responding, aiding in understanding context. It also enables discovery of instances of crosstalk (III.B.2.a, page 24).

Game sonifications produced by the patch are recorded. While sounds are not used in analysis, they allow the researcher to understand the game context completely, recreating the player's experience. This supports, for example, discovery of overhearing, where a player responds to the sounds in another player's game (III.B.2.a, page 24).

The synch track is not audio data, but instead records information about time, enabling coordinated log playback. Each game cycle has an index value and that value is recorded as a sample value on the synch track. The result is a track that spikes to its highest value when the game begins, then gradually decreases over time. The game cycles are synchronized across clients, so the synch tracks are as well. The synch track is similar to Society of Motion Picture and Television Engineers (SMPTE) timecodes used for synchronizing audio and video in recording [Benson and Whitaker 1990].

Table VII.: Independent team and player analysis level variables in T_e^2C with FERs.

variable	description	range	level
Ses	ordinal value indicating the game session	1–4	team
Seq	ordinal value indicating the game in the sequence	1–8	team
Cnd	game condition	[C, D]	team
Rl	player role in game	[S, D]	player

B. Coordinated Log + Audio Playback System (CLAPS)

The *Coordinated Log + Audio Playback System* (CLAPS), first described in Hamilton et al., is used to evaluate T_e^2C players by enabling researchers to observe play with audio [2009]. By combining log playback with audio playback, fully synchronized using the synch track, researchers can discover interesting qualitative data. Researchers can connect play action with speech, disambiguating quantitative measures, like the audio codes described later. Figure 39 shows a screenshot of CLAPS during playback of one of the T_e^2C with FERs user studies.

We use CLAPS to enable researchers to review each game in the context of players' experiences. CLAPS presents the researcher with a re-creation of each player's view and plays back all recorded audio. The reviewer may modify the mix of the audio tracks by controlling the volume and pan of each, allowing them to create a spatial audio mix that facilitates the analysis of particular communications between players. The system also presents a scrub bar with visualizations of game state over time, to allow the reviewer to randomly access points in the game.

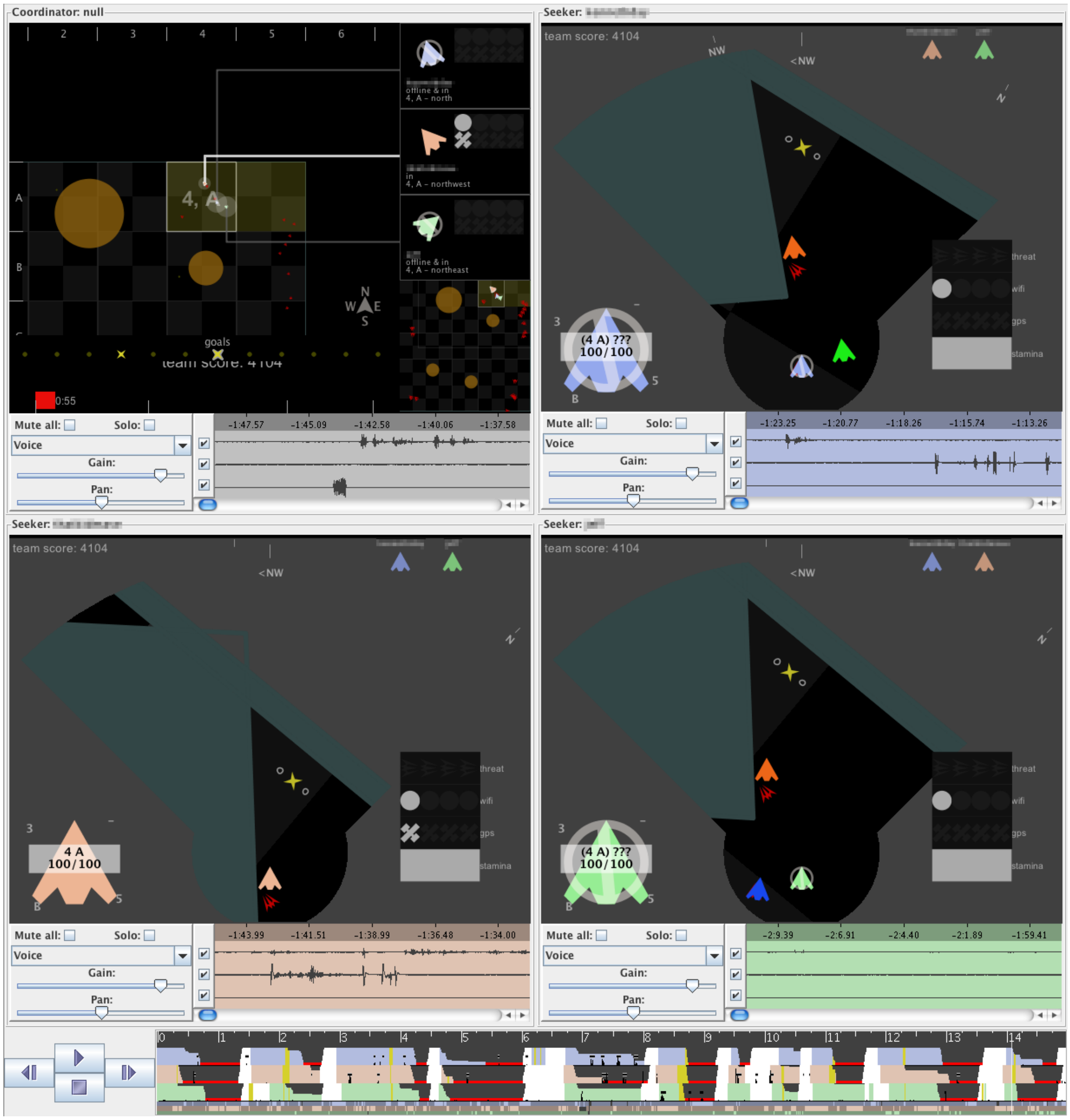


Fig. 39.: Screenshot of the Coordinated Log + Audio Playback System (CLAPS). Each player's view is shown simultaneously and each has a control for the three audible tracks (player speech, team speech, and game audio). Audio tracks can be selectively amplified, soloed, muted, and/or stereophonically spatially positioned. The timeline on the bottom visualizes the HP of each seeker and whether or not they are collecting a goal.

C. Game Data Variables

In this section, we describe variables for evaluating performance in game play. Evaluating players is difficult, because play is complex. The emphasis in analysis is on team performance in the game environment. Discrete game cycles are the proxy for time in T_e^2C: better teams will complete the game faster. Capture by threats is a negative metric that counts the number of times seekers' avatars are reduced to zero hit points. Several variables contribute to game play performance metrics that primarily consider the number of goals collected by the team and how quickly they succeeded. Independent variables at the individual and team levels are described on Table VII. Tables of dependent variables are outlined in Table VIII.

1. Game Cycles

The experience of game play is continuous, but simulation systems running on digital computers are not. Time is divided into discrete game *game cycles* determined by the T_e^2C server. The T_e^2C server executes logic that considers the current state of all seekers (location, hit points, etc.), the flocking algorithms for threats, etc. A game cycle closes when the game server runs its side of the simulation (VI, page 83). The result of each game cycle is recorded to a log. Each game runs for a set number of game cycles, which map to real time at cycles per second (hertz, Hz). Some metrics are based on number of game cycles, using them as a proxy for time.

In the present studies, each game runs for a maximum of 9,000 game cycles and the server updates at 10 Hz; this results in games that run for a maximum of 900 seconds (15 minutes). If a team collects all of the goals, the game ends prematurely. All time-dependent measures are normalized against the number of cycles played by the team. The dependent team level analysis variable *cycRem* is the number of game

Table VIII.: Dependent team level analysis game log variables in all T_e^2C studies.

variable	description
GC_{1S}	number of single-seeker goals collected in game, normalized against total number available
GC_{2S}	number of 2-seeker goals collected in game, normalized against total number available
GC_{3S}	number of 3-seeker goals collected in game, normalized against total number available
cycRem	game cycles remaining when all goals have been collected, normalized against the performance of all teams (if the seekers fail to collect all goals before time is up, this value is 0)
gamePerf	$GC_{1S}+GC_{2S}+GC_{3S}+cycRem$; *gamePerf* directly captures the set of performance measures used in determining the end of the game, it directly measures the team's ability to finish quickly by weighting the total collected goals and cycles remaining evenly
score	game score, normalized within the team; game score is computed during play, it weights the collection of each goal, includes a bonus for finishing quickly, and incorporates the summation of the score computed from the team's status each game cycle; more information can be found in VI.B.3 (page 93)
outs	number of times each seeker captured by threats (taken out of the game), normalized against the cycles played in that game

cycles remaining once all goals are collected.

2. Going Out / Capture by Threats

During play, a seeker's avatar's status may change to *out* (VI.B.1.a, page 87). A seeker's avatar *goes out* or is *captured by threats* if its hit points are reduced to 0 through contact with threats. Per the game rules, seekers may *restore* at bases, where they *come in*. The dependent variable, *outs*, is the total number of times, aggregated for all seekers on a team, that a seeker's avatar's status changed to out during the play of the game, normalized against number of game cycles. For example, if Skr_a went out four times and Skr_b was captured three times, $outs = 7$ (assuming a game in which the team did not collect all of the goals).

3. Game Play Performance

A number of metrics contribute to measuring a team's ability to perform during game play. Many components are directly related to the team's ability to cooperate. The first mechanism looks at the number of each type of goal collected by team members. Two combination metrics are used: game performance and score.

The first measure of performance captures how many goals seekers collected before time ran out (GC_{1S}, GC_{2S}, and GC_{3S}). Cooperative goal collection (GC_{2S} and GC_{3S}) is predicated on the seekers gathering together under dangerous conditions after locating the goal. Number of cycles remaining (*cycRem*), described above, is another measure of performance: if the team manages to collect all goals early, *cycRem* indicates how fast they were able to do so. Number of outs ($outs$) is a negative measure of performance.

Two other measures aggregate the above performance measures. Overall game performance ($gamePerf$) sums the normalized goal collection measures with the normalized time remaining. Score (*score*) is measured as described in the previous chapter. It weights the value of each goal based on its difficulty to collect (cooperative goals are harder), includes a penalty for going out, and provides a bonus based on the game cycles remaining.

D. Speech Coding Scheme

Communication within a team offers insight into its ability to coordinate effectively. To analyze participants' communication, we code each game using a speech coding scheme, which allows us to classify each utterance as a particular type of communication. This converts qualitative information into quantitative data. Applying the coding scheme is labor-intensive, as researchers must listen to all of the audio recorded during play and classify each statement. The result is a count of the number of times each player used a particular speech code. In addition to recording content of communication we also record the communication modality the participant used to relay their communication and the success or failure of the communication (in some cases, radio may fail or be crosstalked).

Two complete speech coding schemes were developed to analyze data from the T_e^2C studies. The coding schemes were based on the metric of anticipation ratio, used for measuring implicit coordination (II.D.1, page 13) and grounded in observations of fire emergency response burn training exercises and interviews with expert responders (Chapter III, page 15). Version 1.0 of the coding scheme was used for the non-FER user study (Chapter VIII, page 143) and is a direct analog of the codes derived from ethnographic data. Version 2.0 iterates version 1.0, condensing some of the codes and applying them within the context of the game more directly. It incorporates observations from the use of version 1.0 and is used to evaluate T_e^2C with FERs (Chapter IX, page 156).

1. Anticipation Ratio

A primary goal of the present research engages participants in team cognition so they improve their ability to implicitly coordinate (II.D.1, page 13). The value of implicit coordination lies in the team's reduction in unnecessary communication, reducing the cognitive, time, and bandwidth burdens associated with communication.

Anticipation ratio (AR) is a measure of implicit coordination, measuring team members' balance of pushing versus pulling information [Entin and Serfaty 1999;

MacMillan et al. 2004]. AR measures the amount of information team members provide against the amount of information requested. Pulling information (making requests) as a form of noise in the limited communication channel. Pulling information does not support the team, but burdens it with additional cognitive load and reduced access to the communication channel. Such communications do not aid team members in making decisions and taking action, but require them to respond with information. The measure places value on pushing information out to the team (making reports). The function for computing AR is:

$$AR = push/pull \tag{7.1}$$

Where *push* is the number of utterances pushing information (reports) by some part of the team and *pull* is the number of utterances pulling information by some part of the team (requests). Other types of utterances are not included in the measure. In practice, AR is calculated using a number of different combinations of team members [Entin and Serfaty 1999; MacMillan et al. 2004], so exactly who is pushing or pulling information varies depending on the research. In the user study chapters that follow, the version of AR used will be described. The AR codes of report information, request information, and other form the basis for our coding schemes.

2. Grounding in Practice

We develop utterance codes through grounded theory [Glaser and Strauss 1967], starting with observations of fire emergency response work practice (Chapter III, page 15). To understand FER practice, we began with interviews with expert emergency responders. In the interviews, the experts described the types of communication used at the fireground. In conjunction with their reports, we observed burn training ex-

Table IX.: Observed speech codes, grounded in observations of burn training and discussions with FERs. Speech codes are originally described in Toups Dugas and Kerne [2007]. Examples are taken from observation of burn training exercises.

code	description	example
information request	asks for information about the incident	"Is the fire knocked out on the first floor?"
fireground report	describes the local environment within the fireground	"No, fire is not knocked out on the first floor."
incident report	describes information about the global incident	"There's no smoke or anything showing on the outside."
status request	asks for information related to the health or progress status of a team	"Attack 2 and 3 are y'all ready for water on that side?"
status report	FER reports on their or their teammates' status	"Advise we are running out of air and are leaving the structure."
order	a command to perform an action	"Go ahead and advance up the stairs on the Charlie-Delta corner."
assistance request	asking for help taking action	"Can I get two personnel to assist Attack 1 in search and rescue?"
progress report	supplies information about the status of an order or set of actions	"Fire's knocked down on first floor."
acknowledgement	indicates that a message was heard and understood (usually repeating it back)	"Copy that. Advancing up stairs, Charlie-Delta corner."
clarification / order request	a request for help with understanding a command, or asking for a new command	"Can you repeat that?"

ercises and video recorded them with audio from the radios. The video was later transcribed.

Through the interviews and observations, we developed the diagram shown in

Figure 9 (page 31). The diagram shows the ways specific types of information flow between workers at the fireground. From the diagram, we derived a speech code system, described in Table IX. Broadly, the codes classify utterances into requests, reports, and other communication, making their use suitable for calculating AR. These codes form the basis of version 1.0 of the audio coding system used for the T_e^2C game.

In fire emergency response work practice, embodied emic information about the fireground flows up the chain of command from firefighters to their superiors. This information is filtered and passed on to the incident commander (IC), who incorporates it with the disembodied etic data acquired from artifacts, as well as observations. From this, the IC makes decisions, which filter back down to those in the fireground. Information communicated over the radio is difficult to understand, but reaches all FERs on scene. Information communicated face-to-face is limited to those involved in the conversation, but is rich and fast.

Information requests result in a return of either a *fireground report* or an *incident report*. A fireground report provides information about the local environment, relative to the speaker. An incident report considers the fireground in context. *Status requests* and *reports* are similar to other requests for information, but revolve around individuals' health and activity status. Similar to a status report is a *progress report*, which describes action and progression toward a shared goal (such as "knocking down a fire").

In addition to gathering and sharing information, FERs must also communicate about action. An *order* requests activity from another FER. An *assistance request* is like an order, but collaborative. It asks one FER to help another in accomplishing a task that is otherwise impossible for the individual or group that is attempting to accomplish it. In the context of FER practice, an order and a request for action are essentially the same thing; it is expected that an FER will follow the command, unless the local situation prevents it.

Metacommunication, communication about communication, is also an essential component of FER communication practice. All commands must be *acknowledged*. A face-to-face acknowledgement may be a simple nod, but use of the radio requires a more concrete response. Consequently, acknowledgements over the radio typically take the form of "copy that", followed by a repeat of the command. The repetition ensures that the command was understood correctly, because the person issuing the command can respond with a correction, if necessary. *Clarifications* ask a speaker to repeat a message so that it can be better understood. An *order request* asks a commander to provide further instruction.

3. Version 1.0

Version 1.0 of the game data coding scheme is a direct analog of the scheme developed from grounded FER practice. It was used to evaluate T_e^2C with non-FERs (Chapter VIII).

In version 1.0, information about the fireground and incident are replaced with *relative game state* and *global game state*. Relative game state reports are typically deictic in nature, they describe information from the point of view of a particular player. Global game state describes the virtual world in terms of absolute positions. *Status requests* and *reports* work in much the same way as FER practice, but describe the seekers and their avatars. In some cases, the coordinator may also report on his/her own status, such as being too busy to respond to a request. *Progress reports* are also the same as their analog in FER practice. Table X outlines the speech codes.

As in FER practice, T_e^2C players must discuss and take action. T_e^2C players use *orders* to direct other players to take action in the virtual world. *Assistance requests*

Table X.: Version 1.0 of the speech coding scheme, used for T_e^2C with non-FERs. The codes are direct analogs of those discovered in FER work practice (Table IX).

code	description	example
game state request	player asks for information about the virtual world (entities, terrain), but not other players	"Where is the threat?"
relative game state report	player supplies information about the virtual world relative to his/her own perspective (typically using diectic reference)	"There's a base here."
global game state report	player supplies information about the virtual world without using their localized perspective	"There's a goal at $(1, 2)$."
status request	player asks for information about another player (including seeker status)	"Where are you?"
status report	player supplies information about him/herself or another player	"I'm out right now."
order	a command to perform an action	"Head south."
assistance request	asking for help taking action	"I need a second seeker."
progress report	player supplies information about status of an order or current set of actions	"We're almost to the base."
acknowledgement	indicates a message was heard and understood	"Understood. Heading south."
clarification / order request	a request for help with understanding a command, or asking for a new command	"Where is the next goal?"
metagame	communication about the game itself	"How do I run?"

are also essential, because players need to cooperate to collect goals, avoid threats, and find safety.

Metacommunication utterances are used to *acknowledge* commands and information, *clarify* requests, and *request orders*. *Metagame* utterances are added to capture instances when players are communicating about the game or apparatus itself, rather

Table XI.: Inter-rater reliability for T^2_eC user study with FERs with audio coding scheme version 2.0. Inter-rater reliability is computed using Pearson correlation coefficients by coder pair and code, averaged over all coded games. Due to lower reliability of coder 1, only coders 2 and 3 were ultimately used; the average inter-rater reliability is 0.89.

		coder pairs		
		1 & 2	2 & 3	1 & 3
codes	game state request	0.67	0.86	0.73
	status request	0.41	0.94	0.17
	action request	0.97	0.96	0.93
	game state report	0.82	0.94	0.89
	status report	0.76	0.85	0.49

that about the elements within the game (e.g. asking which key causes the avatar to take an action).

Codes were applied to games by individual researchers so that each game was coded by a single researcher. When applied, the codes showed very few trends with the games, although significant qualitative data was acquired. The primary discovery from applying the codes was that they were frequently ambiguous. As such, we iterated the specification of the codes to version 2.0.

4. Version 2.0

A number of ambiguities and redundancies were discovered when applying version 1.0 of the game data coding scheme. It included a large range of codes, making it difficult to apply. In iterating the scheme design, version 2.0 simplifies, mapping the same version 1.0 codes into new ones.

Three researchers coded all audio from each player in each game; each player/game was coded by exactly two researchers. Inter-rater reliability (IRR) was computed for each game and audio code, to ensure that the audio codes were properly applied and that the coding scheme was valid. To calculate IRR, the Pearson correlation coefficient of each coder pair for each code was computed. Detailed results are reported on Table XI. The average inter-rater reliability for all coders was computed to be 0.75. Coder 1's results were less reliable, because he was out of the country and unavailable for discussion. The result (with only coders 2 and 3) is a final IRR of 0.89.

For version 2.0, relative and global game state reports were merged into the single *game state report* code. Orders, assistance requests, and order requests became *action request*. In terms of anticipation ratio, we consider action requests to be a type of report. Commands often supply information to the team and do not add noise to the system. Progress reports were included as a part of *status report*, because they supply information about the activity of a player. Acknowledgements and clarification requests were changed to simply be *metacommunication*. Table XII outlines version 2.0 of the coding scheme.

a. Secondary Tags

Secondary tags were introduced to provide nuance and identify gameplay patterns. Any number of secondary tags can be applied to each utterance. Table XIII describes each of the secondary tags. The tags *identify self*, *identify target*, and *repeat back* identify communication patterns common in fire emergency response work practice. The *use coordinates* and *discuss walls* tags were added to see if participants engage in communication about information distribution in play. *Planning*, *collaborating*, and *modifying communication patterns* were all observed to happen in the play of T_e^2C version 1.0, and so were added as tags.

Table XII.: Version 2.0 of the speech coding scheme, iterating version 1.0 and used for T_e^2C with FERs. Includes a mapping back into the version 1.0 codes.

code	mapping	description	example
game state request	–	player asks for information about the virtual world (entities, terrain), but not other players	"Where is the next goal?"
game state report	relative / global game state	player supplies information about the virtual world (entities, terrain), but not other players	"There are threats here!"
status request	–	player asks for information about another player (including seeker status)	"Where are you?"
status report	status / progress report	player supplies information about him/herself or another player, including progression toward an objective	"I'm out right now."
action request	order, assistance request, order request	player asks another player to do something	"Let me know where to go next."
meta-communication	acknowledgement, clarification request	communication about communication, including indicating a message was heard and understood and asking for clarification	"Repeat please."
metagame	–	communication about the game itself	"How do I run?"

b. Hybrid Codes

Ambiguities discovered during the course of coding resulted in the development of hybrid codes. Some utterances are essentially multiple codes in a single message, which is a more efficient way of communicating not captured by AR directly. The most common hybrid code was a game state request / status report: "I need a base." Such a message explicitly asks for a base, but also implies that the seeker is out.

A single utterance suffices to supply two meanings, economizing the communication channel and improving implicit coordination.

Table XIII.: Secondary tags in version 2.0 of the speech coding scheme. The tags enable researchers to note additional nuance about communication in games to identify it as being more similar to FER practice or identify if parts of the game mechanics are being employed.

tag	description
plan	suggesting future activity or requesting orders
identify self	a player identifies him/herself in a communication
identify target	a player identifies the expected recipient of a message
collaboration	a communication identifying a need to work together toward a shared objective
repeat back	a player repeats back a message to the sender to ensure it was heard properly
use coordinates	a player uses virtual world coordinates in a communication
modify communication pattern	a player attempts to set rules about future communication
discuss walls	a player communicates about the presence of walls in the way

E. Quantitative Analysis Methods

Several quantitative analysis methods are used in reporting results in the following chapters. The first method of quantitative analysis consists of a linear model of a dependent (response) variable changing with an independent variable. Results are presented as ([dependent variable]∼[independent variable]: $m = [value]$, $R^2 = [value]$, $p < [value]$), where m is the slope of the regression line, R^2 is the fitness of the line, and p is the significance of the result. A positive regression line slope indicates a direct relationship, while a negative slope indicates an inverse relationship. Where we call attention to a result that is not significant, we omit the m and R^2 values and report p as greater-than, instead of less-than.

The second method of quantitative analysis is Welch's t test [Welch 1947]. The t test compares the mean value of a set of samples in a pair of conditions of possibly unequal variances for a statistically significant difference between them. We report t test results as ([variable], [condition variable]= $\{1stconditionvalue, 2ndconditionvalue\}$: $t = [value]$, $df = [value]$, $p < [value]$), where t is the t statistic, df is the number of degrees of freedom of the data, and p is the significance of the result. In this section, we use one-tailed t tests, which determine if one condition is greater-than (positive t statistic) or less-than (negative t statistic) the other. Throughout, we use one-tailed t tests, because the results are only interesting if they change in one direction, not both.

F. Conclusion: Evaluation Techniques for Team Coordination

Developing quantitative methods for evaluating complex human performance, such as a team coordination, is challenging and an important undertaking for research that develops systems for teaching such performance. We developed a number of metrics for evaluating complex team play in the T_e^2C non-mimetic simulation game environment. Game play variables measure teams' performance in the environment, while communication metrics evaluate teams' abilities to communicate and coordinate effectively.

When determining game play variables, they must be environment-specific. They need to target the skills that the environment is designed to teach. In the case of T^2_eC, we target variables that rely on participants working together (cooperative goal collection) and emphasize those. By building the cooperative metrics into the quantification of team performance (game score), which is displayed to players, they are encouraged to perform better at the non-mimetic simulation task.

Evaluating team coordination in game play through the coding scheme is widely applicable. While the game play coding scheme we provide is information-centric, one could use it in existing multiplayer games, such as *Halo* [Bungie Studios 2001], to gauge team coordination ability.

The following two chapters use the evaluation methodology with two versions of T^2_eC and with two subject populations. The next chapter describes using version 1.0 of T^2_eC with non-FER participants. This study provided evidence of the value of non-mimetic simulation for teaching team coordination and provided valuable insight into the design of T^2_eC. In the chapter that follows, we describe a second user study with version 2.0 of T^2_eC used with FER students at the Brayton Fire Training Field.

CHAPTER VIII

USER STUDY: T^2_eC VERSION 1.0 WITH NON-FERS

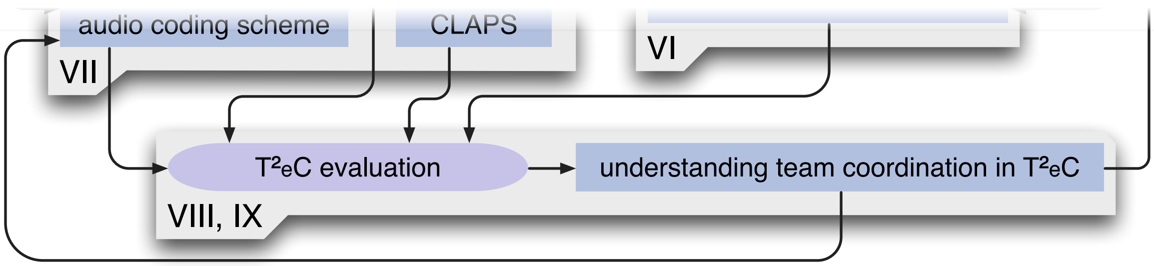


Fig. 40.: Component of the concept map (Figure 1) for user studies of T^2_eC version 1.0 with non-FERs.

To validate our non-mimetic simulation game design, we conducted a controlled user study using version 1.0 of T^2_eC with non-FERs. the purpose of this study was to evaluate T^2_eC in terms of its ability to promote team coordination and motivate play. It was essential to test game designs with non-FERs first, to ensure they were effective, before working with the FER students. Results from the study support the value of non-mimetic simulation and inform the development of version 2.0 of T^2_eC.

This chapter reports on data with 36 non-FERs playing T^2_eC in the laboratory. Data include a total of 72 games (excluding tutorials). The study results are primarily qualitative. They indicate that participants engage with the cooperative elements of the game and begin to use team coordination strategies. Our evaluation methodology was reported in Chapter VII; Figure 40 shows the links from that chapter. In this chapter, we develop hypotheses and methods. Results and analysis follow. Design improvements from the present data were reported in Chapters V and VI (pages 50 and 83, respectively). Non-mimetic simulation design principles, developed from the present study, were presented in Chapter IV (page 34). The present study originally appeared in Toups Dugas et al. [“Emergent team coordination,” 2009].

A. Hypotheses

A number of hypotheses are investigated, supporting the principal hypothesis of the present research. we relax the principal hypothesis here: *by playing non-mimetic simulation games, developed from work practice, players*[1] *learn to more effectively coordinate as a team.* Four hypotheses contribute, addressing aspects of team performance, communication, and support of practice.

- H-1-1 Through game play, participants will improve their ability to accomplish co-operative tasks.
- H-1-2 Through game play, participants will improve their ability to coordinate.
- H-1-3 Communication and activity in T$^{2}_{e}$C will resemble communication and activity of FERs.
- H-1-4 The introduction of a scoring system will motivate play.

B. Methods

The methods for the T$^{2}_{e}$C with non-FERs study are described in Section VII.A (page 116). The study presented here uses version 1.0 of T$^{2}_{e}$C. Teams are referenced by the letter “T” followed by an identifier; identifiers are assigned in the order that individuals volunteered for the study.

[1] instead of FERs

Table XIV.: Non-FER gender demographics. Most participants were male.

gender	number of participants
no response	9 (25.0%)
male	23 (63.9%)
female	4 (11.1%)

Table XV.: Non-FER age demographics.

age (years)	number of participants
no response	8 (22.2%)
18–21	15 (41.7%)
22–25	8 (22.2%)
26–30	3 (8.33%)
31–40	2 (5.56%)

Table XVI.: Non-FER education demographics.

education	number of participants
no response	6 (16.7%)
high school[a] or lower	16 (44.4%)
bachelor's degree[a]	9 (25.0%)
master's degree[a]	2 (5.56%)
Ph.D.[a]	0 (0.0%)

[a] or equivalent

1. Subject Population

36 subjects, recruited from the university and community, were organized into nine teams of four members each. When possible, we recruited groups of people who

Table XVII.: Non-FER prior team experience. Most participants had little to no experience or chose not to respond, although a substantial portion had a moderate amount of team experience.

years[a]	number of participants
no response	8 (22.2%)
0	12 (33.3%)
<1	7 (19.4%)
1–5	8 (22.2%)
6–10	0 (0.0%)
10–20	1 (2.78%)

[a] Based on multiple choice question: "Do you have any experience with *team-based* situations, such as (but not limited to) firefighting, community activism, military service, or police service? If so, how much?" Responses were year ranges.

already knew each other. Tables XIV–XVII provide data about the demographics of the subjects. Subjects were mostly young adult males. Many had higher level education (in college or holding a bachelor's degree). Few had extensive prior experience performing teamwork. Participants were compensated: food was provided at each session, and each participant received a gift card (30USD) when their group completed all four study sessions.

C. Results

Audio with game logs serve as the primary source of data. Each player's audio was coded according to version 1.0 of the coding scheme. Analysis identified instances of strategy, team coordination, and problems. Most significant results are observed through qualitative data. Quantitative data analysis methods and independent and dependent variables are described in Chapter VII (page 116).

1. *Team Task Performance*

Teams improve their team task performance over repeated plays. They collect more goals overall in later games and reduce their play time ($gamePerf{\sim}Seq$: $m = 6.510$, $R^2 = 0.352$, $p < 0.0001$; $score{\sim}Seq$: $m = 6.48$, $R^2 = 0.3499$, $p < 0.0001$; $cycRem{\sim}Seq$: $m = 4.115$, $R^2 = 0.1784$, $p < 0.0001$). Specifically, they collect more of the difficult cooperative goals in later games ($GC_{2S}{\sim}Seq$: $m = 5.473$, $R^2 = 0.2775$, $p < 0.0001$; $GC_{3S}{\sim}Seq$: $m = 5.874$, $R^2 = 0.3067$, $p < 0.0001$). In early sessions, players collect mostly single-player goals (83% 1-seeker, 41% 2-seeker, 35% 3-seeker), which require less coordination. In late games, players collect more cooperative goals, which require them to work together (95% 1-seeker, 86% 2-seeker, 87% 3-seeker). In later games, players go out more frequently ($outs{\sim}Seq$: $m = 1.937$, $R^2 = 0.04588$, $p < 0.06$). Game condition, co-located or distributed, did not impact performance ($gamePerf{\sim}Cnd$: $p > 0.45$; $outs{\sim}Cnd$: $p > 0.6$).

2. *Emergent Role Strategies*

Some teams appointed a *seeker leader* to direct others by monitoring the local environment and incorporating strategy and information from the coordinator. Although no formal seeker leader role was specified in the design, T5, T6, and T8 did, during at least one game, adopt a seeker to lead the team.

Similar to the emergent role of seeker leader was the adoption of a *CAPCOM*[2] who filters all communication to the coordinator from the group of seekers. This role was only effective in the co-located condition, as seekers could rapidly communicate with each other, and the CAPCOM could relay only the important information and

[2] T4 used the term "CAPCOM", which is a role at NASA, responsible for communicating with spacecraft.

requests to the coordinator. T4 adopted this strategy; T2 discussed using it, but never implemented it.

3. Co-Location in the Virtual World

As teams played together and reflected, players eventually adopted a strategy of seekers staying co-located in the virtual world. Early in the study, each seeker played independently, losing the rest of the group, and then needing to be re-united in order to collect any cooperative goals.

In later games, teams evolved strategies. Rather than splitting up, they used a two collectors and one scout (2+1) or all-together strategy. In the 2+1 strategy [T1; T3; T4; T5], two seekers paired up to collect cooperative goals, while the third seeker ran ahead to scout the terrain. The scout's job was to collect single-player goals, and locate the cooperative goals for the pair.

In the all-together strategy [T1; T2; T3; T4; T5; T6; T7; T8], all seekers moved around the map as a team. In this way, they were able to help each other find invisible bases and were almost always able to collect any goal found. If the goal required fewer than three players, the remainder of the group was back-up, in case someone was captured by a threat at the last minute. The disadvantage of the all-together strategy was that it is an all-or-nothing proposition: once a threat captured one player, the rest were often also captured.

4. Team Coordination

During play, instances of team coordination were observed. These instances took the form of players responding to requests with action, rather than communication (implicit coordination) [T3] and leveraging audible cues.

Reports by participants after study sessions indicated that they believed their own teamwork was improving. Members of T2 remarked that playing the game together would improve their skill at team sports. After one game, T5 chided one of their members for "trying to be a hero" by attempting too much on his own. T4 discussed how the coordinator should monitor and anticipate the needs of the seekers. One team member noted "what's genius to me is the idea that each of you has an incomplete set of information, you must communicate, it's not like games where they try to get people to communicate but there's no real reason to" [T4].

5. Competition Motivates Improvement

Many participants expressed an intense interest in not only improving their scores, but improving them relative to the other teams in the study [T2; T4; T6; T7; T9]. Although we did not formally make a leaderboard available to the participants, we did field their questions about other teams' performance. This prompted them to strive harder in successive games. The following anecdote describes the emergent rivalry between two teams who had never met:

> Upon obtaining a record score in the third session, T2 members remarked that, rather than be compensated they would prefer a trophy indicating that they were "Number 1." On hearing about this, T6 members bested T2 in their next session, mentioning that they would be happy to provide the T2 members with a trophy for second place. In their final session, T2 gathered all the goals in less than seven minutes, a record that was never broken in this study.

Of note is the fact that players were at first uninterested in their total score, but more interested in the number of goals collected. Once the team succeeded at collecting all of the goals, they turned to reducing their play time. Both aspects of achievement are included in our scoring rubric for T_e^2C version 1.0 (Table V, page 107).

D. Analysis

In this section, we examine the results to ascertain proof of the hypotheses. We observe players improving at the cooperative tasks in T^2_eC and improving team coordination. We note how game play by non-FERs resembles FER work practice. We see how the scoring system influences players motivation to participate.

1. H-1-1: Improving at Cooperative Tasks

H-1-1 Through game play, participants will improve their ability to accomplish cooperative tasks.

As they play, participants shift from primarily gathering individual goals to gathering cooperative goals. Improving the number of collected cooperative goals is indicative of an improvement in team members' ability to coordinate action and share information effectively. Real-time constraints on goal collection, in the form of the time required to collect the goal and incoming threats, make cooperative goals difficult to collect. To collect a cooperative goal, seekers gather in the same location at the same time while threatened. They either move together, which endangers them all, or gather at a location from diverse positions. Players resolve information distribution by communicating about the goal: its location and type (number of seekers required), the safety of the area (nearby bases, seams, and threats), their locations, and their status.

In fire emergency response work, there is safety in numbers. It is necessary for firefighters to stick together [Toups Dugas and Kerne 2007; Wieder et al. 1993]. A downed firefighter can be pulled out by a teammate, just as a backup seeker can collect a goal when another falls. Multiple firefighters can accomplish more than an individual: their combined strength is necessary to direct a powerful fire hose or lift heavy debris. This synergy of coordination is captured in the simulation by the design of cooperative goals.

2. H-1-2: Improving Team Coordination

H-1-2 Through game play, participants will improve their ability to coordinate.

Teams improve their ability to coordinate by restructuring their teams and allowing the seekers to act independently on situated information, inverting the chain of command. Seeker leaders and CAPCOMs are helpful, because they allow the coordinator to delegate responsibility and give the seekers independence to act on local information and improvise strategy. In the following anecdote [T8], the coordinator directed the seekers to a base. The seeker leader spontaneously overrides with an augmented plan based on local conditions:

> **Coordinator** (radio): "Everybody go east together. Directly east."
>
> **Seeker Leader** (r): "Okay. We have walls to the east. We are going to move around the walls and move east."
>
> **C** (r): "Go around the walls, go north, and...go north around the walls, and then to the east."
>
> **SL** (r): "Negative. We're going to head south, there's a goal directly beneath the base."
>
> **C** (r): "Okay, good, go there."
>
> **SL** (face-to-face): "Okay. Follow me."

3. H-1-3: Play Resembles Practice

H-1-3 Communication and activity in T^2_eC will resemble communication and activity of FERs.

Participants' practice emulates work practice through emergent leadership positions and the use of co-location strategies for the seekers. While player roles substantively reflect FER roles, players add their own roles that strengthen the connection.

The advantage of a seeker leader, like a company officer in FER work practice, is that it reduces the burden on the coordinator. Rather than handle each seeker individually, the coordinator can focus on a single player, who enacts strategy and delegates responsibility. This formalization creates a chain of command within the team that is not formally specified, but that clearly parallels FER work practice [Denef et al. 2008; Wieder et al. 1993; Cary Roccaforte, personal communication].

The game was initially designed such that the coordinator was like the incident commander (IC), with the three seekers mirroring firefighters. As we increased information distribution from the T^2_eC prototypes to version 1.0, with cooperative goals and fuzzy representations in the coordinator's view, the seekers grew more autonomous. FERs also act autonomously, working with a general strategy from outside the fireground [Denef et al. 2008; Wieder et al. 1993; Cary Roccaforte, personal communication]. They must be free to improvise as the situation warrants, because each has unique, valuable, distributed information, that contributes to distributed cognition.

The emergence of additional roles and strategies validates the design of the simulation. The coordinator functions more directly as an IC, the seeker leader or CAPCOM is like a company officer, and the remaining two seekers are like firefighters. Furthermore, the emergence of a leader among the seekers enables them to operate more autonomously than with information distribution alone. T4 mentions this specifically in one of their reflective periods, noting to the coordinator that they do not need to be micro-managed. T5 demonstrates its importance, as the group of seekers works together to collect a 3-seeker goal near an offline region ("dead zone") by walking backwards:

> **Coordinator** (radio): "That point seems to be a bit better defended…"
>
> **Seeker 1** (face-to-face): "I couldn't take it because I was in the dead zone."
>
> **S2** (f2f): "Whoa, that is close…"
>
> **S1** (f2f): "It's important the direction we go to it because one direction is too close [to the offline region of the map]."
>
> **S3** (f2f): "No, no. Back up, go towards it backward. That we can [back over it]…"
>
> **S1** (f2f): "Exactly, that's what we should do."

Sometimes the coordinator can identify patterns that the seekers cannot. While trying to collect the final goal of the game [T3]:

> **Coordinator** (radio): "[S1], can you take them back around the way you just came? If you guys run out of that dead zone, you might be able to get to [the goal] before the threats."

The observed 2+1 and all-together strategies lend themselves to having a seeker leader, who makes group decisions in the field.

4. H-1-4: Score Motivates Play

H-1-4 The introduction of a scoring system will motivate play.

Score and competition between teams is a powerful motivator for participation and improvement. Leaderboards were requested extensively by participants. Team members repeatedly expressed concerns about their ability to perform relative to other teams and were eager to play the game to improve their scores. The extra points for cooperative goals motivated players attempt more difficult goals by working together; this, in turn, required them to coordinate to succeed.

E. Discussion

The findings indicate significant progress toward validating T^2_eC as a non-mimetic simulation of fire emergency response team coordination practice. We hypothesized that a non-mimetic simulation of information flows in fire emergency response practice can effectively engage team coordination skills. Through the simulation design principles (IV.F, page 45) of information distribution, participant roles that limit available action and information, and real-time stress, participants engage in implicit coordination while improving play. Emergent play reflects FER practice. Participants improve team coordination skills by engaging with distributed information; they work together to coordinate diverse perspectives and collect cooperative goals. New roles and strategies emerge, similar to those of FERs. Score motivates play. While higher scores, in themselves, cannot be seen as evidence of learning, we examine how the game stimulates players to improve in team coordination.

We design information distribution to create a distributed cognition environment, wherein team members are reliant on each other for rapidly-changing information. Roles define available actions and information. Participants are under real-time stress to perform. The result is a simulation that successfully captures the human-centered aspects of fire emergency response, engaging participants in the intense team coordination of FERs. Non-FER participants develop emergent strategies that match those in fire emergency response work practice.

What we show in the next chapter is more than what was accomplished here.

The present study does not show strong *quantitative* evidence that participants' team coordination is improving, nor does it directly show evidence that the non-mimetic simulation improves team coordination in the firefighting domain. Further, lessons learned from the present study enabled us to iterate the game design to version 2.0 and refine the coding technique. We perform the same user study, but with fire emergency response students and with iterated designs. Using version 2.0 of the game play coding scheme, we evaluate team coordination performance and use new variables to examine team task performance. The students report on how the game impacts their abilities in burn training exercises.

CHAPTER IX

USER STUDY: T^2_eC VERSION 2.0 WITH FERS

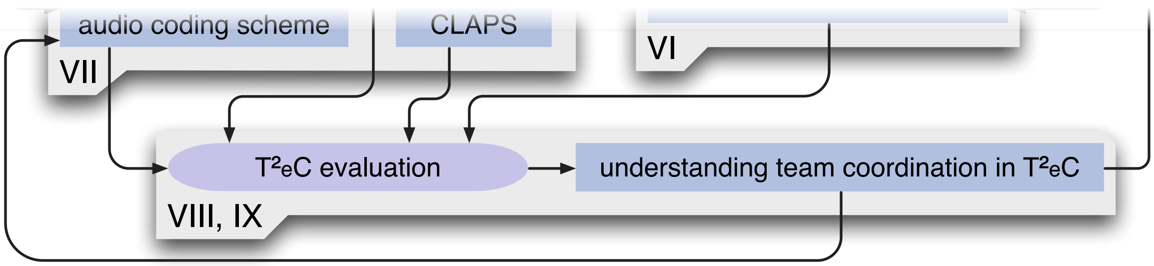


Fig. 41.: Component of the concept map (Figure 1) for user studies of T^2_eC version 2.0 with FERs.

While the previous chapter looked at non-fire emergency responders playing version 1.0 of T^2_eC and produced results validating the non-mimetic simulation, this chapter describes a study of fire emergency responder (FER) students playing at the Firefighter Training Academy (FTA). The primary contribution of this study is that it demonstrates the effectiveness of T^2_eC for teaching team coordination by evaluating play with the target population. We look at how game play and FER education mutually influence each other in the context of the FTA.

The ecological validity of a study is based on how closely its methods approximate reality, supporting the value of the study in terms of its ability to directly impact the world. The present study is designed as it would be used in the FTA, supplementing existing education. Although difficult to recruit and schedule, the FER students who did participate were excited to do so. Our evaluation methodology was reported in Chapter VII; Figure 41 shows the links from that chapter. This chapter reports on data from 28 users who played a total of 56 games. In this chapter, we begin with hypotheses, methods, and metrics. Results and analysis follow, concluding with discussion about the value of T^2_eC for FER training and updates for future study designs.

A. Hypotheses

A number of hypotheses are investigated. The principal hypothesis of the present research is that *by playing non-mimetic simulation games, developed from work practice, fire emergency responders learn to more effectively coordinate as a team.* Six hypotheses contribute, addressing aspects of team performance, communication, and support of practice.

H-2-1 Through game play, participants will improve their ability to accomplish cooperative tasks.

H-2-2 Player roles (IV.F.2, page 47), differentiated by information distribution (III.D.1, page 15; IV.F.1, page 46; V.G.1, page 76) and available action, will impact team communication.

H-2-3 Play condition, either co-located or distributed, will impact ability to accomplish cooperative tasks, reflecting a need to mix communication modalities (III.D.2, page 30).

H-2-4 Through game play, participants will improve their ability to implicitly coordinate (II.D.1, page 13).

H-2-5 Game play will be reflected in team coordination ability in burn training exercises (III.A.2, page 19).

H-2-6 Communication and activity in T^2_eC will resemble communication and activity in fire emergency response work practice.

Table XVIII.: Team names in T^2_eC with FERs user study.

spring (RC 128)	summer (RC 129)
calTEXANADA	Foxtrot and Company
Team Firestorm	Team 5
Team Rainmen	Team 6
	Team 7

Table XIX.: FER student gender demographics. Most participants were male.

gender	number of participants
no response	0 (0.0%)
male	24 (85.7%)
female	4 (14.2%)

Table XX.: FER student age demographics.

age (years)	number of participants
no response	0 (0.0%)
18–21	15 (53.5%)
22–25	9 (32.1%)
26–30	4 (14.2%)
31–40	0 (0.0%)

B. Methods

The methods for the T^2_eC with FERs study are described in Section VII.A (page 116). The study presented here uses version 2.0 of T^2_eC, with improved spatial representations, radio status indicator, and scoring ruberic.

Table XXI.: FER education demographics. Most participants had a high-school education, its equivalent, or lower. Overall, education is lower than that of the non-FERs.

education	number of participants
no response	0 (0.0%)
high school[a] or lower	24 (85.7%)
bachelor's degree[a]	3 (10.7%)
master's degree[a]	0 (0.0%)
Ph.D.[a]	1 (3.57%)

[a] or equivalent

Table XXII.: FER prior team experience. Participants had substantially more experience than non-FERs.

years[a]	number of participants
no response	0 (0.0%)
0	6 (21.4%)
<1	7 (25.0%)
1–5	8 (28.5%)
6–10	5 (17.8%)
10–20	2 (7.14%)

[a] Based on multiple choice question: "Do you have any experience with *team-based* situations, such as (but not limited to) firefighting, community activism, military service, or police service? If so, how much?" Responses were year ranges.

1. Subject Population

Subjects were recruited in groups of four from the ESTI Firefighter Training Academy Recruit Class (RC) 128 (spring 2009) and RC 129 (summer 2009). Each team had participated in the FTA for at least five weeks. Studies were completed prior to participants beginning burn training exercises (III.A.2, page 19). A total of 28 students participated, making seven groups. An effort was made to recruit entire class crews (see III.A.1, page 18) as game teams, so that game teams match those in the classroom. Due to schedule conflicts, only two such teams were created.

This chapter reports on data from 28 users who played a total of 56 games; Tables XIX–XXII summarize the demographic data of the FER student sample. The sample contains similar gender (Tables XIV, XIX) and age (Tables XV, XX) ratios to that of the non-FERs. In the FER population, however, we see an overall lower level of education (Tables XVI, XXI), but a higher level of prior team experience (Tables XVII, XXII).

Participants gave permission to collect all data, including their grades in the FTA. Players selected a pseudonym to be used for the game (if that name was personally identifying, we refer to them as <P-X-Y>, where X is the team number and Y is a player number). Teams were given the opportunity to select a name. Team names are summarized on Table XVIII. Each participant was compensated by providing food at each session and a gift card worth 30 USD on completion of the study.

2. Apparatus

The present study is built around version 2.0 of T^2_eC, as updated from the previous study. For this study, we shifted some information distribution, allowing the seekers to see threats to reduce the feel of “randomness” and enable players to make fast, informed decisions. We added the seeker location context indicator, showing the seeker which block-and-grid coordinates were nearby, enabling communicable representations (V.G.5, page 78). Finally, we added a push-to-talk (PTT) notification animation and sound, to encourage players to wait until the receiver radios picked up prior to speaking. Details of the iteration can be found in Section VI.D, page 100.

The setup is identical to the one used for T_e^2C with non-FERs, except that version 2.0 of T_e^2C was used instead of version 1.0. Details on the experimental method can be found in Section VII.A (page 116). For each game, the locations of goals and starting locations of threats were procedurally determined. To maintain consistency between teams, the seed for the procedural algorithm was the same for each session and game. The positions thus move each game, but are the same across teams. The terrain is held constant for every game.

C. Metrics

Metrics are derived from game log and audio data sources. Metrics are analyzed using the quantitative methods described in Section VII.E (page 140). Independent variables at the team and player levels of analysis are described on Table VII. Game log dependent variables are described on Table VIII. Audio variables are presented on Table XXIII. When a subset of the data is used for a particular role, this is indicated with a bracketed subscript: $_{[S]}$ for seekers, $_{[C]}$ for coordinators.

1. Game Log Analysis

a. Seeker Groups

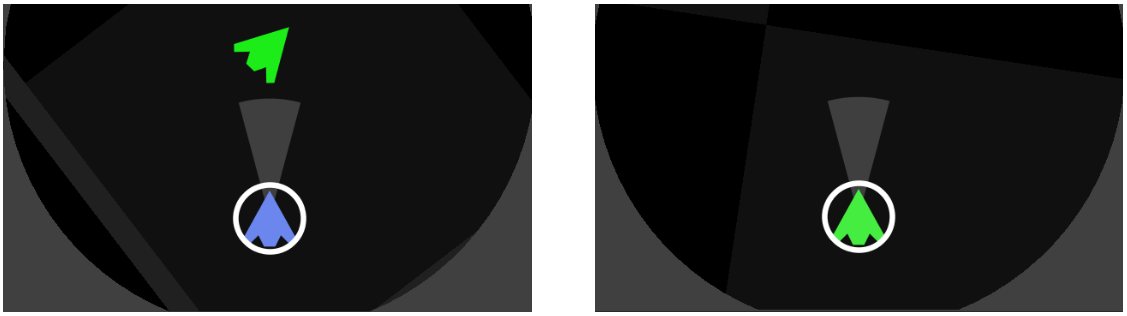
Inspired by the observations in T_e^2C version 1.0, where seekers opt to co-locate in the virtual world, we introduce the seeker grouping metric. Seeker *group* measures count the number of game cycles that seekers' avatars spent together as a group during play as a percentage of play time (game cycles). The metric of seeker groups formalizes the qualitative observations from the T_e^2C with non-FERs study (VIII.C.3, page 3). A seeker is considered to be grouping with another seeker so long as the first seeker can

Table XXIII.: Audio data variables in T$^{2}_{e}$C with FERs.

variable	description
$RQGS_p$	number of *requests* for *game state*, normalized against total number of utterances by the player
RQS_p	number of *requests* for *status*, normalized against total number of utterances by the player
$RPGS_p$	number of *reports* of *game state*, normalized against total number of utterances by the player
RPS_p	number of *reports* of *status*, normalized against total number of utterances by the player
RQA_p	number of *requests* for *action*, normalized against total number of utterances by the player; for purposes of computing AR, RQA_p is considered a report of information
$RQGS_t$	total number of *requests* for *game state*, normalized for *cycRem* in game
RQS_t	total number of *requests* for *status*, normalized for *cycRem* in game
$RPGS_t$	total number of *reports* of *game state*, normalized for *cycRem* in game
RPS_t	total number of *reports* of *status*, normalized for *cycRem* in game
RQA_t	total number of *requests* for *action*, normalized for *cycRem* in game
$AR_{C:S(rd)}$	anticipation ratio of number of coordinator reports of information ($RPGS_{t[C]}$, $RPS_{t[C]}$, $RQA_{t[C]}$) to the number of seeker requests for information over the radio ($RQGS_{t[S]}$, $RQS_{t[S]}$); $AR_{C:S(rd)}$ is computed from player-level data for the *team*
UT_t	$RQGS_t$+RQS_t+$RPGS_t$+RPS_t+RQA_t

see the second. The *grouping* relationship is bi-directional, the *seeing* relationship is not. Because seeker vision is limited to the front of the seeker's avatar (VI.C.1, page 95), a seeker may be seen by a seeker that s/he does not see (Figure 42). Table XXIV summarizes the variables derived from seeker grouping.

To explain seeker groups, we first describe the *can see* operator, 👁. A seeker, Skr_a, can see another seeker, Skr_b, (Skr_a 👁 Skr_b) if Skr_a's viewport includes Skr_b's



(a.) view from blue seeker (b.) view from green seeker

Fig. 42.: Demonstration of the *can see* operator and seeker grouping in action. The blue seeker (a.) can see the green seeker (b.), but the green seeker cannot see the blue seeker because the view port does not extend backward. Because the blue seeker can see the green seeker, the two are grouped.

Table XXIV.: Dependent team level analysis game log variables for seeker grouping.

variable	description
Grp_{1S}	game cycles spent with all seekers isolated, normalized against the cycles played in that game
Grp_{2S}	game cycles spent with two seekers together (one seeker isolated), normalized against the cycles played in that game
Grp_{3S}	game cycles spent with all seekers together, normalized against the cycles played in that game

location. The $\circledast$ operator is not commutative:

$$Skr_a \circledast Skr_b \nrightarrow Skr_b \circledast Skr_a \tag{9.1}$$

With the can see operator, we can define a seeker group. A group of seekers is denoted using set notation, so if Skr_a is grouped with Skr_b, then $\{Skr_a, Skr_b\}$. Thus a group is defined as:

$$(Skr_a \circledast Skr_b) \vee (Skr_b \circledast Skr_a) \leftrightarrow \{Skr_a, Skr_b\} \tag{9.2}$$

Group sets may include all of the seekers in a game ($\{Skr_a, Skr_b, Skr_c\}$). Group sets can be chained; as long as any member of a set can see another seeker (or that seeker can see a member of the group set) then the other seeker is a member of the set too.

$$\text{given: } \exists Skr_a,\ Skr_b,\ Skr_c : \{Skr_a, Skr_b\}, Skr_c$$
$$\{Skr_a, Skr_c\} \vee \{Skr_b, Skr_c\} \leftrightarrow \{Skr_a, Skr_b, Skr_c\} \tag{9.3}$$

The normalized dependent variables, Grp_{iS}, below are based on seeker group *counts*, which are used to determine the percentage of the game seekers spent in groups. The value of i is the number of seekers in the largest group. Since the present study includes only three seekers, Grp_{1S} indicates the percentage of time that no seeker can see any of the others, Grp_{2S} indicates the percentage of time that two seekers are grouped (possibly the 2+1 strategy from VIII.C.3, page 148), and Grp_{3S} indicates the percentage of time that all three seekers are together (possibly the all-together strategy). Game logs are processed offline to calculate $count(Grp_{iS})$ by summing the number of game cycles (VII.C.1, page 128) where the team was in a group formation, then dividing by the total number of game cycles played to get Grp_{iS}. For each game cycle, the $count(Grp_{iS})$ counters are incremented (++) as follows:

$$count(Grp_{1s}) + + \leftrightarrow \{Skr_a\} \wedge \{Skr_b\} \wedge \{Skr_c\} \tag{9.4}$$

$$
\begin{aligned}
count(Grp_{2s}) ++ \leftrightarrow & \\
& (\{Skr_a, Skr_b\} \wedge \{Skr_c\}) \\
& \vee (\{Skr_b, Skr_c\} \wedge \{Skr_a\}) \\
& \vee (\{Skr_a, Skr_c\} \wedge \{Skr_b\})
\end{aligned} \tag{9.5}
$$

$$
count(Grp_{3s}) ++ \leftrightarrow \{Skr_a, Skr_b, Skr_c\} \tag{9.6}
$$

2. Audio Data

Through audio analysis, researchers coded player utterances during play using CLAPS to play back game logs with audio (VII.B, page 126). CLAPS enabled fine-grained analysis of each utterance, linking it back to its game context. Audio is synchronized to the visualization of game activity. Each game was coded four times, once for each player in the game. CLAPS allows the researcher to selectively silence audio tracks, focusing on a single player. Researchers spatially distribute a single player's speech track and radio track to the left and right sides, respectively. Version 2.0 of the audio coding scheme (VII.D.4, page 137) was used to classify player utterances.

a. Audio Code Measures

In the present section, Table XXIII describes how the codes are normalized for use in analysis. For each of the five audio codes, the subscript $_p$ indicates a code utterance count is normalized against all the utterances by the player. An utterance code so normalized measures the *composition of a player's communication.* In T_e^2C, communication is a core mechanic. Player communication composition indicates how players are focusing the information they supply or request in play; it is how they are playing the game. The subscript $_t$ indicates that the code is normalized against the amount of time in a game. This allows measurement of the aggregate communication of teams, supporting *comparisons across teams*.

b. Anticipation Ratio

Anticipation ratio (AR; VIII.D.1, page 131) measures implicit coordination in teams. Recall that the function for calculating AR is:

$$AR = push/pull \tag{7.1}$$

In this chapter, we use a version of AR in which coordinator reports of information (*push*) are compared with seeker requests for information from the coordinator over the limited bandwidth of the radio (*pull*). The utterances used for this calculation are described in Table XXIII. When utterances classified as hybrid codes (VII.D.4.b, page 139), only the report component was included (the request component was not used to penalize AR); if a hybrid was multiple reports, the reports were added multiple times. The higher a team's AR, the better the team is at anticipating one another's information needs. An increase in AR indicates an improvement in implicit coordination.

D. Results

Results of the user study of T_e^2C with FERs consist of the change in team task performance, changes in communication, the impact of the coordinator role on play, the way roles differentiate themselves in terms of communication, and perceived connection to work practice. Quantitative measures are supplemented with qualitative data collected through use of CLAPS, discussions with participants, and comments participants made between games. To identify the source of qualitative data, we use the participant's pseudonym or assigned anonymous identifier (when the pseudonym would identify the participant). Table XXV describes the study participants.

Table XXV.: FTA student study participant interviewees from RC 128, summarizing self-report team activity experience. Member column indicates pseudonym or an assigned anonymous identifier (if pseudonym identifies the participant).

team	member	team activity[a]	years[b]
calTEXANADA	Jeff	firefighter	1–5
	Wilson0803	military, team sports	10–20
	<P-1-3>	band, medic	1–5
	<P-1-4>	<none>	0
Team Firestorm	Boomhower	firefighter	6–10
	Jack	<none>	0
	Ryan	firefighter	6–10
	<P-2-4>	<none>	0
Team Rainmen	Foxtrot1	team sports	1–5
	Hassy	firefighter	10–20
	Ian	auto maintenance	1–5
	<P-3-4>	<not specified>	1–5

[a] Based on free-response question: "Have you had any experiences in which communication was critical in coordinating a real-life team? If so, please describe." and discussions with participants.
[b] Based on multiple choice question: "Do you have any experience with *team-based* situations, such as (but not limited to) firefighting, community activism, military service, or police service? If so, how much?" Responses were year ranges.

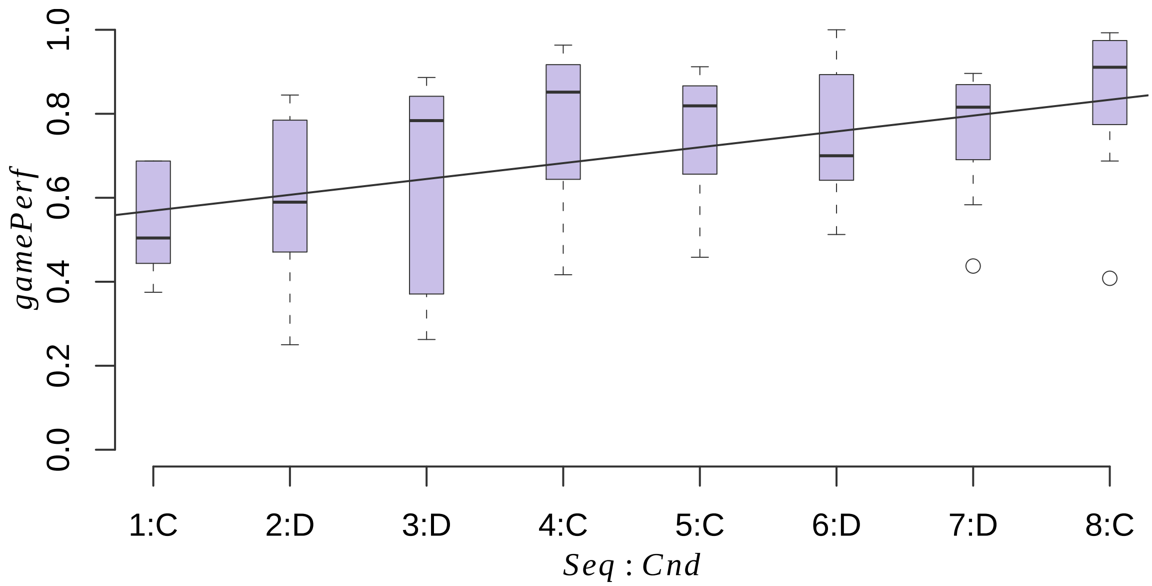


Fig. 43.: Box plot of team performance over time. Teams perform better in later games by cooperatively collecting goals.

1. *Team Task Performance*

For most measures, players improved their ability to play T_e^2C as a team through repeated sessions. They collected more goals in a shorter amount of time ($gamePerf{\sim}Seq$: $m = 3.294$, $R^2 = 0.1699$, $p < 0.005$; $score{\sim}Seq$: $m = 4.104$, $R^2 = 0.2411$, $p < 0.0005$). Teams completed the game faster as they played more ($cycRem{\sim}Seq$: $m = 6.973$, $R^2 = 0.07138$, $p < 0.06$). Game condition did not significantly impact performance ($gamePerf{\sim}Cnd$: $p > 0.4$; $outs{\sim}Cnd$: $p > 0.45$). Figure 43 plots game performance over time, showing the increasing trend. Figure 44 shows the within-team normalized *score* over time; teams' best games are later. *Cooperative task performance* improves over time.

As described above, the Grp_{iS} variables (where i is the largest group of seekers, 1, 2, or 3) indicate the percentage of the game seekers spent with avatars co-located in the virtual world. Game sequence strongly influenced the amount of time seekers

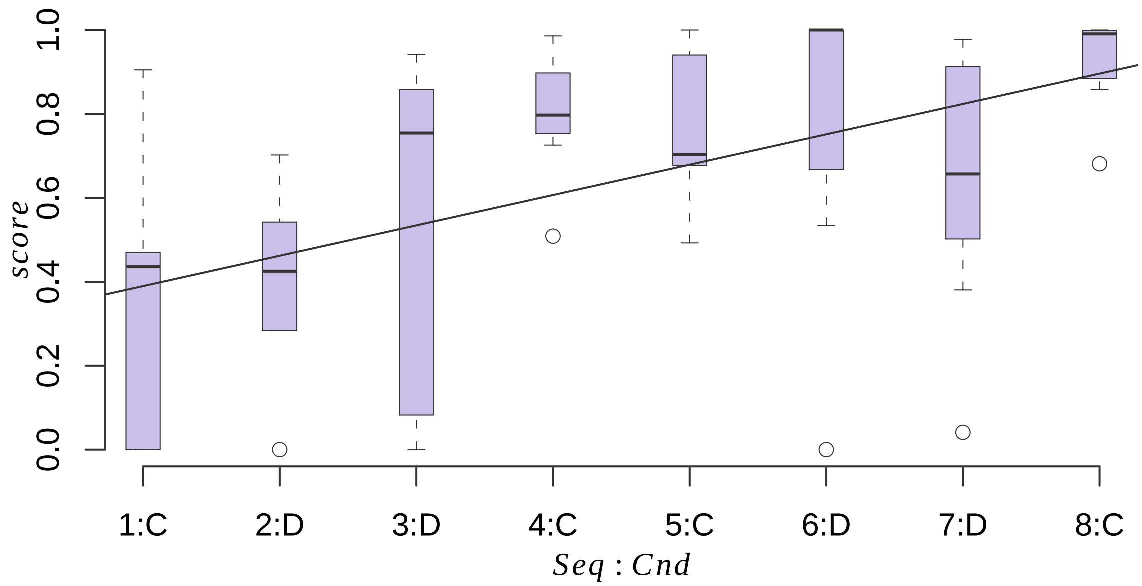


Fig. 44.: Box plot of scores, normalized within team, over time. Teams play their best games in the later sessions.

spent grouped in the virtual world (Grp_{3S}∼Seq: $m = 4.433$, $R^2 = 0.2613$, $p < 0.0001$; Grp_{2S}∼Seq: $m = -2.017$, $R^2 = 0.0713$, $p < 0.05$; Grp_{1S}∼Seq: $m = -4.466$, $R^2 = 0.2734$, $p < 0.0001$). Game condition did not strongly impact seeker group formation (Grp_{3S}∼Cnd: $p > 0.95$; Grp_{2S}∼Cnd: $p > 0.80$). Figure 45 charts the change in Grp_{3S} and Grp_{2S}, together, over game sequence. *Seeker co-location* occurs more frequently in later games.

One measure where the teams did not improve was in *outs*. Seekers were captured by threats more frequently in later games ($outs$∼Seq: $m = 2.165$, $R^2 = 0.08128$, $p < 0.05$). The frequency of going out was directly related to time spent co-located ($outs$∼Grp_{3S}: $m = 2.577$, $R^2 = 0.1191$, $p < 0.01$). *Seeker captures* occur more frequently later, but in conjunction with seeker co-location.

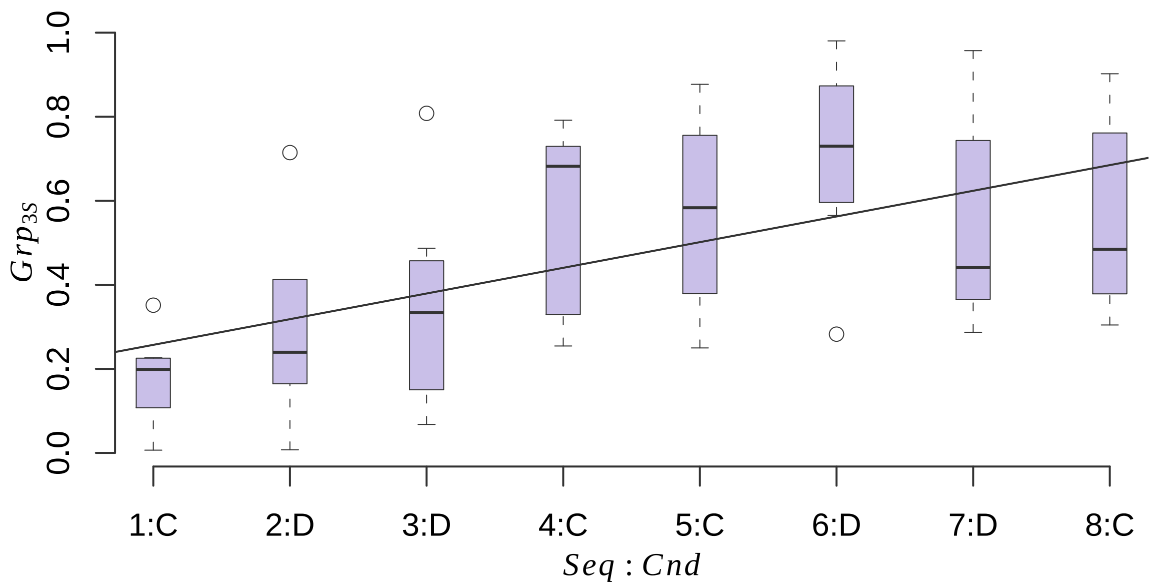


Fig. 45.: Box plot of seeker grouping activity over time. Seekers keep their avatars co-located more frequently in later games.

2. Changes in Communication

Participants reported changes in communication after playing the game. During interviews (Table XXV), participants noted that during burn training, ICs who had played T^2_eC used the radio more effectively: they were "...short, sweet, and to the point" [Boomhower] over the limited radio bandwidth. Participants completed the T^2_eC study prior to beginning burn training. Through play, participants find that *communication efficiency* increases.

In later games, the composition of communication shifts. Seekers request status less frequently ($RQS_{p[S]} \sim Seq$: $m = -3.553$, $R^2 = 0.07397$, $p < 0.0005$), they request game state more frequently ($RQGS_{p[S]} \sim Seq$: $m = 2.249$, $R^2 = 0.03101$, $p < 0.03$). Game sequence does not significantly impact any other communication type for seekers ($RQA_{p[S]} \sim Seq$: $p > 0.95$; $RPGS_{p[S]} \sim Seq$: $p > 0.99$; $RPS_{p[S]} \sim Seq$: $p > 0.45$).

Game sequence did not impact number of utterances by players ($UT_{t[S]} \sim Seq$:

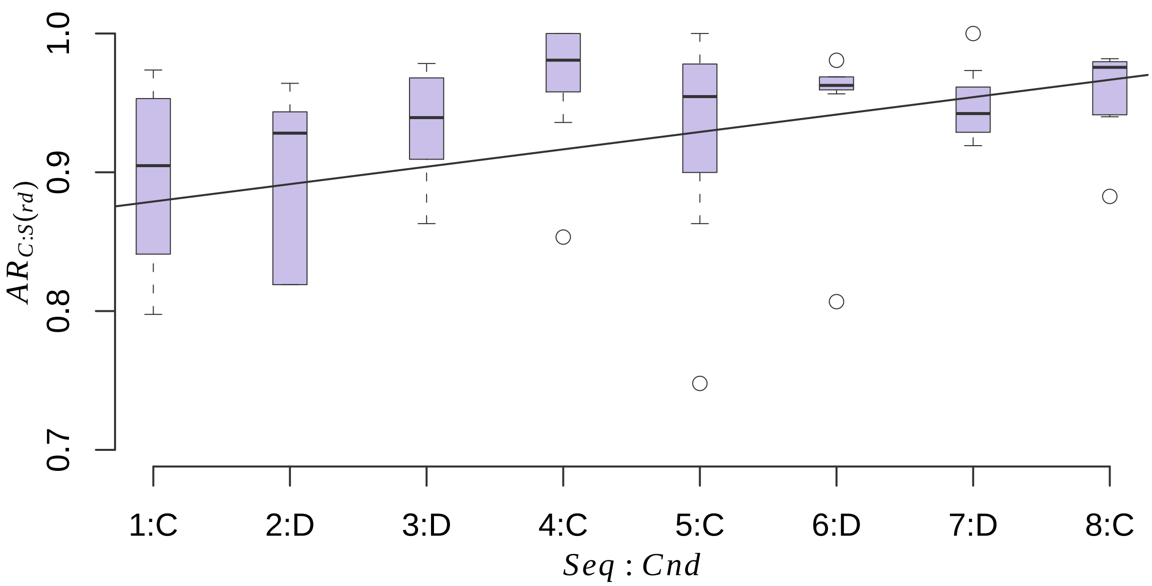


Fig. 46.: Box plot of anticipation ratio over time. Through play, coordinators get better at anticipating the needs of seekers, while seekers request less information.

$p > 0.9$; $UT_{t[C]} \sim Seq$: $p > 0.1$). Condition did impact the total communication by seekers; a one-tailed t test shows that *seekers* communicate more in the co-located condition ($UT_{t[S]}$, $Cnd = \{C, D\}$: $t = 14.9609$, $df = 100.067$, $p < 0.0001$). Condition did not impact total communication by coordinators ($UT_{t[C]}$, $Cnd = \{C, D\}$: $p > 0.3$).

Improvement in the teams' anticipation ratios were observed. For the present analysis, we compared the first pair of games ($Ses = 1$; $Seq = \{1, 2\}$) with the last pair ($Ses = 4$; $Seq = \{7, 8\}$). Using the audio data, we computed the AR for the coordinator's reports of information to players ($RPGS_{t[C]}$, $RPS_{t[C]}$, $RQA_{t[C]}$) to the seekers' requests for information over the radio ($RQGS_{t[S]}$, $RQS_{t[S]}$). This produced the measure, $AR_{C:S(rd)}$.

A one-tailed t test was performed, comparing $AR_{C:S(rd)}$ for $Ses = 1$ to $AR_{C:S(rd)}$ for $Ses = 4$. The result indicates an increase in anticipation ratio between the first and last sessions ($AR_{C:S(rd)}$, $Ses = \{1, 4\}$: $t = -1.8377$, $df = 12.638$, $p < 0.05$). Further analysis with a linear model revealed an overall increase in AR over repeated sessions ($AR_{C:S(rd)}$~Seq: $m = 2.035$, $R^2 = 0.07247$, $p < 0.05$). Condition did not meaningfully impact AR ($AR_{C:S(rd)}$~Cnd: $p > 0.2$). Using the version 2.0 game play coding scheme, we see that *anticipation ratio improves* through play.

Through CLAPS analysis, it is clear that participants sometimes respond to communication with action, rather than more communication. For example, requests for action, such as "follow me" did not prompt further communication, instead the indicated player follows the speaker. This supports the observation that AR improves through play.

3. Coordinator Performance Impacts Play

The coordinator's communication impacts the way participants perform in-game. Taking coordinator communication as an independent variable, coordinators requesting game state negatively impacted participants' ability to finish the game quickly ($cycRem$~$RQGS_{p[C]}$: $m = -2.018$, $R^2 = 0.07138$, $p < 0.05$). Further, coordinators reporting status negatively predicted time seekers spent together ((Grp_{3S}+Grp_{2S})~$RPS_{p[C]}$: $m = -2.495$, $R^2 = 0.1051$, $p < 0.05$).

4. Roles Impact Communication

The role players take on in the game (Rl) impacted the composition of their utterances to other players. A one-tailed t test was performed for each type of player communication (Table XXIII: $RQGS_p$, RQS_p, $RPGS_p$, RPS_p, and RQA_p), comparing the composition of communication by Rl. Figure 47 shows a box plot of the percentages, clearly showing the difference in communication types favored by roles.

Seekers request game state and status more frequently than coordinators do ($RQGS_p$, $Rl = \{S, C\}$: $t = -10.6609$, $df = 170.135$, $p < 0.0001$; RQS_p, $Rl = \{S, C\}$: $t = -8.7135$, $df = 209.778$, $p < 0.0001$). They also report status more frequently

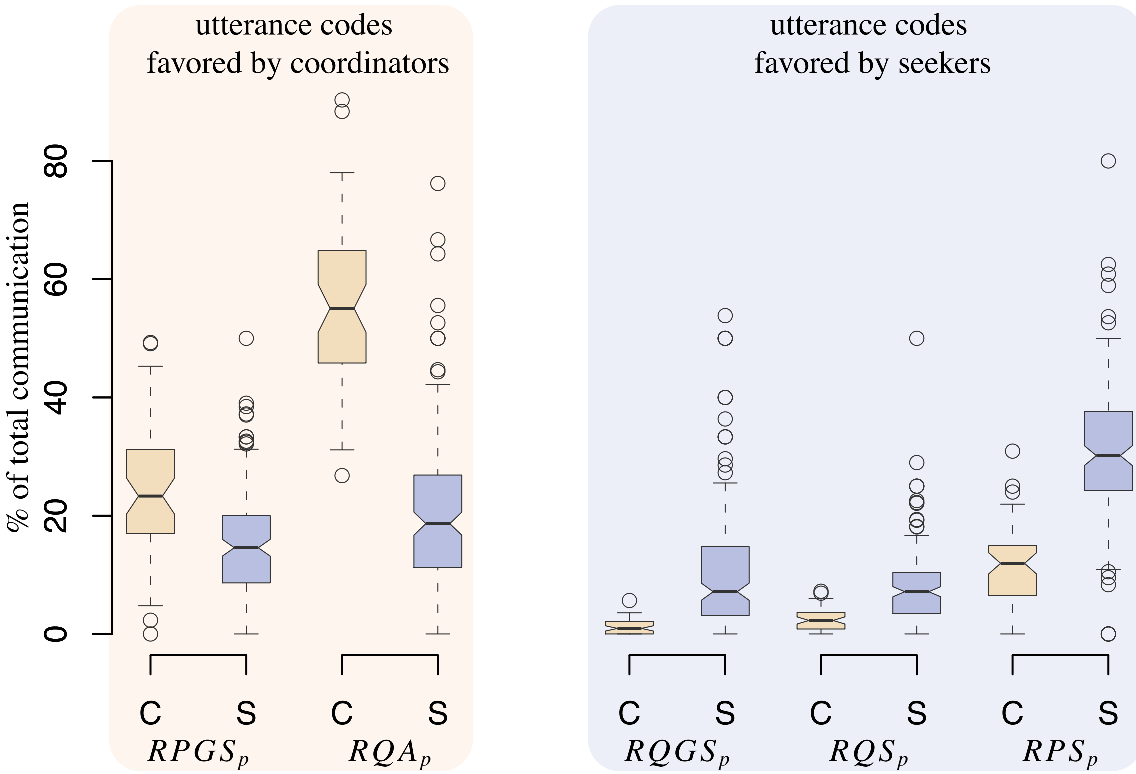


Fig. 47.: Box plot of impact of role on communication. In each pair, coordinator-preferred on the left, seeker-preferred communication types are on the right. Each graphed point represents one instance of a player in a game (since each player plays 8 games, there are 8 points for each player). Reports of game state and requests for action are used by coordinators, while requests for game state, requests for status, and reports of status are used by seekers.

(RPS_p, $Rl = \{S, C\}$: $t = -14.6489$ $df = 172.135$, $p < 0.0001$). Coordinators report on game state and request action more frequently than seekers ($RPGS_p$, $Rl = \{S, C\}$: $t = 5.1134$, $df = 78.126$, $p < 0.0001$; RQA_p, $Rl = \{S, C\}$: $t = 16.327$, $df = 94.253$, $p < 0.0001$). *Communication composition is dependent on role.*

5. *Communication Practice*

Based on qualitative data gathered from interviews with FER T^2_eC players, we found that players perceive a connection between the game and FER practice. The interviewees are shown on Table XXV, which summarizes their previous experience in team situations, as reported on pre-questionnaires.

Participants reported that “the rules of using a radio” were the same in T^2_eC and in FER practice [Jack]. According to participant Ryan, “The key to the game was (almost) less communication, and it’s the same on the fireground, too.” <P-1-3> noted that “on the fireground, there’s only one radio frequency, so you have to really... key in on when they’re talking to you... it really helped being able to listen for that.”. Another player noted that:

> It’s the learning of communication. . . it’s blanketed, it is not just with the game or with the fire service, once you learn how to communicate with a team, it just comes natural to start communicating like that. [Wilson0803]

During log playback, researchers noticed many instances of effective team coordination. In some cases, seekers inverted the chain of command, countermanding orders from a coordinator, based on situated information. This was particularly true around virtual world terrain walls, which the coordinator could not see. For example, in one exchange Ryan is the coordinator and addressed the seekers:

> **Ryan** [coordinator, addressing all seekers]: “Alright, head south. There should be a goal just south of you.”
>
> <**P-3-4**>: “’Kay, we’re going to head southeast and around this wall.”

In another game [Team 5], the coordinator told the seekers to head east to find goals. The seekers spotted a three-seeker goal nearby, to which the coordinator was not directing them. They notified the coordinator that they were stopping to collect the nearby goal, first.

Seekers used deictic reference to identify the invisible components of the virtual world. They use their avatars as pointers, then use statements such as “over there” or “this way”. In several games, Foxtrot and Company, Team 6, and Team 7 used the location of one of the seekers to indicate to the others the location of an invisible base.

In some teams, we observed a single player being designated as the lead communicator: the only seeker in a set of co-located seekers who will use the radio. This strategy reduced the load on the radio. In the case of firefighter students this may also be an outcome of training exercises: in many cases, burn training exercises are run where only the leader of a group of firefighters carries a radio. Jack explained:

> In a fireground, all three of us, if we were in one company sticking together, there would be one radio and one person talking, and we’d follow that guy. That’s kind of what we did.

This leader directs the group s/he is with and communicates to the IC.

Anecdotal evidence suggested that the creation of intermediate levels of command may be a helpful learning exercise, supplementing classroom learning. During a reflective session, calTEXANADA appointed one of their seekers as a “task force leader”[1]. The seeker leader would direct the other two seekers on the team during the next game.

The FTA Program Coordinator overheard part of the exchange. He asked the participant where the team had picked up “task force leader”, since they had not participated in class when it was discussed. The participant jokingly remarked that maybe they were paying attention after all.

---

[1] *task force*: “Any combination of [personnel or equipment used in an operation] assembled to support a specific mission or operational need. All resource elements within a Task Force must have common communications and a designated leader.” [U.S. Department of Homeland Security 2004]

E. Analysis

The principal hypothesis of the present research—*by playing non-mimetic simulation games (T_e^2C), developed from work practice, FERs learn to more effectively coordinate as a team*—is supported by six subordinate hypotheses. In this section, we describe which of our subordinate hypotheses were supported by the results. The principal hypothesis is treated directly in the Conclusion (Chapter X, page 186).

1. *H-2-1: Improving at Cooperative Tasks*

H-2-1 Through game play, participants will improve their ability to accomplish cooperative tasks.

Players improve their *cooperative task performance* over time by practicing collaborative action, supporting H-2-1. The design of cooperative goals in T_e^2C requires that players work together to play effectively [Toups Dugas et al., "Game design principles," 2009]. The performance of the team depends on seekers gathering together at specific points in the map, without going out. In spite of the difficulty of gathering, players succeed at collecting more goals in less time.

We see that seekers learn to *co-locate* in the virtual world and successfully collect more cooperative goals. It makes sense that these findings go together, as being grouped is a prerequisite to collecting the goals. There are two possible mechanisms for gathering: moving together or meeting up. The amount of time spent together indicates that seekers find it effective to move together through the virtual world. According to Boomhower, Team Firestorm "...learned pretty quick that if all three people stayed together... that was the easiest way to get it done." An alternative strategy, that is rarely employed, is to locate a goal that requires multiple seekers, then meet up at that location.

Moving together can be difficult because the seeker view port only shows them what is ahead and not, for example, that a companion is following behind (see Figure 42). Staying together means that seekers are frequently in more danger, as one threat can easily destroy the whole group.

One puzzling result that is that *seeker captures* occur more in later games. This is likely due to the dangers of grouping: once a group of threats attacks one seeker, it is easy to attack the other seekers nearby. It could also be that the teams become desensitized to the score penalty associated with going out (VI.B.3, page 93), instead favoring winning quickly. In FER work practice, failure to move safely through an environment can result in injury or death; the consequences are significantly more severe in the real world than in the game.

Some player communications indicated that other players should move to a location, regardless of whether or not they are attacked. The players' rationale was that there are sufficient bases at which to restore, so it is better to hurry to the next location than to avoid attacks on the way. This suggests interesting future research in which the penalty for going out is more severe.

2. H-2-2: Differentiation of Roles

H-2-2 Player roles, differentiated by information distribution and available action, will impact team communication.

That *communication composition is dependent on role* demonstrates that information distribution is effective in altering team communication, supporting H-2-2. Coordinators, who can only influence game play through radio communication, use communication that *directs* and *informs*. Seekers, who need information about the world outside of their scope receive that information from the coordinator. They *request* what they need to know. They supply one another and the coordinator with information about their own *status*, about which they are intimately aware.

In FER work practice, alternate perspectives and positions at the emergency incident enable different sets of action and communication. The IC has access to etic information through information artifacts (III.D.1, page 28); these enable tracking status of firefighters, like the coordinator's interface. Radio communication is available to both the IC and the firefighters, supporting low-fidelity communication. The IC directs the team, as the coordinator does.

The firefighters, at the fireground, have direct access to emic information about the situation, like the seekers. They know and communicate about the state of their environment and their bodies, like reporting game state and status. While in T_e^2C, the coordinator reports game state more frequently, it is the smallest difference of all the types of communication ($|t| = 5.1134$ for $RPGS_p$, the next smallest is $|t| = 8.7135$ for RQS_p).

We also see that seekers, but not coordinators, communicate more frequently in co-located games. These games offer more expressive power than distributed games, as players can communicate face-to-face, instead of only using the radio. The coordinator, like the IC, cannot communicate face-to-face.

The design principle of information distribution is derived directly from work practice, and is hypothesized to be essential for non-mimetic simulation of team coordination. This hypothesis is proven through H-2-2.

3. H-2-3: Play Condition Does Not Impact Cooperative Tasks

H-2-3 Play condition, either co-located or distributed, will impact ability to accomplish cooperative tasks, reflecting a need to mix communication modalities.

We find that game condition does not significantly impact team performance. There were no significant relationships found between the performance and game condition or grouping and game condition. The data do not support H-2-3.

In fire emergency response work practice, FERs can dynamically reconfigure their teams: they can split up and come together. This enables a rich mix of face-to-face and radio communication, as the situation permits. Unlike in fire emergency response work practice, T_e^2C players cannot make decisions about splitting up and coming together. They are constrained by the medium through which the game is presented. In a future, mixed reality version of T_e^2C, players would be free to move, split up, and join together. This suggests that a mixed reality version of T_e^2C will more strongly reflect mixing communication modalities.

4. H-2-4: Improving Implicit Coordination

H-2-4 Through game play, participants will improve their ability to implicitly coordinate.

We find that team *anticipation ratio improves through play*, supporting H-2-4. A high AR is indicative of a shift to implicit coordination [Entin and Serfaty 1999], that team members are actively sharing information and finding that their own information needs are fulfilled. The observed increase in participants' AR suggests they are learning to implicitly coordinate. The team reduces their communication overhead [MacMillan et al. 2004], increasing the amount of communication that informs and commands, rather than requests. The requests are noise; less noise is better.

The fact that a decrease in overall communication was not observed is not unusual. Entin and Serfaty [1999] observed that after intervention, their participants only decreased overall communication in a low-stress condition, where there was less information about which participants needed to communicate. In the high-stress condition, the communication rate did not change, although AR improved.

We find that one strategy that improves AR is that team members respond with action, rather than communication. In connecting to practice, participants noted that it was essential to communicate less and that their *communication efficiency* increases. Ryan noted that while responding to communication with action was essential, the game design allowed the coordinator to see this, while in reality, the IC might not. This suggests an interesting new line of research, in which we manipulate information distribution to provide the coordinator with even less information.

An essential component of effective team coordination is implicit coordination. The purpose of the T$_e^2$C game design is to encourage participants to develop good implicit coordination skills.

5. H-2-5: Reflection of Play in Practice

H-2-5 Game play will be reflected in team coordination ability in burn training exercises.

Participants report that game play impacts burn training, offering qualitative support for H-2-5. They note that ICs who have played the game are more effective during burn training; they display expert use of the radio. Participants see that learning to communicate is a skill that can be applied outside of the game. Future work will investigate H-2-5 through quantitative means.

6. H-2-6: Reflection of Practice in Play

H-2-6 Communication and activity in T$_e^2$C will resemble communication and activity in fire emergency response work practice.

We find that participants act like FERs while playing the game, supporting H-2-6. FER students employ FER jargon while playing and communicating. Some players refer to threats as “fire”.

Moving together reflects fire emergency response work practice. FERs work together for safety; they stay within sight of each other [Toups Dugas and Kerne 2007]. A minimum of two FERs are required to do any work at the fireground. The behavior of staying together while performing tasks in the game suggests the ecological validity of the game activity for fire emergency response work.

Further, moving together is made difficult by the game design. When players move together, there is not safety in numbers, but rather danger that the whole team will be lost. Nonetheless, participants find it to be an effective strategy, which helps to explain away the fact that players go out more frequently in later games.

Seekers act on situated information, like FERs. They use local, detailed information to make decisions that may countermand their orders. This may include careful navigation through spaces about which the coordinator is not aware, or collecting nearby goals that the coordinator has missed. In FER practice, taking situated action [Suchman 1987] is essential [Toups Dugas and Kerne 2007].

F. Discussion

Many of the findings with FERs parallel those findings with non-FERs (VIII, page 143). This evidence supports our hypothesis that non-mimetic simulation can transferred across domains. In this section, we address the value of play in firefighter education, discuss the selective mimesis used in T^2_eC, consider iterations on the study design, and explore alternative game mechanics that alter the information distribution on the team and could provide testbeds for future fire emergency response field technologies.

1. Value of Play

Participants report that they see the value of play. They note that communication in the game reflects work practice. Participants employ FER jargon while playing.

Although they do not always directly connect threats with fire ("fire doesn't chase you around the building" [Jack]), they do see the value of threats for creating real-time stress (IV.F.3, page 48). Members of Team Firestorm remarked that without the threats, the game would be too easy and it would not be as necessary to communicate. Players of Team 5 explicitly referred to threats as "fire" in their communication.

In keeping with the design goal that T_e^2C not have a specific theme (VI.E, page 114), threats are designed to be different from fires. They are not intended to directly replicate fire, they do not exhibit the behavior of fire, but are intended to place constraints on play. The virtual-world danger supplied by threats requires participants to make fast decisions about what information is most critical to the team's success.

2. Selective Mimesis

The increase in the number of times seekers go out in later games may indicate that the selective mimesis is effective. While one might expect that FER players would avoid "dying" in the virtual world, going out does not have the same ramifications as failure in FER practice. This is by design: permanent "death" would reduce the play and educational value of the simulation. This shows that the FER students see the environment as different from their normal training; they take advantage of the unique characteristics of the simulation.

In allowing players to restore at bases, they are able to continue play; going out is a setback, but not game over. Further, if all players are permanently out, the game must end prematurely, reducing the amount of time participants are able to engage with it.

3. Updates to Study Design

Based on the results of this study, we revised our study methods for future research. The next design introduces more experimental control, while potentially reducing the ecological validity of the study. The first update removes the game conditions. Rather than running two games per session, one co-located and the other distributed, all games are distributed. The second update introduces control subject teams. These teams will play a board game, rather than T^2_eC. Further, we will gather the grades of students who play neither game. We can then compare burn training and classroom performance of T^2_eC teams, non-T^2_eC game teams, and non-playing teams.

To discourage players from discounting going out, we modified the map layout. The new map layout features fewer bases, and an off-center starting area. Bases are small, with large spaces in between. This retains the design choice that players are able to restore ("death" is not permanent), but makes restoring more difficult. The starting point is the most familiar region of the map for players, because they experience it repeatedly. In the designs presented here, the starting point is near the center of the terrain. The new, off-center starting point means that players have to explore a larger distance from the place they start in order to find all the goals.

Because much of the later variance in play comes from the time taken to complete the task, and not the number of goals collected, we increased the number of goals in the game. We also hypothesize that the longer participants are engaged with the game, the more it will impact their performance in real life. Because better performing teams finish faster in the current design, they engage with the system less. In future studies, all maps have twice as many goals (24 instead of 12). The map is also four times as large, to support the increased number of goals and create greater distances between the goals.

4. Alternative Game Mechanics

Based on observations of play and team performance, alternative game mechanics are suggested. One alternative further manipulates information distribution, so that the coordinator is even more reliant on seekers. This might take the form of seekers self-reporting their locations and the coordinator recording this information on the interface. Such a design could investigate the use of touch screens (including multi-touch) for tracking teams in dangerous environments. It could be used to prototype real life FER support tools, similar to the interface prototype by Denef et al. [2008]. We might algorithmically manipulate the seekers' locations, causing a delay between when they move and when their avatars move, or introduce noise into the location data so that locations are uncertain.

Another alternative game mechanic might encourage seeker groups to break up and come together. Goals could require that seekers to gather at *different* points on the map, rather than the same point. Play would shift so that seekers need to coordinate action while not co-located, putting more reliance on effective disembodied communication, rather than deictic reference.

5. Motivation

Participants were highly motivated to participate in game play. Teams competed with one another, using score and public leaderboards. They were excited and interested in how other teams performed, relative to their own. Competition motivated improvement and engagement with the system. The framing of the simulation as game successfully engaged participants.

CHAPTER X

CONCLUSION

The present research creates and evaluates game designs for the *non-mimetic simulation of team coordination* for fire emergency responders. Non-mimetic simulations, as invented and developed in the present research, are economical, focused, and potentially transferrable; crafted as games, they provide motivation. The present research investigates how they are economical, focused, and motivating. Future work will investigate transferability.

We argue that the games we develop are not mere "training devices" [Gagné 1954], but are non-mimetic *simulations*. While the goal in traditional simulation is to capture the situated context in which a task (or many tasks) is to be performed, the present research captures the task itself and re-situates it abstractly. In re-situating, we enable a range of possibilities, including economy of scarce simulation resources, intrinsic motivation to engage with the simulation, focus on the task, and, potentially, transferability.

We have shown that non-FERs improve at the cooperative tasks in the T^2_eC game and see them develop strategies that substantively match those of FERs. Participants find that *relevant aspects of work practice are simulated*; we show that players engage in the same processes as practitioners. T^2_eC helps FER students learn to team coordinate more effectively. Participants improve their ability to accomplish cooperative tasks; they improve their implicit coordination skills, marking a shift toward becoming a high-performance team. Design principles uncovered through the present work have far-reaching implications, suggesting ways in which team coordination learning can effectively take place through non-mimetic simulations and cooperative games.

The principal hypothesis of the present research is that *by playing non-mimetic* *simulation games (T^2_eC), developed from work practice, FERs learn to more effectively coordinate as a team.* Through the present research we develop a deep understanding of team coordination within the domain of fire emergency response work practice. We invented the model of non-mimetic simulation to capture the tasks and skills used by high-performance teams to economize limited communication channels and share information effectively, abstracting human- and information-centric aspects of practice. We iteratively developed a set of game designs from work practice to capture the essential skills of team coordination. From a grounding in practice and observation, we construct new measures to evaluate team coordination. To determine the value of non-mimetic simulations of team coordination practice, show the value of games and play in education, and iterate designs to be more effective, we tested the game designs with non-FERs and FERs. Through playing $\mathrm{T^2_eC}$, FER students learned to implicitly coordinate.

A. The Task of Team Coordination

To develop team coordination education systems, a deep understanding of team coordination in practice was essential. This work began with an ethnographic investigation of work practice at one of the world's largest firefighter schools: Brayton Fire Training Field. Through that work, we came to understand the essential value and burden of distributed teams with distributed information. Team roles are dynamically configured, and include possible action, information access, and communication capabilities. Communication needs must be balanced against the situation at hand, creating a need to dynamically mix communication modalities to match. FERs economize expensive communication by overhearing critical environment and teammate sounds. Team members cooperate to perform complex activities under real-time stress, while sharing information.

Information distribution and team coordination support situation awareness in teams. FER teams are flexible because they can effectively redistribute and reconfigure themselves in response to changes in the incident. Team members use their diverse perspectives to gather information. The information from these situated perspectives is synthesized to make new discoveries. Team members use their prior knowledge, the information that is fed to them through the radio and through face-to-face meetings, and their observations. They combine what they know with what they are observing, leading to discoveries about needs that must be addressed and creating awareness of the situation. Once synthesized, the information must be filtered and transformed. What is necessary to share? How can it be shared? How does it fit into the team's objectives?

The roles in FER teams are defined not just by what actions are available and the duties to be performed, but also information access and communication capabilities. On the surface, actions are the most important: teams are designated to perform specific tasks to which they are suited. The actuality is that *where* a task takes place determines *what information is available*, *the form of information*, and *which team members are co-located*. All team members need to gather and share information.

Once information is gathered, filtered, and transformed, it must be disseminated to the team. The nature of the information and the situation drive the choice of how and what to share. Face-to-face communication is possible only in a local scope; small teams are co-located, but others are spread over a wide area. Some information is only locally relevant, so there is only a need to speak face-to-face with other nearby FERs. In other cases, it is overly complex, warranting a face-to-face meeting with someone remote. Radio reaches all team members simultaneously, but is slow and difficult to understand. If the information is short and clear, or involves all team members at the incident, it should be carried over the radio.

Teams need to economize their limited communication resources. Resources include the time and cognitive overhead of communication, as well as technological bandwidth. In reducing time and cognitive overhead, the team is able to act more; in the case of technological bandwidth (radio use), the opportunity cost is that the bandwidth is unavailable for other, potentially more important, uses. One effective mechanism employed by FERs involves overhearing and monitoring. FERs are able to monitor remote environments by listening in on communications for background sounds. They overhear others' conversations and incorporate the data obtained into their mental models.

All team activities take place under real-time constraints: activities must be performed quickly to save lives and property, while minimizing risk to the FERs. Actions are highly interdependent and cooperative. Dangerous situations change constantly; sometimes predictably and sometimes not. Constant situation awareness aids FERs in tracking the progress of an incident, supporting prediction of dangerous events.

The present understanding of the task of team coordination in FER practice suggests the following hypotheses be investigated in testing whether or not an education system constructed for teaching team coordination is effective:

H-1-1, H-2-1 Through game play, participants will improve their ability to accomplish cooperative tasks.

H-1-2 Through game play, participants will improve their ability to coordinate.

H-2-3 Play condition, either co-located or distributed, will impact ability to accomplish cooperative tasks, reflecting a need to mix communication modalities.

H-2-4 Through game play, participants will improve their ability to implicitly coordinate.

B. Simulating the Team Coordination Task

As described above, a number of elements are essential to team coordination in practice. Participants have to learn to gather, synthesize, filter, and transform information from diverse perspectives while under real-time stress. The model of non-mimetic simulation derives from these human- and information-centered aspects of practice; it takes abstraction as its central design principle.

Fundamental to the design of effective mimetic simulations is the level of fidelity, the faithfulness of recreating the concrete world. Unlike traditional simulations, in which the goal is to reproduce the real world environment in a high level of detail, non-mimetic simulations use abstraction as a design principle. In non-mimetic simulations, participants work in a *zero-fidelity* task environment.

Once a domain is selected, the design task becomes one of *evaluating what must be practiced unchanged*, *what can be transformed*, and *what can be eliminated*. This is discovered through a grounding in practice. What components of the environment are not essential to performing the task? What components can be transformed without loosing their essential natures? Deep knowledge of the domain is necessary to answer these questions. While we observed no need to mimic fire and smoke, the need to limit visibility and create real-time stress were essential. In the case of using the half-duplex radio, its fundamental qualities make it essential and so it is incorporated, unchanged. Information distribution is central to the character of fire emergency response practice; it is a necessary component of the work and was essential to reproduce in simulation.

The present research has developed a number of abstractions of the FER team coordination domain: information distribution, mixing communication modalities, audible cues, real-time stress, and participant roles. From our deep understanding of team coordination, we take these abstractions to be the essential components of team coordination as it is practiced in fire emergency response.

The design principles underlying the model of non-mimetic simulation suggest the following hypotheses be investigated:

H-1-1, H-2-1 Through game play, participants will improve their ability to accomplish cooperative tasks.

H-1-2 Through game play, participants will improve their ability to coordinate.

H-1-3 Communication and activity in T$^{2}_{e}$C will resemble communication and activity of FERs.

H-2-2 Player roles, differentiated by information distribution and available action, will impact team communication.

H-2-3 Play condition, either co-located or distributed, will impact ability to accomplish cooperative tasks, reflecting a need to mix communication modalities.

H-2-4 Through game play, participants will improve their ability to implicitly coordinate.

H-2-5 Game play will be reflected in team coordination ability in burn training exercises.

H-2-6 Communication and activity in T$^{2}_{e}$C will resemble communication and activity in fire emergency response work practice.

C. Iterative Development of Non-mimetic Simulation Game Designs

Non-mimetic simulations provide a focused, economical learning environment, while educational games motivate participants to engage with them. Games are fun; they are intrinsically motivating. People engage with a game for no reason other than playing the game. Games can also provide external motivation through reward structures. Competition and cooperation are essential components of the joy of play.

The present research uses scoring systems to provide players with feedback on their performance. When compared between teams, the scores are a powerful competitive motivator. We offer players externally motivating rewards at the team level, encouraging teams of cooperating players to compete across teams, but not within.

Team coordination is a form of cooperation. When it is part of the game mechanics, cooperation can be part of the motivation for play. Communication becomes a core mechanic. The present work engages players in cooperative activities. Through constant playtesting, we develop a set of design principles for engaging cooperative play, from a grounding in non-mimetic simulation of team coordination. The principles engage players in cooperation and communication as game mechanics, without sacrificing the design needs of our non-mimetic simulation.

In cooperative games, *information should be distributed among players*, so that players are reliant on one another. This reliance creates the *need to communicate*, engaging players in processes of team coordination. Distributing information can be accomplished by *modulating visibility* in the game interface, selectively making information visible or invisible to different players.

Because communication takes time to perform, and game mechanics continuously unfold, participants must be able to communicate information easily. Thus, *information timing* must be considered when modulating visibility. Rapidly changing information that is distributed must either be easy to discuss, or readily available to players that need the information. Slow-changing information is a good candidate for making invisible and creating interdependency.

Making game entities predictable supports shared mental model formation between players. While players are situationally aware, they can predict how the game will react to their input. This enables a level of abstraction in game communication: players can communicate about trajectories rather than current, absolute information.

Representations of information must be *readily communicable*. Simplifying by reducing granularity is one strategy for making information communicable. Simplifying the information to be communicated supports players in coordinating as a team and developing shared mental models.

The benefits of educational game play and the design considerations it requires suggest the following hypotheses be tested:

H-1-1, H-2-1 Through game play, participants will improve their ability to accomplish cooperative tasks.

H-1-4 The introduction of a scoring system will motivate play.

D. Evaluating Team Coordination

Evaluating team coordination performance is difficult. Some prior methods rely on eliciting information from participants to uncover shared mental models. Other methods look at self-reports of the social bonds between team members. Observation of instances of effective coordination and audio coding are also employed. The present research contributes to knowledge of how to evaluate team coordination by developing metrics for automatic computation of team task performance and a coding scheme for quantifying the content of team communication.

The value of game play for investigating team coordination is dependent on the game consisting of mechanics that invoke the task being learned. T^2_eC players engage in learning team coordination, so measurement focuses on the aspects of play that are cooperative. We look at cooperative goal collection, which requires that seekers perform risky tasks together. Their success at completing these tasks indicates that they are effectively timing simultaneous actions while under real-time stress. Another measure is seeker co-location, where players stay together and support each other by providing information and guidance.

Communication is a window into team coordination; prior research suggests that implicit coordination can be observed through communication. The game play audio coding scheme is grounded in work practice and game play. Independent researchers are able to apply it consistently to game playback. Through its application, we show how information distribution affects the composition of communication in different roles. We see anticipation ratio improve over time, indicating the shift to implicit coordination.

E. Learning to Effectively Coordinate by Playing T^2_eC

> By playing non-mimetic simulation games (T^2_eC), developed from work practice, fire emergency responders (and players) learn to more effectively coordinate as a team.

The supported subordinate hypotheses in the previous two chapters build up evidence supporting the the principal hypothesis: through play, participants improve team coordination. Non-FERs and FER students learn to accomplish cooperative tasks by sharing information and synchronizing actions in the virtual world. We find that participants use different types of communication behavior, depending on their role in play. Players react to the information distribution of their roles, which mirror those of FER practice.

Participants improve their implicit coordination skills. Implicit coordination has been shown to be essential to high performance teams, like fire emergency response teams. The value of implicit coordination is that it reduces communication overhead, freeing workers to focus on the task at hand and keep communication bandwidth open for emergency use. Participants find that the shift from explicit coordination to implicit coordination prepares them for burn training exercises. Burn training exercises do not specifically target team skills, but team coordination is essential to excel. Play encourages FER students to think about the bandwidth of the radio, and consider its economy.

The present game design is not a direct mimesis of FER work practice. Despite the lack of mimesis, the reflection of practice in play indicates that the non-mimetic simulation is sufficiently like work practice. It engages participants in real-time stress, which motivates them to act as if there were an emergency. The *team coordination tasks of fire emergency response work practice are successfully simulated.*

F. Future Work

The present research highlights a number of areas of promising future work. The hypothesized transferability of non-mimetic simulations across disciplines is one such area. Another addresses the need of human teams to dynamically switch between co-located and distributed team layouts. The development of mixed reality games will investigate the value of such abilities for learning team coordination.

1. Investigating Transferability

We intend to investigate the transferability of this non-mimetic simulation into other domains where team coordination is critical. In particular, we intend to work with teams of programmers. Experiments will determine if the T^2_eC game developed from the intense team coordination of fire emergency response work practice will support learning team coordination for these participants.

Because the present research works with teams, an alternate form of transferability looks at how team performance transfers across teams within the same domain. Future research may investigate remixing team members during the T^2_eC study to examine if their performance improves with unfamiliar team members. Indications from the present studies are that the team knowledge is general and not specific to the group that played together. Further, the work by Gorman et al. suggests that team performance may initially degrade, but will ultimately improve when team members are mixed [2006].

2. Mixed Reality

Additional future work will address the value of mixed reality forms of the same non-mimetic simulation. Such designs will support natural mixing of communication modalities. Participants are able to dynamically reconfigure their groups, with concomitant changes in available communication modality. The mixed reality version of T^2_eC is hypothesized to better support the learning of team coordination skills because communication modalities selection will be dynamic and need to consider an embodied operating environment.

G. Closing

The present work has developed a specific type of non-mimetic simulation to show how human-centered aspects of work can be practiced in an alternative environment. It successfully abstracts team coordination tasks from the fire emergency response domain and focuses learning.

Most simulations focus on being mimetic, expending resources to accurately capture as much of the real world as possible. Such simulations produce easily demonstrable results. While the benefit of training with mimetic simulations is immediately clear, the present work develops a different paradigm. Non-mimetic simulations provide a focused learning experience, without the distraction of other components of work practice. They are economical, avoiding the unnecessary expenditure of resources. Developed as games, they are entertaining. The game framing supports engagement. Internal motivation derives from the joy of playing: the experience is autotelic, fulfilling in and of itself. External motivation is provided through the use of score and public leaderboards. By competing with other teams, participants are motivated to try harder.

Non-mimetic simulation abstracts tasks from a real-world environment and resituates them in an alternative one. It opens an exciting door for new forms of hands-on education in which participants learn human-human interaction skills that are essential in a number of domains. As abstract, socio-technical systems, they can be used to educate participants in distributed cognition tasks.

Games are becoming an increasingly important component of education. The value of games in education cannot be denied, but difficult design questions remain. In many systems, there is a balance between learning and fun. In failed systems, students disengage or do not learn. In successful designs, such as T_e^2C, participants enjoy the experience and learn without a need to consider balance. Players are engaged and improve their abilities of cooperation and communication through practice with each other.

REFERENCES

ANTONISSE, J. AND JOHNSON, D. 2008. *Hush*. [PC]. [self published]. Played June 2010. Available from: http://interactive.usc.edu/members/jantonisse/2008/01/hush.html.

AONUMA, E. AND MIYAMOTO, S. 2006. *The Legend of Zelda: Twilight Princess*. [Wii]. Nintendo, USA. Played February 2006.

ARROW, H., HENRY, K. B., POOLE, M. S., WHEELAN, S., AND MORELAND, R. 2005. Traces, trajectories, and timing: The temporal perspective on groups. In *Theories of Small Groups: Interdisciplinary Perspectives*, M. S. Poole and A. B. Hollingshead, Eds. Sage Publications, Inc., Thousand Oaks, CA, USA, 313–367.

BALLAGAS, R. A., KRATZ, S. G., BORCHERS, J., YU, E., WALZ, S. P., FUHR, C. O., HOVESTADT, L., AND TANN, M. 2007. REXplorer: A mobile, pervasive spell-casting game for tourists. In *CHI '07: CHI '07 Extended Abstracts on Human Factors in Computing Systems*. ACM Press, 1929–1934.

BARAFF, D. AND WITKIN, A. 1999. Physically based modeling course notes. *SIGGRAPH '99: Courses*.

BARKHUUS, L., CHALMERS, M., TENNENT, P., HALL, M., BELL, M., SHERWOOD, S., AND BROWN, B. 2005. Picking pockets on the lawn: The development of tactics and strategies in a mobile game. In *Ubicomp '05: Proceedings of the 7th International Conference on Ubiquitous Computing*. Springer, 358–374.

BARTHES, R. 1991. Myth today. In *Mythologies*. The Noonday Press, New York, NY, USA, 109–158. Translation by Annette Lavers.

BAYLISS, P. 2007. Notes toward a sense of embodied gameplay. In *Situated Play: Proceedings of the 2007 Digital Games Research Association Conference*, B. Akira, Ed. The University of Tokyo, 96–102.

BEDERSON, B. B. AND BOLTMAN, A. 1999. Does animation help users build mental maps of spatial information? In *INFOVIS '99: Proceedings of the 1999 IEEE Symposium on Information Visualization*. IEEE Computer Society, 28–36.

BEDWELL, B., SCHNÄDELBACH, H., BENFORD, S., RODDEN, T., AND KOLEVA, B. 2009. In support of city exploration. In *CHI '09: Proceedings of the 27th International Conference on Human Factors in Computing Systems*. ACM Press, 1171–1180.

BELL, M., CHALMERS, M., BARKHUUS, L., HALL, M., SHERWOOD, S., TENNENT, P., BROWN, B., ROWLAND, D., AND BENFORD, S. 2006. Interweaving mobile games with everyday life. In *CHI '06: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM Press, 417–426.

BENFORD, S., CRABTREE, A., FLINTHAM, M., DROZD, A., ANASTASI, R., PAXTON, M., TANDAVANITJ, N., ADAMS, M., AND ROW-FARR, J. 2006. Can you see me now? *ACM Transactions on Computer-Human Interaction 13,* 1, 100–133.

BENFORD, S., FLINTHAM, M., DROZD, A., ANASTASI, R., ROWLAND, D., TANDAVANITJ, N., ADAMS, M., FARR, J. R., OLDROYD, A., AND SUTTON, J. 2004. Uncle Roy All Around You: Implicating the city in a location-based performance. In *Proceedings of ACM Advances in Computer Entertainment (ACE) 2004*. ACM Press, [published online].

Benford, S., Rowland, D., Flintham, M., Drozd, A., Hull, R., Reid, J., Morrison, J., and Facer, K. 2005. Life on the edge: Supporting collaboration in location-based experiences. In *CHI '05: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM Press, 721–730.

Benson, K. B. and Whitaker, J. C. 1990. *Television and Audio Handbook for Technicians and Engineers*. McGraw-Hill Publishing Company, New York, NY, USA.

Björk, S., Falk, J., Hansson, R., and Ljungstrand, P. 2001. Pirates! using the physical world as a game board. In *Proceedings of IFIP INTERACT01: Human-Computer Interaction 2001*. IFIP, 423–430.

Blattner, M., Sumikawa, D., and Greenberg, R. 1989. Earcons and icons: Their structure and common design principles. *Human-Computer Interaction 4,* 1, 11–44.

Blizzard Entertainment. 1994. *WarCraft: Orcs & Humans*. [PC]. Blizzard Entertainment, USA.

Borriello, G., Chalmers, M., LaMarca, A., and Nixon, P. 2005. Delivering real-world ubiquitous location systems. *Communications of the ACM 48,* 3, 36–41.

Brevik, D., Hedlund, S., Schaefer, E., Clements, C., Schaefer, M., and Sexton, E. 2000. *Diablo II*. [PC]. Blizzard Entertainment, USA. Played June 200.

Brewster, S. A. 2002. Non-speech auditory output. In *The Human Computer Interaction Handbook: Fundamentals, Evolving Technologies, and Emerging Applications*, 2nd ed., J. Jacko and A. Sears, Eds. Lawrence Earlbaum Associates, New York, NY, USA, 247–264.

Brown, B., McColl, I., Chalmers, M., Galani, A., Randell, C., and Steed, A. 2003. Lessons from the lighthouse: Collaboration in a shared mixed reality system. In *Proceedings of the CHI 2003 Conference on Human Factors in Computing Systems*. ACM Press, 577–584.

Bungie Studios. 2001. *Halo: Combat Evolved*. [Xbox]. Microsoft Game Studios, USA. November 2001.

C3Fire. 2009. C3Fire.org - C3Fire - home. Available from: http://c3fire.org.

Cakebread, S. 2008. *Geometry Wars: Retro Evolved 2*. [Xbox 360]. Activision, USA. Played May 2010.

Cannon-Bowers, J. A. and Salas, E. 1998. Team performance and training in complex environments: Recent findings from applied research. *Current Directions in Psychological Science 7,* 3 (June), 83–89.

Cannon-Bowers, J. A., Salas, E., Blickensderfer, E., and Bowers, C. A. 1998. The impact of cross-training and workload on team functioning: A replication and extension of initial findings. *Human Factors 40*, 92–101.

Cannon-Bowers, J. A., Salas, E., and Converse, S. 1993. Shared mental models in expert team decision making. In *Individual and Group Decision Making: Current Issues*, N. J. C. Jr, Ed. Earlbaum Associates, Hillsdale, NJ, USA, 221–246.

Chalmers, M. and Galani, A. 2004. Seamful interweaving: Heterogeneity in the theory and design of interactive systems. In *DIS '04: Proceedings of the 2004 Conference on Designing Interactive Systems*. ACM Press, 243–252.

Cheok, A. D., Goh, K. H., Liu, W., Farbiz, F., Fong, S. W., Teo, S. L., Li, Y., and Yang, X. 2004. Human Pacman: A mobile, wide-area entertainment system based on physical, social, and ubiquitous computing. *Personal Ubiquitous Computing 8,* 2, 71–81.

Dasilets, P. and Raymond, J. 2007. *Assassin's Creed*. [Xbox 360]. Ubisoft, USA. Played January 2009.

Davis, K. 2007. Chore Wars :: Claim experience points for housework. Available from: http://chorewars.com.

de Saussure, F. 1959. *Course in General Linguistics*. Philosophical Library, New York, NY, USA. Translation by Wade Baskin.

Denef, S., Ramirez, L., Dyrks, T., and Stevens, G. 2008. Handy navigation in ever-changing spaces: An ethnographic study of firefighting practices. In *DIS '08: Proceedings of the 7th ACM Conference on Designing Interactive Systems*. ACM Press, 184–192.

Do, E. Y.-L. 1996. The right tool at right time – drawing as an interface to knowledge based design aids. In *Proceedings of the 1996 National Conference, Association for Computer Aided Design in Architecture 1996 (ACADIA 96)*. University of Arizona, Tucson, 191–199.

Dourish, P. 2001. *Where the Action Is: The Foundations of Embodied Interaction*, 1st ed. MIT Press, Cambridge, MA, USA.

EA Digital Illusions CE. 2008. *Mirror's Edge*. [Xbox 360]. Electronic Arts, USA. Played December 2008.

Ellington, H. 1982. *A Handbook of Game Design*. Kogan Page, London, UK.

Endsley, M. R. 2000. Theoretical underpinnings of situation awareness: A critical review. In *Situation Awareness Analysis and Measurement*, M. R. Endsley and D. J. Garland, Eds. Lawrence Erlbaum Associates, Mahwah, NJ, USA, 3–6.

Entertainment Technology Center. 2005. HazMat: Hotzone. Available from: http://www.etc.cmu.edu/projects/hazmat_2005/index.php.

Entin, E. E. and Serfaty, D. 1999. Adaptive team coordination. *Human Factors 41,* 2 (June), 312–325.

Falstein, N. 2005. Stealth education. *Game Developer 12,* 10 (November), 40.

Feiner, S., MacIntyre, B., Hollerer, T., and Webster, A. 1997. A touring machine: Prototyping 3D mobile augmented reality systems for exploring the urban environment. In *ISWC '97: Proceedings of the 1st IEEE International Symposium on Wearable Computers*. IEEE Computer Society, 208–217.

Forlizzi, J. and Battarbee, K. 2004. Understanding experience in interactive systems. In *DIS '04: Proceedings of the 5th Conference on Designing Interactive Systems*. ACM Press, 261–268.

Gagné, R. M. 1954. Training devices and simulators: Some research issues. *American Psychologist 9,* 3, 95–107.

Galloway, A., Brucker-Cohen, J., Gaye, L., Goodman, E., and Hill, D. 2004. Design for hackability. In *DIS '04: Proceedings of the 5th Conference on Designing Interactive Systems*. ACM Press, 363–366.

GameLayers, Inc. 2010. Welcome to The Nethernet. Available from: http://thenethernet.com.

Gaver, W. W. 1991. Technology affordances. In *CHI '91: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM Press, 79–84.

Gentner, D. and Stevens, A. L. 1983. *Mental Models*. Lawrence Earlbaum Associates, Hillsdale, NJ, USA.

Gibson, J. J. 1986. *The Ecological Approach to Visual Perception*. Lawrence Erlbaum Associates, Hillsdale, NJ, USA.

Glaser, B. G. and Strauss, A. 1967. *The Discovery of Grounded Theory: Strategies for Qualitative Research*. Aldine Publishing Company, Chicago, IL, USA.

Google. 2010. Google Earth. Available from: http://earth.google.com.

Gorman, J. C., Cooke, N. J., Pedersen, H. K., Winner, J., Andrews, D., and Amazeen, P. G. 2006. Changes in team composition after a break: Building adaptive command-and-control teams. In *Proceedings of the Human Factors and Ergonomics Society*. Human Factors and Ergonomics Society, 487–491.

Granlund, R., Johansson, B., and Persson, M. 2001. C3Fire a micro-world for collaboration training in the ROLF environment. In *Proceedings of SIMS 2001 the 42nd Conference on Simulation and Modelling, Simulation Theory and Practice*. Scandinavian Simulation Society.

Gregersen, A. and Grodal, T. 2009. Embodiment and interface. In *The Video Game Theory Reader 2*, B. Perron and M. J. P. Wolf, Eds. Routledge, New York, NY, USA, 65–83.

Gurtner, A., Tschan, F., Semmer, N. K., and Nägele, C. 2007. Getting groups to develop good strategies: Effects of reflexivity interventions on team process, team performance, and shared mental models. *Organizational Behavior and Human Decision Process 102*, 127–142.

Guyot, J.-C. 2008. *Prince of Persia*. [Xbox 360]. Ubisoft, USA. Played February 2009.

Guzdial, M. 1994. Software-realized scaffolding to facilitate programming for science learning. *Interactive Learning Environments 4,* 1, 1–44.

Hackman, J. R. and Wageman, R. 2005. A theory of team coaching. *Academy of Management Review 30*, 269–287.

Hamilton, W. A., Toups Dugas, P. O., and Kerne, A. 2009. Synchronized communication and coordinated views: Qualitative data discovery for team game user studies. In *CHI EA '09: Proceedings of the 27th International Conference Extended Abstracts on Human Factors in Computing Systems*. ACM Press, 4573–4578.

Hays, R. T. and Singer, M. J. 1989a. A conceptual history of training fidelity. In *Simulation Fidelity in Training System Design: Bridging the Gap Between Reality and Training*. Recent Research in Psychology. Springer-Verlag, New York, NY, USA, 23–46.

Hays, R. T. and Singer, M. J. 1989b. Definitions and problems in training system design. In *Simulation Fidelity in Training System Design: Bridging the Gap Between Reality and Training*. Recent Research in Psychology. Springer-Verlag, New York, NY, USA, 4–22.

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

Heath, C. and Luff, P. 2000. Team work: Collaboration and control in London Underground line control rooms. In *Technology in Action*, R. Pea, J. S. Brown, and C. Heath, Eds. Learning in Doing: Social, cognitive, and computational perspectives. Cambridge University Press, Cambridge, UK, 88–124.

Heidegger, M. 1967. *Being and Time*, translated from the 7th German ed. Harper Perennial, New York, NY, USA. Translation by John Macquarrie and Edward Robinson.

Hellquist, P. and Levine, K. 2007. *BioShock*. [Xbox 360]. 2K Games, USA. Played December 2008.

Hightower, J. and Borriello, G. 2001. Location systems for ubiquitous computing. *Computer 34,* 8, 57–66.

Hofstadter, D. R. 1979. *Gödel, Escher, Bach: An Eternal Golden Braid*. Basic Books, New York, NY, USA.

Hollan, J., Hutchins, E., and Kirsh, D. 2000. Distributed cognition: Toward a new foundation for human-computer interaction research. *ACM Transactions on Computer-Human Interaction 7,* 2, 174–196.

Hutchins, E. 1995a. *Cognition in the Wild*. MIT Press, Cambridge, MA, USA.

Hutchins, E. 1995b. How a cockpit remembers its speeds. *Cognitive Science 19,* 3, 265–288.

Itten, J. 1997. *The Art of Color: The Subjective Experience and Objective Rationale of Color*, Revised ed. John Wiley & Sons, Inc., New York, NY, USA. Translation by Ernst van Haagen.

Jiang, X., Chen, N. Y., Hong, J. I., Wang, K., Takayama, L., and Landay, J. A. 2004. Siren: Context-aware computing for firefighting. *Pervasive Computing 3001*, 87–105.

Jiang, X., Hong, J. I., Takayama, L. A., and Landay, J. A. 2004. Ubiquitous computing for firefighters: Field studies and prototypes of large displays for incident command. In *CHI '04: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM Press, 679–686.

Johansson, B. and Branlund, R. 2003. C3Fire in command and control research. *Cognition, Technology & Work 5,* 3 (August), 191–196.

Jonassen, D. H. and Henning, P. 1996. Mental models: Knowledge in the head and knowledge in the world. In *ICLS '96: Proceedings of the 1996 International Conference on Learning Sciences*. International Society of the Learning Sciences, 433–438.

Juul, J. 2005a. Rules. In *Half Real: Video Games between Real Rules and Fictional Worlds*. MIT Press, Cambridge, MA, USA, 55–120.

Juul, J. 2005b. Rules and fiction. In *Half Real: Video Games between Real Rules and Fictional Worlds*. MIT Press, Cambridge, MA, USA, 163–196.

Kerne, A. 2001. CollageMachine: A model of "Interface Ecology". Ph.D. thesis, New York University.

Kerne, A. 2005. doing interface ecology: the practice of metadisciplinary. In *Electronic Art and Animation Catalog*. SIGGRAPH, ACM Press, 181–185.

KLANN, M. 2007. Playing with fire: Participatory design of wearable computing for fire fighters. In *CHI '07: CHI '07 Extended Abstracts on Human Factors in Computing Systems*. ACM Press, 1665–1668.

KLEINMAN, D. L. AND SERFATY, D. 1989. Team performance assessment in distributed decisionmaking. In *Proceedings of Interactive Networked Simulation For Training*, R. Gilson, J. P. Kincaid, and B. Goldiez, Eds. 22–27.

KONGREGATE. 2010. Kongregate: Play free games online. Available from: http://kongregate.com.

LAKOFF, G. AND JOHNSON, M. 1999. The embodied mind. In *Philosophy in the Flesh: The Embodied Mind and its Challenge to Western Thought*. Basic Books, New York, NY, USA, 16–44.

LANDGREN, J. 2006. Making action visible in time-critical work. In *CHI '06: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM Press, 201–210.

LANDGREN, J. AND NULDEN, U. 2007. A study of emergency response work: Patterns of mobile phone interaction. In *CHI '07: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM Press, 1323–1332.

LAVE, J. AND WENGER, E. 1991. *Situated Learning: Legitimate Peripheral Participation*. Learning in doing: Social, cognitive, and computational perspectives. Cambridge University Press, Cambridge, UK.

MACMILLAN, J., ENTIN, E. E., AND SERFATY, D. 2004. Communication overhead: The hidden cost of team cognition. In *Team Cognition: Understanding the Factors that Drive Process and Performance*, 1st ed., E. Salas and S. M. Fiore, Eds. American Psychological Association, Washington, DC, USA, 61–82.

MALONE, T. W. 1981. Toward a theory of intrinsically motivating instruction. *Cognitive Science 5,* 4 (Oct-Dec), 333–369.

MANSLEY, K., SCOTT, D., TSE, A., AND MADHAVAPEDDY, A. 2004. Feedback, latency, accuracy: Exploring tradeoffs in location-aware gaming. In *SIGCOMM 2004 Workshops: Proceedings of ACM SIGCOMM 2004 Workshops on NetGames '04*. ACM Press, 93–97.

MARKS, M. A., SABELLA, M. J., BURKE, C. S., AND ZACCARO, S. J. 2002. The impact of cross-training on team effectiveness. *Journal of Applied Psychology 87,* 1 (February), 3–13.

MARSHALL, C. AND ROSSMAN, G. B. 1999. The "how" of the study. In *Designing Qualtiative Research*, 3rd ed. Sage Publications, Inc., Thousand Oaks, CA, USA, 55–103.

MATHIEU, J. E., GOODWIN, G. F., HEFFNER, T. S., SALAS, E., AND CANNON-BOWERS, J. A. 2000. The influence of shared mental models on team process and performance. *Journal of Applied Psychology 85,* 2, 273–283.

MERI, J. W., Ed. 2005. *Medieval Islamic Civilization: An Encyclopedia*. Vol. 1. Routledge, New York, NY, USA.

METZEN, C. AND PHINNEY, J. 1998. *StarCraft*. [PC]. Blizzard Entertainment, Sierra Entertainment. Played March 1998.

MICROSOFT CORPORATION. 2010. Xbox.com | home page - my Xbox. http://live.xbox.com.

MILGRAM, P. AND KISHINO, F. 1994. A taxonomy of mixed reality visual displays. *IEICE Trans. Information Systems E77-D,* 12, 1321–1329.

MITCHELL, K., MCCAFFERY, D., METAXAS, G., FINNEY, J., SCHMID, S., AND SCOTT, A. 2003. Six in the city: Introducing Real Tournament - a mobile IPv6 based context-aware multiplayer game. In *NETGAMES '03: Proceedings of the 2nd Workshop on Network and System Support for Games*. ACM Press, 91–100.

MIYAMOTO, S. AND TEZUKA, T. 1986. *Super Mario Bros.* [NES]. Nintendo, USA. Played May 1986.

NARAYANASAMY, V., WONG, K. W., FUNG, C. C., AND RAI, S. 2006. Distinguishing games and simulation games from simulators. *Computers in Entertainment 4,* 2, 1–18.

NORMAN, D. A. 1999. Affordance, conventions, and design. *interactions 6,* 3, 38–43.

NORMAN, D. A. 2002. *The Design of Everyday Things*, 2002 ed. Basic Books, New York, NY, USA.

PAGE, E. H. AND SMITH, R. 1998. Introduction to military training simulation: A guide for discrete event simulationists. In *WSC '98: Proceedings of the 30th Conference on Winter Simulation*. IEEE Computer Society Press, 53–60.

PALEN, L. AND LIU, S. B. 2007. Citizen communications in crisis: Anticipating a future of ICT-supported public participation. In *CHI '07: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM Press, 727–736.

PALEN, L. AND VIEWEG, S. 2008. The emergence of online widescale interaction in unexpected events: Assistance, alliance & retreat. In *CSCW '08: Proceedings of the ACM 2008 Conference on Computer Supported Cooperative Work*. ACM Press, 117–126.

PARDO, R., KAPLAN, J., AND CHILTON, T. 2004. *World of Warcraft*. [Online Game]. Blizzard Entertainment, USA. Played June 2007.

PIKE, K. L. 1954. *Language in Relation to a Unified Theory of Structure of Human Behavior*. Vol. 1. Summer Institute of Linguistics, Glendale, CA, USA.

PUCKETTE, M. 2009. *Pure Data*. [PC]. [self published]. Available from http://puredata.org.

Q-GAMES. 2009. *PixelJunk Shooter*. [PlayStation 3]. Sony Computer Entertainment America, USA. Played January 2010.

REDER, L. AND KLATZKY, R. L. 1994. Transfer: Training for performance. In *Learning, Remembering, Believing: Enhancing Human Performance*, D. Druckman and R. A. Bjork, Eds. National Academies Press, Washington, DC, USA, 25–56.

REEVES, W. T. 1983. Particle systems - a technique for modeling a class of fuzzy objects. *ACM Transactions on Graphics 2,* 2, 91–108.

REYNOLDS, C. W. 1987. Flocks, herds and schools: A distributed behavioral model. In *SIGGRAPH '87: Proceedings of the 14th Annual Conference on Computer Graphics and Interactive Techniques*. ACM Press, 25–34.

ROUSE, III, R. 2006. Game analysis: Centipede (2001). In *The Game Design Reader: A Rules of Play Anthology*, K. Salen and E. Zimmerman, Eds. MIT Press, Cambridge, MA, USA, 460–475.

SALAS, E., DICKINSON, T. L., CONVERSE, S. A., AND TANNENBAUM, S. I. 1992. Toward an understanding of team performance and training. In *Teams: Their Training and Performance*, R. W. Swezey and E. Salas, Eds. Ablex Publishing Corporation, Norwood, NJ, USA, 3–29.

Salas, E. and Fiore, S. M., Eds. 2004. *Team Cognition: Understanding the Factors that Drive Process and Performance*, 1st ed. American Psychological Association, Washington, DC, USA.

Salen, K. and Zimmerman, E. 2004a. Defining rules. In *Rules of Play: Game Design Fundamentals*. MIT Press, Cambridge, MA, USA, 118–125.

Salen, K. and Zimmerman, E. 2004b. Games as the play of experience. In *Rules of Play: Game Design Fundamentals*. MIT Press, Cambridge, MA, USA, 312–327.

Salen, K. and Zimmerman, E. 2004c. Games as the play of pleasure. In *Rules of Play: Game Design Fundamentals*. MIT Press, Cambridge, MA, USA, 328–361.

Salen, K. and Zimmerman, E. 2004d. Games as the play of simulation. In *Rules of Play: Game Design Fundamentals*. MIT Press, Cambridge, MA, USA, 421–458.

Salen, K. and Zimmerman, E. 2004e. Interactivity. In *Rules of Play: Game Design Fundamentals*. MIT Press, Cambridge, MA, USA, 56–69.

Salen, K. and Zimmerman, E. 2004f. Meaningful play. In *Rules of Play: Game Design Fundamentals*. MIT Press, Cambridge, MA, USA, 30–37.

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

Salen, K. and Zimmerman, E. 2004h. Rules on three levels. In *Rules of Play: Game Design Fundamentals*. MIT Press, Cambridge, MA, USA, 126–139.

Schaafstal, A. M., Johnston, J. H., and Oser, R. L. 2001. Training teams for emergency management. *Computers in Human Behavior 17*, 615–625.

Schaefer, E., Brevik, D., Schaefer, M., Sexton, E., and Williams, K. 1997. *Diablo*. [PC]. Blizzard Entertainment. Played January 1997.

Schechner, R. 1985. Restoration of behavior. In *Between Theater and Anthropology*. University of Pennsylvania Press, Philadelphia, PA, USA, 35–116.

Schön, D. A. 1984. *The Reflective Practitioner: How Professionals Think in Action*. Basic Books, New York, NY, USA.

Seager, W. and Fraser, D. S. 2007. User responses to gps positioning information on a digital map. In *CHI 2007 Workshop: Mobile Spatial Interaction Whitepaper*. ACM Press, 28–31.

Serfaty, D. E., Entin, E. E., and Volpe, C. 1993. Adaptation to stress in team decision-making and coordination. In *Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting*. Vol. 37. Human Factors and Ergonomics Society, 1228–1233.

Shapiro, M. J., Morey, J. C., Small, S. D., Langford, V., Kaylor, C. J., Jagminas, L., Suner, S., Salisbury, M. L., Simon, R., and Jay, G. D. 2004. Simulation based teamwork training for emergency department staff: Does it improve clinical team performance when added to an existing didactic teamwork curriculum? *Quality and Safety in Health Care 13*, 417–421.

Shklovski, I., Palen, L., and Sutton, J. 2008. Finding community through information and communication technology in disaster response. In *CSCW '08: Proceedings of the ACM 2008 Conference on Computer Supported Cooperative Work*. ACM Press, 127–136.

Shneiderman, B. 1996. The eyes have it: A task by data type taxonomy for information visualizations. In *Proceedings of the 1996 IEEE Symposium on Visual Languages*. IEEE, 336–343.

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

Sims, K. 1990. Particle animation and rendering using data parallel computation. In *SIGGRAPH '90: Proceedings of the 17th Annual Conference on Computer Graphics and Interactive Techniques*. ACM Press, 405–413.

Small, S. D., Wuerz, R. C., Simon, R., Shapiro, N., Conn, A., and Setnick, G. 1999. Demonstration of a high-fidelity simulation team training for emergency medicine. *Simulation Training 6,* 4 (April), 312–323.

Smith, R. D. 2003. Simulation. In *Encyclopedia of Computer Science*, 4th ed., A. Ralston, E. D. Reilly, and D. Hemmendinger, Eds. Nature Publishing Group, London, UK.

Smith, S. M. 1994. Getting into and out of mental ruts: A theory of fixation, incubation, and insight. In *The Nature of Insight*, R. J. Sternberg and J. Davidson, Eds. MIT Press, Cambridge, MA, USA, 229–252.

Sniderman, S. 1999. Unwritten rules. *The Life of Games* 1 (Oct), 2–7.

Song, A. A. and Kleinman, D. L. 1994. A distributed simulation system for team decisionmaking. In *Proceedings of the Fifth Annual Conference on AI, Simulation, and Planning in High Autonomy Systems, Distributed Interactive Environments*. IEEE, 129–135.

Sony Computer Entertainment America LLC. 2010. PlayStation®Network - PlayStation.com. Available from: http://us.playstation.com/psn/index.htm.

Stout, R. J., Cannon-Bowers, J. A., Salas, E., and Milanovich, D. M. 1999. Planning, shared mental models, and coordinated performance: An empirical link is established. *Human Factors 41,* 1 (March), 61–71.

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

Teuber, K. 1995. *The Settlers of Catan*. [Board Game]. Mayfair Games. Played November 2006.

Texas Engineering Extension Service. 2009. TEEX fact sheet. Available from: http://teex.org/teex.cfm?templateid=1156.

Tezuka, T. and Miyamoto, S. 1992. *The Legend of Zelda: A Link to the Past*. [Super NES]. Nintendo, USA. Played April 1992.

TheTeam@Criterion. 2009. Criterion games – article – everything you need to know about additional amendments arriving alongside the Party Pack. Available from: http://www.criteriongames.com/article.php?artID=384.

Thomas, B., Close, B., Donoghue, J., Squires, J., Bondi, P. D., and Piekarski, W. 2002. First person indoor/outdoor augmented reality application: ARQuake. *Personal Ubiquitous Computing 6,* 1, 75–86.

Thorndike, E. L. and Woodworth, R. S. 1901. The influence of improvement in one mental function upon the efficiency of other functions (I). *Psychological Review* 8, 247–261.

Toups Dugas, P. O. and Kerne, A. 2007. Implicit coordination in firefighting practice: Design implications for teaching fire emergency responders. In *CHI '07: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM Press, 707–716.

Toups Dugas, P. O., Kerne, A., and Hamilton, W. 2009. Game design principles for engaging cooperative play: Core mechanics and interfaces for non-mimetic simulation of fire emergency response. In *Sandbox '09: Proceedings of the 2009 ACM SIGGRAPH Symposium on Video Games*. ACM Press, 71–78.

Toups Dugas, P. O., Kerne, A., Hamilton, W., and Blevins, A. 2009. Emergent team coordination: From fire emergency response practice to a non-mimetic simulation game. In *GROUP '09: Proceedings of the ACM 2009 International Conference on Supporting Group Work*. ACM Press, 341–350.

Tufte, E. R. 1990a. Color and information. In *Envisioning Information*. Graphics Press, Cheshire, CT, USA, 81–96.

Tufte, E. R. 1990b. *Envisioning Information*. Graphics Press, Cheshire, CT, USA.

Tufte, E. R. 1990c. Layering and separation. In *Envisioning Information*. Graphics Press, Cheshire, CT, USA, 53–66.

Turner, P. and Turner, S. 2002. Embedding context of use in CVE design. *Presence: Teleoperators and Virtual Environments 11,* 6, 665–676.

Twin Galaxies International Inc. 2010. Welcome to Twin Galaxies. Available from: http://twingalaxies.com.

Under Secretary of Defense for Acquisition Technology. 1998. *DoD Modeling and Simulation (M&S) Glossary*. Number DOD 5000.59-M. U.S. Department of Defense.

U.S. Army. 2002. *America's Army*. [PC]. U.S. Army, USA.

U.S. Department of Homeland Security. 2004. *National Incident Management System*. U.S. Department of Homeland Security, Washington, DC, USA.

Valve Corporation. 2010. Welcome to Steam. Available from: http://steampowered.com.

Volpe, C. E., Cannon-Bowers, J. A., and Salas, E. 1996. The impact of cross-training on team functioning: An empirical investigation. *Human Factors 38*, 87–100.

Ward, A. 2008. *Burnout Paradise*. [Xbox 360]. Electronic Arts, USA. Played February 2009.

Ware, C. 2004. *Information Visualization: Perception for Design*, 2nd ed. Interactive Technologies. Morgan Kaufmann, San Francisco, CA, USA.

Welch, B. L. 1947. The generalization of the "Student's" problem when several different population variances are involved. *Biometrika 34,* 1-2, 28–35.

Wieder, M. A., Smith, C. M., and Brakhage, C. S., Eds. 1993. *Fire Service Orientation and Terminology*, 3rd ed. Fire Protection Publications, Oklahoma State University, Stillwater, OK, USA.

Zogg, J. M. 2007. Essentials of satellite navigation - compendium. Tech. Rep. GPS-X-02007-C, u-blox AG.

APPENDIX A

NOMENCLATURE: ABBREVIATIONS

AR	Anticipation Ratio
CLAPS	Coordinated Log + Audio Playback System
CVE	Collaborative Virtual Environment
ESTI	Emergency Services Training Institute
FER	Fire Emergency Responder
FTA	Firefighter Training Academy
GPS	Global Positioning System
HMD	Head Mounted Display
HP	Hit Point(s)
HUD	Head Up Display
Hz	Hertz
IC	Incident Commander
MR	Mixed Reality
MRT^2_eC	Mixed Reality Teaching Team Coordination (Game)
ms	Millisecond
NIMS	National Incident Management System
OODSS	Object Oriented Distributed Semantic Services
p-action	Primitive Action
Pd	Pure Data

PDA	Personal Digital Assistant
PSN	PlayStation Network
PTT	Push To Talk
RC	Recruit Class
SCBA	Self Contained Breathing Apparatus
TEEX	Texas Engineering Extension Service
T^2_eC	Teaching Team Coordination (Game)
VoIP	Voice Over Internet Protocol
XBL	Xbox Live
XML	Extensible Markup Language

APPENDIX B

NOMENCLATURE: FIRE EMERGENCY RESPONSE JARGON

"burns"	burn training
"fire chief"	chief fire officer
"knocking down a fire"	putting a fire out completely
"stepping on"	crosstalking over radio
"walking on"	crosstalking over radio

APPENDIX C

FER INTERVIEW QUESTIONS (NOVEMBER 2005)

General Information

1. name (confidential)
2. gender
3. age
4. each firefighting job held, rank, and time held

Supervising (FERs who have supervised)

1. Before entering a situation, how do you plan with your team?
2. How much time do you spend planning?
3. What do you plan?
4. How important is preplanning strategy to the safety of your team?
5. How often do you have to improvise new strategy in the field?
6. How do you communicate a new strategy once firefighters are deployed to an emergency?
7. What information do you use when coordinating a team?
8. What tools do you use to organize the information (or what artifacts contain the information)?

9. How do you moderate communication with members of the team?
10. What information do you communicate to your team?
11. What information do they communicate to you?
12. Do you feel you understand each team member's situation and their plans of action?
13. Is this based upon what information they communicate to you from the field, or more upon what is preplanned before entering the situation?
14. How do you build a shared understanding of the environment you are working in?
15. How difficult is it to organize the information?
16. What is challenging about this?
17. Do you believe an alternate command topology would be more effective? How and why?

In the Field

1. What information does your supervisor communicate to you in emergency situations?
2. What information do your fellow team member's communicate to you in emergency situations?
3. Do you often communicate information, or requests for information?
4. Do you often feel that you understand the situation of your fellow team members: what they are doing, what they are going to do, their goals, etc.?

Other

1. Have you ever experienced a situation in which proper communication saved your life, a fellow team-member's life, or the life of someone involved in the emergency?
2. What was important about how that communication was conducted?
3. Do you feel that current firefighter communication methodologies are adequate and safe?
4. What are the shortcomings of the communication methodologies?
5. Do you feel that modern firefighter communication hardware is sufficient and safe?
6. What are the shortcomings of the communication hardware?

VITA

Phoebe Olivia Toups Dugas received her Bachelor of Arts in computer science from Southwestern University in Georgetown, Texas in 2003. After teaching English in Japan for a year, she entered the Ph.D. program at Texas A&M University in College Station, Texas in 2004. In 2005, she joined the Interface Ecology Lab with Prof. Andruid Kerne as her advisor. She completed her Ph.D. in computer science in 2010.

She plans to investigate the role games play in memory, using them as a means to educate, prepare for the future, and recall the past.

Phoebe can be reached by email (phoebe.toups.dugas@acm.org) or by mail:

Department of Computer Science and Engineering

c/o Dr. Andruid Kerne

Texas A&M University

College Station, Texas, USA 77843-3112