Game Design Principles for Engaging Cooperative Play: Core Mechanics and Interfaces for Non-Mimetic Simulation of Fire Emergency Response

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Abstract

Core mechanics are the activities that players repeat to play a game, the central aspects of play constrained by rules. Interfaces mediate play experiences, impacting engagement with core mechanics. We design core mechanics for gathering, integrating, and sharing information, based on team coordination practices of fire emergency responders. We connect these mechanics with interfaces that impact player engagement. Mechanics and interfaces combine into a *non-mimetic* simulation game, which eschews fire and smoke, in favor of re-creating information flows and team structures.

We describe the iteration of mechanics and interface components as shaped by practice, pilot games, participatory re-design sessions, and long-term user studies. The result is integrated core mechanics that we develop from work practice and interface components that support engagement with them. From this data, we construct game design principles for engaging cooperative play: information distribution, modulating visibility, providing the right information in the right time, making predictable, and understandable representations for shared mental models.

Keywords: Core mechanics, interface design, cooperation, communication, coordination, work practice, emergency response.

CCS: H.5.2 User Interfaces.

1 Introduction

Core mechanics are essential aspects of play, constrained by rules, that game players repeat [Salen and Zimmerman 2004]. In digital games, user interfaces mediate this experience, shaping the way players perceive and interact with game structures. The affordances [Norman 2002] of the interface signal action opportunities to players, indicating the way to play. Information provided by the interface impacts players' decisions.

We design core mechanics from prior design implications for teaching team coordination [Toups and Kerne 2007] and non-mimetic simulation principles [Toups et al. 2009]. These elucidate the need, in fire emergency response practice, to gather, integrate, and share information among team members. Because the implications and principles do not specify a need to model fire and smoke, we develop a *non-mimetic simulation* game to teach team coordination. Players take on roles that reflect those of fire emergency response and gather, integrate, and share information from a virtual environment, like firefighters. Non-mimetic simulation is a novel form, eschewing the concrete aspects of the simulated environment, such as fire and smoke, and focusing scarce simulation resources on human-centered processes from a grounding in practice [Toups et al. 2009]. We develop games because they are engaging and provide intrinsic motivation to learn [Malone 1981].

The core mechanics of team games differ from those of single-player games. Human-human interaction becomes essential, adding communication and coordination to the array of options already available. In our game design to teach team coordination skills, these mechanics are essential. Design implications for teaching team coordination, uncovered from ethnographic field work [Toups and Kerne 2007], shape interface components that contribute to engagement in the core mechanics, grounding the design in practice. Non-mimetic simulation principles guide game mechanic design [Toups et al. 2009]. 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 [Hutchins 1995] by perceiving, integrating, transforming, and sharing information in order to make sense of the game environment.

We analyze interface components that contribute to engagement in the core mechanics of a team game, leading players to cooperate. From this analysis, we develop cooperative game design principles for core mechanic and interface design: distributing information, modulating visibility, information timing, making predictable, and representations for shared mental models.

We describe relevant background: simulation, game design, interface design, team coordination, and grounding in practice. We discuss the current iteration of our non-mimetic simulation game for teaching team coordination. We describe core mechanics derived from work practice that encourage players to cooperate through processes of gathering, integrating, and sharing information. For each mechanic, we describe the interface elements that support engagement by examining the iteration of the design with pilot games, participatory re-design sessions, and sustained user studies. We develop and discuss game design principles for core mechanics and interfaces in cooperative games.

2 Background and Prior Work

We connect background from diverse sources. We construct simulations, considering prior work. Game design and interface design are essential. The team coordination literature includes distributed cognition and team cognition. Finally, we explore the ethnographic grounding for the game design, looking at fire emergency response work practice.

2.1 Simulation

Simulations are operational environments that enable participants to practice skills in a safe setting [Page and Smith 1998]. Traditionally, simulations capture, in some level of fidelity, the real world. *Non-mimetic simulation* differs from traditional simulations in that it eschews concrete aspects of the real-world environment. Rather than expend resources attempting to re-create reality, non-mimetic simulation focuses on human-centered

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aspects of practice, such as information flows, as discovered through examinations of work practice [Toups et al. 2009].

Several notable simulations for team coordination and emergency response exist. In the Distributed Dynamic Decision simulation, participants manipulate virtual entities and discuss decisions about resource allocation [Song and Kleinman 1994]. In C3Fire, participants are presented with a map of terrain and direct virtual units to respond to emergencies [Granlund et al. 2001].

2.2 Game Design

Salen and Zimmerman frame games in terms of rules and play [2004]. *Rules* are the mathematical and logical structures that define the boundaries of the game, a set of restrictions on free action. Rules constrain *play*, the freedom to make choices and act within the rules.

Game *mechanics* are experiences of rules and play together. The *core mechanics* of a game are the sets of actions that are repeated to play [Salen and Zimmerman 2004]. In a game of Tic-Tac-Toe, for example, the core mechanic is claiming territory on the board by marking an "X" or "O". According to Salen and Zimmerman, player actions should have clear, discernable outcomes to facilitate understanding the game system [2004].

2.3 Interface Design

Interfaces are border zones [Kerne 2005] between humans, machines, games, and information systems. Interfaces mediate the ways in which humans can act and perceive information within a computer system. Interaction design principles urge *making visible* by providing information to guide the user [Norman 2002]. Color [Itten 1997; Tufte 1990], animation [Ware 2004; Bederson and Boltman 1999], information visualization techniques [Ware 2004; Tufte 1990], and sonifications [Blattner et al. 1989] provide the user with information, enhancing understanding. As in games, *feedback* indicates the outcome of actions taken in an interface, which is essential for building mental models [Norman 2002]. *Mental models* are structures describing objects and people that enable inference and prediction of outcomes in an environment [Gentner and Stevens 1983].

2.4 Team Coordination

Distributed cognition takes a holistic view of the information flow in a working environment, considering how cognitive processes are embodied in humans and artifacts, and that they change through time [Hutchins 1995]. Distributed cognition examines the ways in which individuals transform and transport information across media. We take distributed cognition as our lens for examining fire emergency response work practice.

Team cognition considers teams as functional cognitive units [Salas and Fiore 2004]. When team members *share* mental models, they can work together smoothly, lessening the need to communicate [Cannon-Bowers et al. 1993]. *Implicit coordination* occurs when team members operate effectively with little communication, leading to a beneficial reduction in cognitive and technological bandwidth, and time [MacMillan et al. 2004].

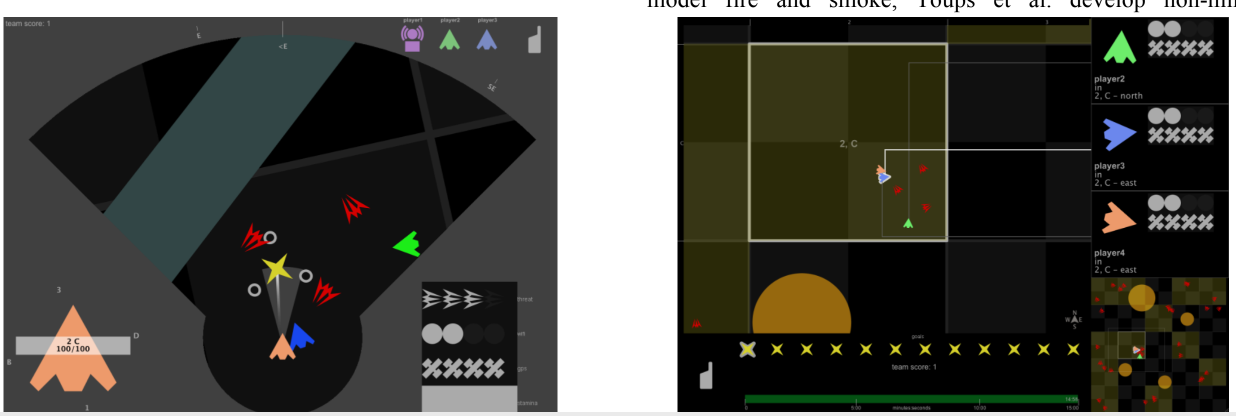
2.5 Fire Emergency Response Practice

Our design is grounded in human-centered aspects of fire emergency response work practice. Fire emergency responders (FERs) work in multiple distributed teams, providing perspectives from in and around the fireground [Denef et al. 2008; Toups and Kerne 2007; Landgren 2006; USDHS 2004]. Teams observe and communicate to make sense of the situation, find and rescue victims, and put out fires.

FERs in the role of *firefighter* act in teams in and around the fireground. An *incident commander* (IC), the highest ranking individual at an incident, directs the teams. The IC is positioned away from the fireground, observing it in context and using a variety of information artifacts [Toups and Kerne 2007, Xiaodong et al. 2004]. Information flows are complex and multi-way, with firefighters at the fireground providing information from multiple perspectives and taking situated action [Suchman 1987] while the IC coordinates them.

Toups and Kerne develop design implications for teaching team coordination from ethnographic investigation of fire emergency response practice [2007]. Each team member's unique perspective, background, and information access create *information differential*. FERs *mix communication modalities*: they prefer to use face-to-face communication whenever possible, because it is fast, rich, and easy to understand. Some situations make face-to-face communication impossible, and so half-duplex radios are used instead. The use of *audible cues* enables firefighters to perceive more about their environment and sense information remotely through background sounds over the radio. These design principles are embodied in our game design to teach team coordination skills through non-mimetic simulation of fire emergency response work.

Because the design implications do not specify a need to model fire and smoke, Toups et al. develop non-mimetic



(a.) seeker local view (b.) coordinator overview

Figure 1. Screenshots of non-mimetic simulation game for teaching team coordination. The seeker's view (a.) is highly detailed, showing other seekers, threats, goals, and walls; it is also local. The coordinator's view (b.) is an overview of the game world that is less detailed, showing seekers, threats, bases, and regions containing goals. In the pictures, Player3 (orange) is starting to collect a cooperative goal that requires all three seekers, while under attack by a flock of threats. The coordinator is tracking Player2 (blue) and observing the team act. The two sides of the team can communicate using radio.

simulation principles [2009]. *Information distribution* develops information differential to reflect a grounding in distributed cognition. Participants need diverse perspectives that inter-relate so that they are reliant one another for the information they need to succeed; further, these perspectives should require information transformation to be effective. Dividing information along *participant roles* reflects FER work practice. *Real-time stress* ensures that participants must make quick decisions about what information to share, and how to share it.

3 Game Design

We develop game designs for non-mimetic simulation of fire emergency response. The game designs reflect human-centered aspects of response work practice through core mechanics that engage participants in processes of information transformation and communication. In this section, we describe the most recent iteration of our game design, including the game entities, player roles, and communication.

Players act in teams structured like FER teams. Information access and action capabilities reflect FER practice, following the non-mimetic simulation principle of participant roles [Toups et al. 2009]. A team of four human players works together to play. Three players take on the role of *seeker* and search a virtual environment to find *goals* while avoiding *threats*. A time limit, along with the goal collection mechanics and the behavior of threats creates real-time stress. The *coordinator* assists the team by observing and communicating about a virtual world overview with different information from the seekers. The team members communicate information in order to work together effectively.

3.1 Game Entities

The objective of the game is to find and collect all of the goals in the virtual world within a time limit. Seekers collect goals by facing them for several seconds. Some goals are cooperative, requiring two or three seekers to gather simultaneously. The game includes a scoring mechanic, and cooperative goals are more valuable than single-seeker goals.

Threats are virtual world entities that hunt down the seekers. Contact with a threat reduces a seeker's hit points (HP). Once the seeker's HP reach zero, that seeker must locate a *base*, a safe area that restores HP. A seeker with zero HP cannot collect goals.

3.2 Roles

Each seeker sees a local view in a high level of detail, limited to an arc in front of their avatar (Figure 1, a.). The arc shows walls, threats, and goals, but not bases. The seeker head-up display (HUD), arranged around the viewing arc, includes information about location and orientation, distance to nearby threats, HP remaining, and the colors and names of teammates.

A coordinator assists the group of seekers by observing the virtual world from an overview (Figure 1, b.). The coordinator's view is less detailed than that of the seekers. Coordinators can see the locations of seekers, threats, and bases. They can see regions that contain goals, but not their exact locations. The interface allows the coordinator to monitor the team's progress in the game, track the status of individual players, and observe the game world as a whole.

Seekers are analogs for firefighters: they can act in the game world and can see a local, detailed perspective. The coordinator's role is like that of the IC: observing and directing the team.

3.3 Communication

To facilitate voice communication between players, each player has a push-to-talk (PTT) radio. The radio functions through a monaural wireless headset and is controlled by the game software.

Some status changes for seekers include sound effects, to provide additional information about the game. Sound effects are routed through the radio, as well as individual's headsets. If a player's PTT is active, then that player's game sound effects will be heard by other listening players. We thus fulfill the audible cue design principle [Toups and Kerne 2007] to enable remote sensing through the radio for players.

4 Evaluation Method

The data that inform the core mechanics and interface design principles comes from a series of studies and iterative designs that span four years. A series of early pilot studies rapidly iterated the game design, with later pilot studies refining it significantly. A sustained user study, in which 40 unique participants played 8 games each over the course of four weeks followed. Integrating feedback from the sustained user study, we conducted a participatory design phase, in which the authors played the game with an expert FER who has 30 years of experience. Finally, we examined data from an ongoing FER student user study, in which students at a local fire school play the game during their off hours.

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-IP with wireless headsets. This became problematic due to lag issues 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. Keyboard and mouse are the inputs to the game.

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, most games are 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

Table 1. Summary of evaluations and resulting changes to the team game design. One session is a set of two games (one with seekers co-located, the other all isolated), played by 4 participants.

evaluation	sessions	unique participants	resulting changes
early pilot studies	12	8*	cooperative goal mechanic; HP mechanic; block-and-grid coordinates
later pilot studies	3	12	making goals invisible in the coordinator interface; discernable patterns for threats
sustained user study	40	40	goal collection status indicator; PTT status indicator
FER expert participatory design	4	4†	making threats visible to seekers; seeker location context indicator; PTT status audio
FER student user study	13	16	remove PTT warning from PTT status indicator

* participants included one author

† participants consisted of the authors and expert FER, Cary Roccaforte

reflect the design principle of mixing communication modalities [Toups and Kerne 2007].

In the sustained and FER student user studies, participants play a set of four sessions (8 games) on the same team over the course of a month. The 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. Participants are given time before, in between, and after the games to reflect on effective strategies [Schön 1983]. Participants are compensated (30 USD gift card and food at each session).

Data is collected for all user studies through questionnaires, game logs, and audio. Questionnaires gather background, such as participants' experience with video games and teams (emergency response, for example), as well as asking participants to recount specific events of teamwork during play. Logs are recorded on the game server and capture every aspect of the game state at 10Hz. All audio passing through the game system and spoken in the laboratory is recorded, including during the reflective periods. In-game audio and log data are synchronized using timestamps and played back together for analysis that includes quantitative evidence of improved teamwork skills through coding audio, as well as qualitative instances of coordination [Hamilton et al. 2009].

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

5 Designing Core Mechanics and Interfaces

We develop core mechanics around activities of gathering, integrating, and sharing information to engage in distributed cognition while under real-time stress. FERs gather information about the incident and integrate it into their understanding to effectively fight fire and rescue victims. They share relevant portions of their understanding with one another to assist others in making sense of the environment, enabling strategy formation and protecting lives. These activities are undertaken by FERs as discovered through investigations of work practice [Toups and Kerne 2007, Landgren 2006].

Interfaces mediate interaction with the game. Their design impacts the ways and extent to which participants engage in the core mechanics. We connect each core mechanic to interface components, and describe the components' evolution based on data and feedback from users' experiences. A summary of data sources can be found in Table 1.

5.1 Gathering: Locating Goals

FERs search the fireground for victims and dangers. They use pre-plans (documents created from an inspection of local buildings), schematics, and maps, as well as direction from outside to plan actions at an incident. Gathering information is an essential activity in fire emergency response [Denef et al. 2008; Toups and Kerne 2007].

The objective of the game is to collect all of the goals in the terrain before time runs out. Central to the objective is locating goals and gathering intelligence about nearby terrain and the type of goal. Cooperative goals require multiple seekers to collect, so seekers must synchronize activities to be in the same place at the same time without being captured by threats.

5.1.1 *Making Invisible: Hiding Goal Information*

In early designs, the exact location of each goal was visible in the coordinator's view (Figure 2, a.). The result, observed in a series of pilot studies, was that the coordinator and seekers did not have to collaborate to gather information. There was no need to gather information, as the coordinator had access to all that was necessary, and could share with the team. Typically, this took the form of top-down orders, directing seekers exactly where to go.

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 2, 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 interface.

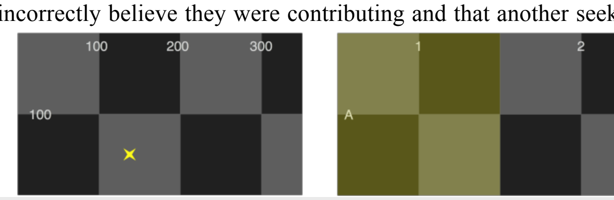
The goal mechanic design was iterated, along with the game's interfaces. Originally, all goals required only a single seeker to collect. We added cooperative goals. Through further iterations, a piece of information was removed from the coordinator's interface: the number of seekers required to collect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

5.1.2 *Making Visible: Revealing Cooperative Goals*

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 1, a.; Figure 3 – the goal requires three seekers, as indicated by the three white rings around it). This information is hidden from the coordinator (Figure 1, b; Figure 2, b), who may need to assist the seekers in grouping together. In the sustained and FER student user studies, this led to players developing strategies for scouting out goals. In this instance, we make visible.

5.1.3 *Making Visible: Goal Collection Attribution*

Once the cooperative goal mechanic was introduced, 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 for its collection (Figure 3, a.). In the original design, each ring was filled by a seeker (Figure 3, b.). 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 they were contributing and that another seeker



(a.) precise goal locations and coordinates (b.) fuzzy goal locations and block and grid coordinates

Figure 2. Goals in the original (a.) and current (b.) 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.

was not. Problems appeared in the long-term 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 3, c.). In addition, we draw a line from each collecting seeker to the goal, linking that player to the goal to indicate their action (Figure 1, a.). This feedback is a change to making visible, and in later user studies, no further confusion has occurred.

5.1.4 *Summary*

Seekers can see only a local view, which allows them, when they get close enough, to spot the exact locations of goals and the number of players required to collect them. The coordinator can only see which regions still contain uncollected goals. Fundamentally, these interfaces distribute information within the team. Coordinators are presented with a broad overview that lacks detail, while seekers can change their local views (by moving) and gather detailed information about the proximate environment.

In iterating the design, we alter information distribution between players, making it more even and preventing one part of the team from knowing too much. We hide information, so that players must seek it out in the game environment, practicing gathering information. In this case, distributing information involves sometimes making invisible, contrary to traditional interface design [Norman 2002], and making visible in others. *Modulating visibility* is important in designing information distribution to ensure that participants need to work together.

5.2 Integrating: Evading Threats

Firefighters integrate observations of the fireground with their knowledge of how fire works and their shared mental models of teammates [Gentner and Stevens 1983; Cannon-Bowers et al. 1993], to effectively fight fire and work together [Toups and Kerne 2007]. This allows them to predict future events and plan accordingly, reducing communication overhead and improving implicit coordination [MacMillan et al. 2004].

As firefighters searching for victims avoid fires, so seekers must avoid threats in the non-mimetic simulation game. They build up mental models of the locations of bases and offline areas to protect themselves from threats and remember goal locations.

5.2.1 *Discernable Patterns: Avoiding Threats*

Threats supply real-time stress. 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 hit point (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 [Reeves 1983] to the threats, and used flocking [Reynolds 1987] and particle choreography [Sims 1990] 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 [Gentner and Stevens 1983].

5.2.2 *Information Timing: Threat Locations*

Information timing must be tuned to promote distributed cognition. In our sustained user studies and participatory design sessions, we observed seekers having difficulty avoiding threats, despite the HP mechanic and discernable 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 1, a.) 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: coordinator would tell the seekers where the threats were, and seekers would avoid them, rarely materialized.

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 ongoing user study with FER students, this has improved play. Seeker players do not feel like they were taken out of the game randomly. 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.

5.2.3 *Summary*

Players experience threats through macro/micro views [Tufte 1990]. The coordinator can discuss threat behavior in macro, because s/he can see the flocks of threats moving about the map. The flocks are coherent, and move predictably. It becomes unnecessary to speak about them in micro, because seekers can see the local threats and react. This makes the game feel less random to players, and more predictable, but no less challenging. Here we see that making visible is essential.

We suggest that *making predictable* is important as well, contributing to participants' mental models [Salen and Zimmerman 2004; Gentner and Stevens 1983]. The discernable patterns enable participants to make plans while taking situated action [Suchman 1987].

Because some information is ephemeral, its value to the team

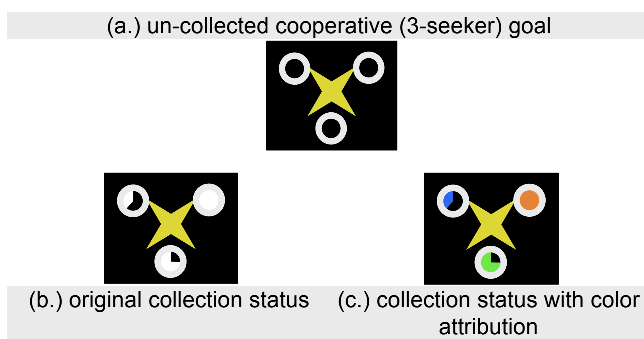


Figure 3. Goal collection status indicators. Un-collected cooperative goal (a.) shows three empty rings, one for each seeker necessary to collect the goal. Original collection status indicators (b.) do not show who is collecting the goal. Current collection status indicators (c.) indicate how much each seeker has contributed to the collection of the goal through color.

extremely brief. Information timing must provide players with *the right information in the right time*. This reduces the burden on players who must communicate about it, easing frustration and making the game more fun.

5.3 Representations for Shared Mental Models

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 to 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. Sensemaking 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.

Communication between coordinator and seekers and between the seekers themselves 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.

In early game designs, the seekers did not communicate: there was no need to. The coordinator knew the exact location of every goal and exactly how many players were needed to collect each (1). Players had difficulty understanding how the radio worked, and thus shunned its use. This did not reflect fire emergency response practice.

5.3.1 *Sharing Location*

In the early pilot studies, location was difficult to communicate within the team because locations were given as a pair of detailed coordinates in the X / Y plane (e.g. 123.83, 475.20; Figure 2, 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 2, 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.

5.3.2 *Collaborative Navigation*

In sustained user studies and participatory re-design, it became clear that seekers had difficulty navigating to locations specified by the coordinator. While the coordinator could provide directions, this was often a cumbersome process, made more difficult by seekers moving constantly.

During a series of participatory re-design sessions with an FER expert (30 years experience), 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 (Figure 4). 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.

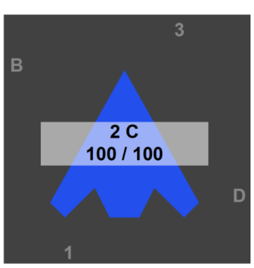


Figure 4. Seeker location and status indicator. The seeker avatar icon in the background shows the current state of the seeker; overlaid is location and hit points. Letters and numbers around the edge indicate nearby locations.

5.3.3 *Monitoring Communication Status*

Players had difficulty developing an understanding 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 push-to-talk (PTT). There is a 500ms – 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.

To address these issues, we introduce a radio status visualization to all of the game interfaces (Figure 5). The status visualization 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 their radio, the visualization turns yellow for a second, then turns green. In addition, a set of waves animate from the antenna on the radio to indicate it is transmitting.

An audio interface is also used to help 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.

Based on recent FER student user studies, we plan to make invisible a part of the PTT status indicator. In real life, FERs do not have a warning light to indicate to them that someone may be trying to use the radio. According to an expert FER, cross-talk is common with half-duplex radios and FERs must learn to deal with it effectively in the field. As part of modulating visibility, we plan to remove the PTT warning from the PTT status indicator.

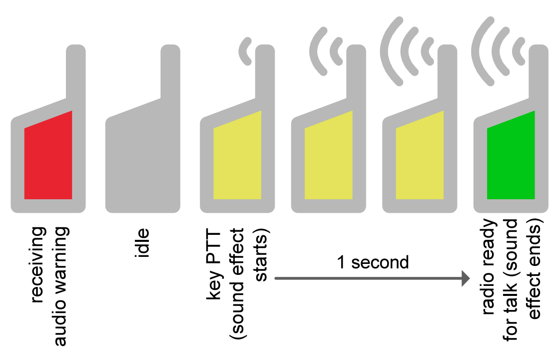


Figure 5. Radio status indicator animation and sound. The animation and sound help participants understand that the radio takes about a second to connect to the radios of other players.

5.3.4 *Summary*

To better reflect the field of fire emergency response, where the firefighters are the eyes and ears of the IC and where the IC provides direction [Toups and Kerne 2007], we make the seeker interface more detailed to provide good representations on which to build shared mental models. We simplify map references by using a block-and-grid system. Although this reduces the granularity of the map for communication and navigation, it simplifies what players must communicate about.

Crafting visualizations and sonifications for the radio assists players in building a mental model of its use. Players become better able to time their transmissions and avoid speaking when they will be unheard by the team.

6 Cooperative Game Design Principles

From the iterative design of our non-mimetic simulation team game, we describe game design principles from the core mechanics and interface components. Information distribution applies the non-mimetic simulation design principle of information distribution to game mechanics, impacting the way participants play the game [Toups et al. 2009]. Modulating visibility is essential to distributing information between players, encouraging communication and cooperation. The timing of information distribution must also be considered, as it can impact the way in which players are able to communicate with each other and engage game mechanics. Predictability impacts players' abilities to form mental models and maintain situation awareness, contributing to team members' ability to work together.

6.1 Information Distribution

Previously described as an interface design implication for teaching team coordination skills [Toups and Kerne 2007] and a non-mimetic simulation principle [Toups et al. 2009], we consider information distribution as a game mechanic. Information is shared between players through their interfaces, often modulating visibility, but it impacts the way they play the game.

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 different participant roles [Toups et al. 2009]. Players must be reliant on each other to complete the game. Information distribution encourages engagement with the core mechanic of team communication, and requires participants in different roles to gather and integrate different types of information in different representations.

6.2 Modulating Visibility

Despite the interaction design mantra of making visible [Norman 2002], we find that making *invisible* can be just as important when designing cooperative game interfaces. As part of information distribution [Toups and Kerne 2007], 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-changing information (such as goal locations, which never change) 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 is one way of accomplishing this.

6.3 The Right Information in the Right Time

Part of creating information distribution and real-time stress [Toups et al. 2009] involves rapid information change. Information in games may be ephemeral. The temporality of information must be considered when players need to communicate about it. 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 in the right time. While we made threats visible to avoid too-fast information timing, we were able to make goal details invisible to the coordinator, because of their slow timing.

6.4 Making Predictable

Mental models enable players to understand and manipulate the game in their heads [Salen and Zimmerman 2004; Gentner and Stevens 1983]. When mental models are shared, players are able to cooperate more effectively, because their mental models predict things in the same way [Cannon-Bowers et al. 1993]. Game mechanics must be consistent [Salen and Zimmerman 2004], they must provide some level of predictability, to enable mental model formation.

Threat behaviors were introduced to make the threats predictable. 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.

6.5 Communicable Representations

The way information is presented in a game's interface impacts the way players are able to use it. 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. The block-and-grid coordinate system is one mechanism for this: it makes it easier for players to communicate about location in a way that is meaningful and staisfices [Simon 1996] for the situation. Information to be shared should be easy to communicate, in order to reduce communication overhead.

7 Conclusion

We have developed game design principles for cooperative game play. We described the core mechanics and interfaces for a non-mimetic simulation game of fire emergency response work practice that focuses on learning team coordination skills. Based on prior design implications for teaching team coordination and non-mimetic simulation principles, the game eschews fire and smoke in favor of human-centered aspects of firefighting, such as information flows. Core mechanics center around players' ability to gather, integrate, and share information. We examined interface components that contribute to engagement in the core mechanics using pilot studies, sustained user studies, and participatory re-design sessions to evaluate them.

Use of the game design principles directs play such that players must coordinate to succeed. Information must be distributed, so that team members work together to build the information picture. Modulating visibility, rather than simply making visible, is essential for distributing information and encouraging communication. Designing for information timing helps team members enjoy the game without the burden of trying to communicate information that will be stale and rarely useful. Predictability of game elements helps eliminate a sense of randomness and creates accountability for the game system, assisting players in formulating shared mental models that help them to coordinate. Representations of distributed information can be designed in consideration of the clues that different players receive to facilitate communication and promote the formation of shared mental models.

Through the non-mimetic simulation of fire emergency response, we are constructing a system for teaching team coordination to FERs. We hypothesize that a non-mimetic simulation of fire emergency response may also prove effective for teaching team coordination to other types of teams. Future research will investigate how well this system teaches team coordination to FERs and other teams, such as programmers.

We work through a science of design, constructing educational game software. The implications from such software will be useful for constructing engaging, fun games for learning in other domains. The principles presented here should be considered for any cooperative team game in which the goal is to encourage teamwork and interaction among players.

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