Designing Information Displays to Support Awareness in *Ad Hoc,* Interdisciplinary Emergency Medical Teamwork

A Thesis

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When I applied to the Ph.D. program, I promised the Lord that I would do my best, and do it all in His name. I learned a lot about myself on this journey. I have had my patience tested and have been humbled many times, but He was always there by my side.

Praise the Lord.

Give thanks to the Lord, for He is good;

His love endures forever.

Psalm 106:1 (NIV)

Although sometimes it might have felt like I was walking along a lonely path, I was never alone.

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TABLE OF CONTENTS

List of Figures

List of Tables

Abstract

Designing Information Displays to Support Awareness in
Ad Hoc, Interdisciplinary Emergency Medical Teamwork
Diana Sachiko Kusunoki
Aleksandra Sarcevic, Ph.D.

This research focuses on designing an information display to support awareness during *ad hoc*, collocated, interdisciplinary, and emergency medical teamwork in the trauma resuscitation domain. Our approach is grounded in participatory design (PD), emphasizing the importance of eliciting and addressing clinician needs while gaining long-term commitment from clinicians throughout system development. Engagement in iterative participatory and user-centered design activities with clinicians over the course of two years involved a series of PD workshops, heuristic evaluations, simulated resuscitation sessions, video observations, video review sessions, and a focus group. Sixteen iterations of an information display design were created. A perspective is offered on what awareness means within the context of an *ad hoc*, collocated, interdisciplinary, and emergency setting by examining teams treating severely ill patients with urgent needs.

Major findings include descriptions of: (1) the aspects of trauma teamwork that require support; (2) the main information features to include on an information display; (3) the individual role-based differences in information needs; (4) the role of temporal awareness in trauma teamwork; and (5) clinicians' concerns about using the information display in real events. Based on these findings, we contribute rich descriptions of four facets of awareness that trauma teams manage—team member awareness, teamwork-oriented and patient-driven task awareness, overall progress awareness, and elapsed and estimated time awareness.

Two major design tensions that researchers must manage when developing information displays for teamwork—process-based versus state-based design structures and teamwork-oriented versus patient-driven information—are also illustrated through iterations of the display design. We found balance in a shared information display that featured patient-driven information presented through a state-based design.

The outcomes of this study have potential uses for researchers interested in using participatory design strategies to develop information technologies for *ad hoc*, collocated, interdisciplinary teams working in time- and safety-critical settings. We show how the display designs as well as design techniques were customized to reconcile the role-based differences in information needs that emerged due to the nature of teamwork in the trauma resuscitation setting. This research provides a rich case study demonstrating the value of taking an iterative participatory and user-centered approach to design.

CHAPTER 1: INTRODUCTION AND PROBLEM STATEMENT

1.1 Motivation

User needs and, consequently, the information systems designed to support users' behaviors, are becoming increasingly complex (Kling et al. 2005). Designing technologies to support interdisciplinary group work, particularly in healthcare settings, poses a number of difficulties in representing the needs of multiple types of users and the intricacies of their interactions in complex and evolving spaces. To ensure that designs address user needs, researchers need to gain an understanding of the contexts and behaviors within the environment. Researchers can then use this understanding to work with users to create or adapt contextually appropriate design features that suit their particular and sometimes conflicting needs and then to pursue designs that fit both individual and group-level needs.

Two major gaps in the CSCW research in healthcare settings have been discussed in the literature. First, as recently pointed out by the editors of the special *CSCW Journal* issue on awareness, there is a need for understanding how technologies can be designed to support various aspects of awareness and to be specifically adapted to the "concrete conditions of tasks and their social, spatial and organizational context" (Kolfschoten et al. 2013, p. 109). A recent review of 25 years of awareness research in CSCW also indicated that there is a notable "design tension" between creating technologies that can "span across time, distance, and domains" but still address requirements that are highly specific to the domain (Gross 2013, p. 459). Furthermore, CSCW studies in the medical literature have argued for understanding awareness needs at the micro level as well as the details of what information is needed, when, how, and from whom (Pratt et al. 2004; Tjora & Scambler 2009). Second, according to a 25-year review of CSCW research in healthcare (Fitzpatrick & Ellingsen 2013), there is a need for studies that take participatory or action research approaches to engage clinicians in the design of the information technologies that will inevitably shape their work practices. Emphasis has been placed on understanding work practices through observations and interviews, but less research has focused on the design process and eliciting clinician-generated designs (Fitzpatrick & Ellingsen 2013).

The emergency medical domain called trauma resuscitation provided us with an ideal research space with design challenges relevant to the CSCW community. Examining the trauma resuscitation domain allowed us to address the aforementioned needs and gaps while gaining an understanding of awareness at the micro level (domain specific) with implications for expanding our understanding of awareness in the field of CSCW at the macro level. Although opportunities for technological innovation are evident, designing to support awareness in emergency medical domains such as trauma resuscitation is challenging for several reasons. First, trauma teams are *ad hoc* and hierarchical and involve medical professionals from multiple disciplines, leading to a diversity of information needs. Second, the resuscitation environment—the trauma bay—is complex and filled with medical equipment, imposing physical design constraints. Finally, resuscitations are fast-paced, safety-critical events in which teams deal with a considerable amount of information that emerges from the process, incomplete information, and unpredictable problems that add even more design constraints.

The approach taken in this research is rooted in participatory design (PD) (Kensing & Blomberg 1998; Muller 2003) to address these needs, gaps, and challenges. This approach allowed us to create a design process that supports both researchers and practitioners in achieving common understanding across disciplines. Engaging clinicians in various design and evaluation sessions throughout the formative, iterative, and participatory development process allowed us to create a system that is tailored specifically to the domain and that addresses individual and group-level needs, despite the *ad hoc*, interdisciplinary nature of teamwork in this setting. In particular, we combined video analysis with an iterative design process, rapid prototyping, and PD techniques to develop solutions that will meet the needs of these dynamic and interdisciplinary teams. Throughout the design process, we worked on an multidisciplinary team composed of researchers in information science, computer science, engineering, and emergency medicine to create and evaluate prototypes using empirically accessible events and practitioner participation that included design workshops, interviews, video review sessions, heuristic evaluation of paper prototypes, and simulated resuscitation events with entire trauma teams using a high-fidelity prototype.

1.2 Research Objectives

My dissertation is part of a larger research program of an interdisciplinary team composed of ten researchers and practitioners as well as two undergraduate students at four institutions to develop ideas for technological innovation and to support emergency medical teamwork. Previous work involved interviews, direct observation, and extensive video analyses of resuscitation events (Sarcevic & Burd 2008; Sarcevic & Burd 2009; Sarcevic 2010; Sarcevic et al. 2011a; Sarcevic et al. 2011b). Although this prior work highlighted issues that are relevant to awareness support, it mainly focused on information and coordination behaviors by looking at communication practices and questions posed during resuscitations. In this research, I take a more holistic approach to system design by building on previous work and iterating on the results from various design and evaluation sessions conducted with clinicians.

This research aims to understand how to design to support awareness and coordination in *ad hoc*, interdisciplinary, and emergency team settings. Working with clinicians in the trauma resuscitation domain allowed me to better understand the challenges, outcomes, and implications of designing information displays to support awareness for these types of settings. My dissertation addresses four main research questions and sub-questions (Table 1).

Table 1. Research questions addressed in this dissertation.

RESEARCH QUESTIONS		SEE PAGES
Understanding Visual Attention—Feasibility Study		
1	How do clinicians use the vital signs monitor—the only information technology currently available in most trauma rooms?	30 – 59
1a	How do clinicians use the vital signs monitor to support their awareness?	38 – 47 54 – 56
1b	How much time is allocated to the vitals signs monitor?	44 – 49
1c	Who are the most frequent users of the vital signs monitor?	49 – 53
Understanding Information Needs and Coordination		
2	*Ad hoc*, collocated, interdisciplinary trauma teams working under extreme time pressure with safety critical demands must manage a considerable amount of information that emerges from the process. What types of information support do they need to accomplish their work?	97 – 150
2a	What are the most important information features clinicians need?	97 – 127
2b	How are the information needs of roles similar or different?	117 – 127
2c	How do clinicians perceive using the information display in real events?	142 – 150
Understanding and Designing for Awareness		
3	How does awareness manifest in *ad hoc*, collocated, interdisciplinary teamwork in time and safety critical settings?	127 – 142 154 – 186
3a	How do clinicians manage their awareness and what aspects of awareness are most important in this setting?	154 – 166
3b	Which methods are most suitable for presenting awareness information and coordination support on an information display?	127 – 142 166 – 186
Using Participatory Design Techniques		
4	In what ways can we then translate (1) clinician described needs and design input and (2) our understanding of the nature of awareness and coordination into information displays designed to support the awareness and coordination of these types of teams?	117 – 142 166 – 174
4a	How can participatory design techniques be used to mitigate differences in information needs	117 – 142
4b	What are the challenges, outcomes, and implications of engaging clinicians throughout the formative design process when they work on these types of teams?	174 – 186

1.3 Overview of the Document

This document extends four completed and published studies that were conducted over a period of two years with a team of researchers. Work completed for my dissertation is summarized in Table 2 below. For each major activity, the dates, description, collaborators, and resulting publications are noted. I organized the document as follows.

The first chapters of the document introduce the research domain and related work. Chapter 2 describes the ***trauma resuscitation domain***, detailing the process, trauma team members' roles, and existing technologies in the research space. In chapter 3, I present the ***related work*** on which this research builds, discussing the concepts of awareness, temporality, and coordination in CSCW and healthcare. Related approaches to designing information displays in safety-critical teamwork are also reviewed. Portions of this section appear in previous publications (Kusunoki et al. 2013; Kusunoki et al. 2014a; Kusunoki et al. 2014b; Kusunoki & Sarcevic, 2015).

In the fourth chapter, I summarize the results of a ***feasibility study*** of visual attention to characterize the trauma resuscitation process and to understand how clinicians use this technology. I analyzed the duration, frequency, and patterns of visual attention in videos of simulated trauma resuscitations. Our findings demonstrate that information displays are viable in the resuscitation environment. Results from this study were published in the ACM CSCW 2014 paper (see Kusunoki et al. 2013).

Chapter 5 details the ***methods*** I used throughout the research process. I describe the research team, participatory design approach, participants, and research sites. Various

Table 2. Summary of work completed for this dissertation.
***Initials of collaborators: Randall Burd (RB), Nicole Ferraro (NF), Ivan Marsic (IM), Aleksandra Sarcevic (AS), Genevieve Tuveson (GT), Nadir Weibel (NW), Maria Yala (MY), Zhan Zhang (ZZ)**

DATES	ACTIVITY	COLLABORATORS*		PUBLICATIONS
2011–2012	Feasibility Study	AS	Conceptual framework, data analysis, results, discussion	(Kusunoki et al. 2013)
		ZZ	Recording monitor looks	
2013	PD Workshops	AS	Designing and conducting sessions	(Kusunoki et al. 2014a) (Kusunoki et al. 2014b) (Kusunoki & Sarcevic 2015)
		ZZ	Analyzing discussions	
		GT	Coordinating sessions, taking notes	
		NW	Observing session	
		MY	Recording & analyzing design feedback	
2013–2014	Simulated Resuscitations	AS	Designing and conducting sessions, designing prototype	(Kusunoki et al. 2014a) (Kusunoki & Sarcevic 2015)
		RB	Designing sessions and prototype, leading simulations, developing clinical scenarios	
		NW	Designing sessions, designing and developing prototype	
		ZZ	Designing backend interface, conducting sessions, demonstrating prototype, analyzing discussions	
		GT	Presenting simulation overview, developing clinical scenarios, coordinating sessions	
		IM	Designing prototype, discussing findings	
		MY	Recording & analyzing design feedback	
		NF	Transcribing & analyzing discussions	
2013	Heuristic Evaluation	AS	Designing and conducting sessions	(Kusunoki et al. 2014b)
		GT	Conducting remote session	
2014	Video Observations			
2014	Video Reviews	GT	Coordinating sessions	(Kusunoki & Sarcevic 2015)
2014	Focus Group	ZZ	Conducting session, demonstrating prototype	
		GT	Coordinating session	

data collection techniques were employed, including participatory design (PD) workshops, simulated resuscitations, heuristic evaluations with interviews, video observations of live trauma resuscitations, video review sessions with interviews, and a focus group. The data analysis techniques I used were thematic analysis of discussions and content analysis of design artifacts and design feedback from participants. Portions of this section also appear in previous publications (Kusunoki et al. 2013; Kusunoki et al. 2014a; Kusunoki et al. 2014b; Kusunoki & Sarcevic, 2015).

The sixth chapter presents the ***findings*** in four parts. First, I characterize teamwork and the features of teamwork that require support. Second, I examine the role-based similarities and differences in information needs through analyzing PD workshop discussions and clinician created sketches of an information display. Third, I describe the role of temporality in this time-critical context. Finally, I review clinicians' concerns about using the information display in real events. These findings were first reported in three publications: ACM CHI 2014 (Kusunoki et al. 2014a), CSCW Journal 2014 (Kusunoki et al. 2014b), and ACM CSCW 2015 (Kusunoki & Sarcevic 2015).

In the seventh chapter, I ***discuss*** the findings in relation to the greater CSCW context, demonstrating the implications for understanding awareness and designing information systems to support users in related contexts with *ad hoc*, interdisciplinary, and emergency teamwork characteristics. I characterize four facets of awareness clinicians manage that extend the facets of awareness presented in the CSCW literature: (1) overall progress awareness (i.e., process awareness); (2) team member awareness (i.e., social and spatial awareness); (3) teamwork-oriented and patient-driven task awareness (i.e., activity and articulation awareness); and (4) elapsed and estimated time awareness (i.e., temporal awareness). I describe how I designed the display to support awareness, especially temporal awareness because it was found to be the most prominent facet in this time-critical context. Finally, I outline the tensions that emerged from the design process, including using process-based versus state-based design structures, using teamwork-oriented versus patient-driven information, and creating role-based versus team-based display designs. Portions of the discussion section were first reported in three publications: ACM CHI 2014 (Kusunoki et al. 2014a), CSCW Journal 2014 (Kusunoki et al. 2014b), and ACM CSCW 2015 (Kusunoki & Sarcevic 2015).

The last two chapters conclude this document by reflecting on the dissertation and thinking ahead. Chapter 8 proposes the ***contributions and future work*** related to this dissertation research. Here I propose an initial conceptual model of awareness for continuing my research in other healthcare contexts. Finally, chapter 9 includes my ***reflections*** on what I have learned about research and design from completing my PhD.

CHAPTER 2: TRAUMA RESUSCITATION BACKGROUND

2.1 Domain Overview

The area of focus of this research is on *trauma resuscitation*—a fast-paced and dynamic process that requires a team of medical experts to administer life-saving treatments to address blunt or penetrating injuries, such as those sustained in motor vehicle accidents or falls. Patients are treated in a dedicated facility in the emergency department, called the *trauma bay* (Elliott & Burd 2011; Ludwig & Lavelle 2010). A number of factors can complicate clinicians' abilities to maintain temporal and situation awareness during trauma resuscitation. Unlike other medical settings, trauma resuscitation relies on emerging rather than existing information, demanding the intense, collocated effort of 7 to 20 medical specialists from various disciplines (Barach & Weinger 2007). Trauma teams consist of emergency medicine physicians, nurses, critical care specialists, respiratory therapists, anesthesiologists, and surgeons. Teams are formed *ad hoc* upon receiving a patient arrival notification, with members called from different departments, making their prior acquaintance with each other somewhat unlikely (Lee et al. 2012; Sarcevic et al. 2011). Lack of deep ties and common experiences in learning from each other may make the teams less efficient in establishing common ground, integrating knowledge, and reaching coherent solutions (Majchrzak et al. 2012).

2.2 Resuscitation Process

The process of trauma resuscitation is one of the most challenging in healthcare, requiring a team to focus on shared tasks for a short time period (20-30 minutes, on average) with the need for a critical decision about once a minute (Fitzgerald et al. 2011).

The first hour after trauma injury—the "Golden Hour"—is a critical period that is indicative of patient outcomes (Spanjersberg et al. 2009). It is therefore essential that the total time spent on diagnosis, treatment, and patient monitoring is kept as short as possible. To improve efficiency, reduce errors, and guide the initial evaluation of patient injuries, teams follow the Advanced Trauma Life Support (ATLS) protocol—a set of established protocols for patient evaluation and management. The ATLS protocol focuses on major physiological systems ("ABCDE") including: **A**irway maintenance, **B**reathing and ventilation, blood **C**irculation and control, **D**isability and neurological assessment, and **E**xposure and environmental control (American College of Surgeons 2008).

Clinicians start with an evaluation of the major physiological systems to identify life-threatening injuries, followed by a thorough head-to-toe evaluation for other injuries. Initial assessment and management procedures are done sequentially, in the order of importance, with periodic reevaluation of each system to identify any deterioration in the patient status (American College of Surgeons 2008). Clinicians must rapidly collect and sift through extensive amounts of information from various sources by detecting patterns and changes in patient status as well as by filtering out irrelevant data (Barach & Weinger 2013). After the patient's major physiological systems stabilize, clinicians conduct a secondary survey of non-life threatening, physical injuries.

Each resuscitation is unique—different combinations of factors dynamically interact and contribute to the mechanism of the patient's injury, demographics, symptoms, and reactions to treatments. Teams deal with competing priorities, unpredictable problems, and incomplete information while adapting to complex and changing circumstances. Patient evaluation is complex and sometimes requires deviation from the protocol. Task coordination is also dynamic and changes with variations in patient status. Despite these dynamic factors, the ATLS protocol still serves as a structured mechanism by which teams manage the complexity of articulating their work (Schmidt 2002) and stabilizing the patient in any resuscitation.

2.3 Trauma Team Roles

Resuscitation teams are interdisciplinary, consisting of clinicians with a variety of specializations, experience levels, ranks, and work responsibilities. Teams are also hierarchical so it is clear which person is leading the resuscitation and who is performing each task. Each team member has a specific role and a set of defined tasks (Elliott & Burd 2011; Ludwig & Lavelle 2010). For instance, anesthesiologists and respiratory therapists manage the patient's airway. Physician surveyors perform patient examinations to identify injuries. Scribe nurses document all of the findings, interventions, and outcomes of the event. Bedside nurses (primary nurse and nurse right) make sure intravenous (IV) access is established and medications and fluids are administered. Surgical attending physicians (team leader) and emergency medicine (EM) physicians oversee the whole process by making decisions and facilitating teamwork. *Critical care specialists* are typically called in to consult with the team leader and EM physician for more critical resuscitations. Each role is strategically positioned around the patient bed (Figure 1): *respiratory therapist* and *anesthesiologist* at the head of the bed managing the airway; *physician surveyor* at the side evaluating the patient; *bedside nurses* on both sides administering treatments; *scribe* at the foot of the bed documenting the event; and *team leader* and *EM physician* (and critical care specialist if present) in the back overseeing team activities. Roles of individual team members can usually be inferred from their

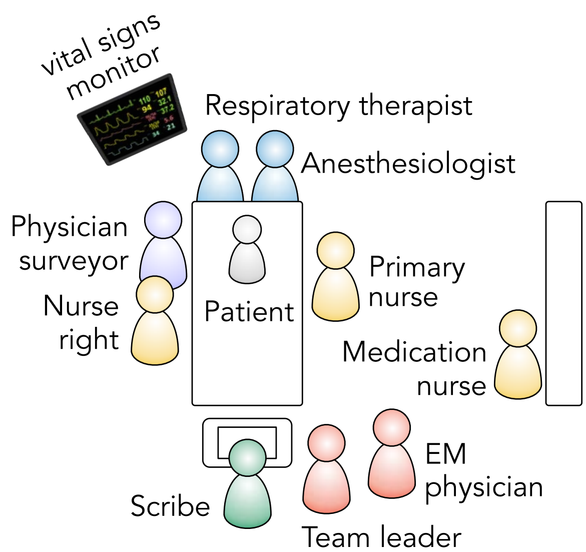


Figure 1. Team organization and layout of the trauma bay.

initial positioning around the patient stretcher, but constant movement around the room makes positioning an unreliable cue (Sarcevic et al. 2011b).

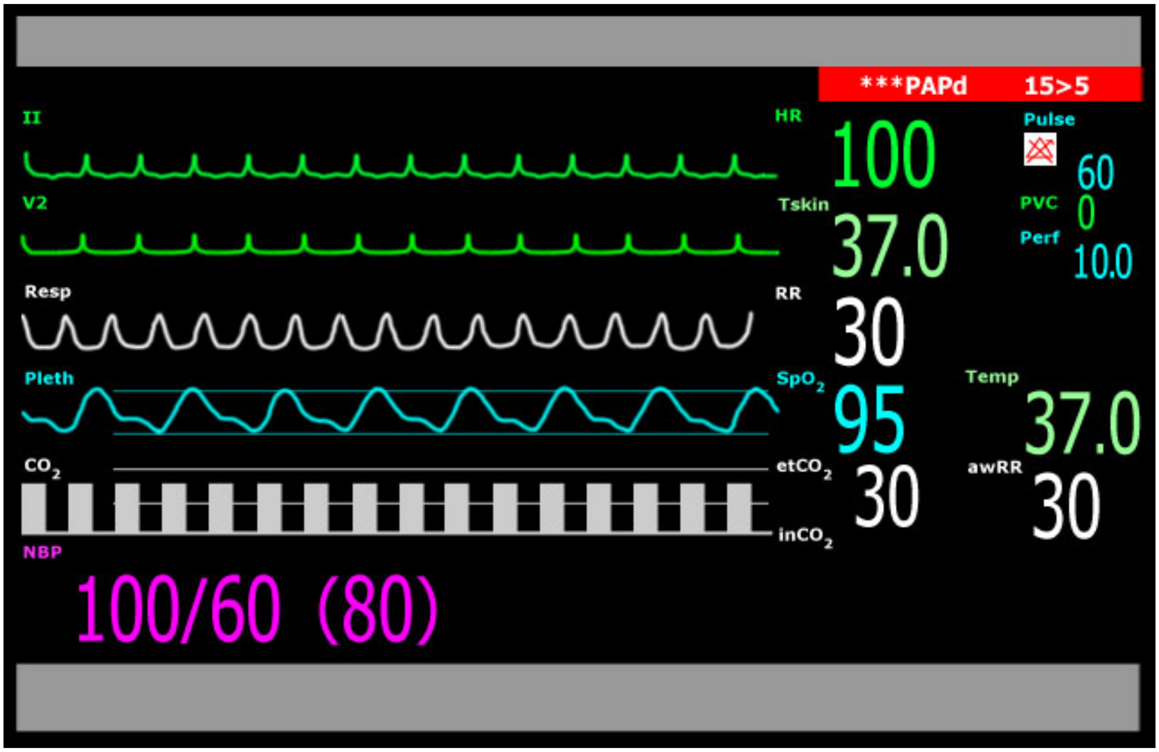
Strong and effective leadership is especially important in cases with critically injured patients and inexperienced teams, when the most skillful and experienced team member, typically the attending surgeon, needs to personally take charge of the resuscitation to provide the highest level of treatment (Xiao et al. 2004; Yun et al. 2005). While surgical leadership is common in most US trauma centers, many centers have emergency medicine programs with emergency department (ED) physicians and fellows regularly assuming leadership roles. The resulting leadership structures can therefore include leaders from different specialties with differing levels of experience (Sarcevic et al. 2011a). Although intended to provide complementary expertise, these leadership structures often cause confusion among other team members about the designated leader (Sarcevic et al. 2011a). Similarly, the high turnover among trauma team members and the *ad hoc*, interdisciplinary nature of team composition often lead to coordination difficulties, highlighting the need for role identification.

2.4 Existing Information Technologies

Several information technologies and tools assist teams during trauma resuscitations. The most common technologies include the vital signs monitor, temporal artifacts, and the paper-based trauma flowsheet. The vital signs monitor is an essential information technology that provides feedback to clinicians about the patient's status. Temporal artifacts typically include a wall clock, stopclock, and timers to help teams manage their time. There are also paper-based trauma flowsheets used to document the process manually. Below, I describe these technologies and tools in further detail.

2.4.1 Vital Signs Monitor

Although *information-rich* with constantly changing vital signs, bedside reports of patient status, and multiple treatments being ordered and given at different times, resuscitation settings are also *information-poor* in that they have few information technologies designed to support teamwork by synthesizing patient information or monitoring team activities (Xiao et al. 2006). The vital signs monitor is currently the only electronic display in the trauma bay at most hospitals. Monitoring patient status using the vital signs monitor (Figure 2) is essential for determining indications for and responses to life-saving treatments. Because adequate resuscitation is often best assessed by improvement in physiological parameters, the vital signs monitor is central to patient care and team performance.



Waveforms		
II	EKG lead selection	C
V2	EKG lead placement site	C
Resp	Respiration	B
Pleth	Plethysmography (lung volume/capacity)	B
CO2	Carbon Dioxide levels	A, B
Numerical Value		
HR	Heart Rate	C
Pulse	Pulse	C
Tskin	Skin Temperature	S
PVC	Premature Ventricular Contractions (arrhythmia)	C
Perf	Perfusion (blood flow)	C
NBP	Noninvasive Blood Pressure	C
RR	Respiratory Rate	B
SpO_2	Oxygen Saturation Percentage	A, B
Temp	Temperature	S
$etCO_2$	End-Tidal (exhaled carbon dioxide)	A, B
$inCO_2$	Inspired (inhaled carbon dioxide)	A, B
awRR	Airway Respiratory Rate	A, B

Figure 2. Vital signs monitor displaying waveforms and numerical values of vital signs and table of information displayed on the vital signs monitor. Last column indicates the ATLS protocol steps during which this information is used.

Patient data is displayed on the vital signs monitor as waveforms or numerical values (or both) and includes heart rate (HR), blood pressure, pulse, oxygen saturation levels (SpO_2), carbon dioxide levels (CO_2) inhaled and exhaled from the lungs, respiratory rate (Resp and RR), and temperature (Temp and Tskin). The waveforms represent the most recent trends of selected vital signs but span only a short amount of time (less than a minute). These vital signs data are used to make critical decisions when treating severely injured patients but are based solely on data read from sensors attached to the patient's body. This sensor-based data provides limited contextual information about patient status, team activities, treatments, and outcomes that can be obtained only through direct patient examination—such as airway obstructions [A], breath sounds [B], IV access points [C], cognitive impairment [D], and types or extent of secondary injuries [S]. The vital signs monitor mainly provides information useful for evaluating the patient's **A**irway, **B**reathing, and **C**irculation.

Teams also have several information resources for documenting patient information, including a medical flowsheet used by scribe nurses and a resuscitation checklist used by team leaders at the research site. These resources, however, are typically paper-based and are used to record patient data manually even when digital devices are used for data acquisition. The data available through these resources are therefore static, not visible to all team members, and rarely used for real-time decision-making.

2.4.2 Temporal Artifacts

Because time is a major factor in high-risk, safety-critical patient management, most resuscitation settings are equipped with some type of temporal artifact. Trauma bays typically have three kinds of temporal artifacts installed—clocks, stopclocks, and timers—currently the only mechanisms for time management at most hospitals. First, there are *clocks* presenting the *absolute time*, which is important information for coordinating work not only within the room but also with other hospital departments. Scribe nurses rely on the clock to provide timestamps for procedures and trends in vital signs, which the nurses document manually on paper flowsheets. Second, there are *stopclocks* mounted to the wall that show the *resuscitation time* (time elapsed since the resuscitation started), an important feature for presenting the temporal context of the resuscitation. Teams are instructed to have a team member manually turn on the stopclock by pressing a button on the stopclock upon patient arrival and turn it off upon patient discharge. Finally, there are *timers* that *count down from a specified amount of time* to read blood pressure every automatically five minutes and remind clinicians to check vital signs. When time permits, the bedside nurse setting up the vital signs monitor will configure the amount of time between reminder alerts to suit work style preferences (typically between 3-5 minutes). These temporal artifacts are essential for team efficacy, yet little is known about how clinicians perceive and manage time during high-risk, safety-critical patient care.

2.4.3 Paper-Based Trauma Flowsheet

Scribe nurses use paper-based trauma flowsheets to document the resuscitation process. The flowsheet is designed for capturing essential information such as the mechanism of injury, vital signs, procedures, medications and treatments, findings, and laboratory and radiology orders. The flowsheet is a large, tri-fold document with carbon copies to record the large amount of information needed for hospital records. Sometimes the team leader and EM physician reference the information on the flowsheet when they miss, forget, or want to validate information. These paper-based flowsheets are part of current work practice in most hospitals, but some hospitals are preparing to move toward direct input into digital health records.

In an environment in which tasks are distributed, information load is high, and time is limited, we believe that it is beneficial to add existing displays with information that supports teamwork and awareness of contexual information beyond vital signs. To design a display for awareness support, it is necessary first to understand clinicians' current work practices, awareness and information needs, and use and perceptions of existing information artifacts in this setting. Peripheral information displays can serve as a useful mechanism for presenting contextual information, reducing the amount of missed or forgotten information (Bardram et al. 2006).

2.5 Domain Specific Communication and Coordination Challenges

To obtain and interpret contextual information about the patient, the team's past and current activities, administered treatments and outcomes, and pending tasks, team members rely mainly on verbal and non-verbal communication. Dedicated roles report different types of information to members of the team. For example, the physician surveyor calls out findings from the physical exam as they emerge, while bedside nurses report their progress on establishing IV access. Because few mechanisms exist to help externalize information and distribute team cognition, the leadership must internally synthesize information reported by multiple team members (Sarcevic et al. 2012). High levels of verbal communication are necessary to keep team members on the same page; however, this level frequently results in repeated questions and reports, noise, and lost information (Barach & Weinger 2013; Bergs et al. 2005; Sarcevic et al. 2008). Poor information sharing leading to procedural errors and delays has been observed even among experienced trauma teams (Westli et al. 2010).

To support the team's situation awareness, clinicians (especially those in leadership roles) must also communicate directives specifying the priority, urgency, and time frame expectations of the requested task. This temporal information provides clinicians with awareness about the timing of past, present, and future activities (Bardram et al. 2006) and is critical for timing and prioritizing tasks (Cabitza et al. 2009a). Priorities in trauma resuscitation, however, change dynamically and may not always be the same across all team members at all times (Hertz & Ezer 1997). Medical personnel in general use time as a frame of reference to evaluate team performance, and they gauge and adjust their actions accordingly (Bardram & Hansen 2010).

These prior studies have focused mostly on understanding leadership effectiveness and behaviors, as well as coordinative mechanisms and team interactions, but did not discuss coordination issues with regard to awareness support. Furthermore, few studies directly have tackled ways of providing concrete design solutions to address awareness needs, various features of teamwork, and the design of information displays for *ad hoc*, collocated, and interdisciplinary teams working on patients with time-critical needs (Wu et al. 2013). Clinical training and low-tech interventions such as clocks and stopclocks have been used for improving team coordination, but errors and inefficiencies still occur often. Computer-based coordination mechanisms can provide a degree of visibility and flexibility to their analog counterparts (Schmidt & Simone 1996), but their design first requires an understanding of how features of teamwork are perceived and managed in actual work.

CHAPTER 3: RELATED WORK

3.1 The Concept of Awareness in CSCW and Healthcare

The concept of awareness has become critical in CSCW research in healthcare. The increasing specialization of medical knowledge and services, as well as the distributed nature of collaboration and communication in hospital work, have led to a large number of CSCW studies highlighting the challenges of maintaining awareness and coordinating activities (Fitzpatrick & Ellingsen 2013). This body of research has identified facets of awareness that require information technology support—including social, temporal, spatial, activity, and process awareness. The ways in which awareness is achieved in medical work, however, have been examined mostly from department or inter-department level coordination of teams with longer or asynchronous time trajectories. For example, Bardram et al. (2006) studied how clinicians in a surgical department achieve social, spatial, and temporal awareness through large interactive displays situated around the department. Although emergency medical situations share several characteristics with previously studied hospital settings such as surgery and critical care (e.g., interdisciplinary teams, division of labor), awareness requirements differ in emergency medical work due to the *ad hoc* team formation, collocated nature of teamwork, lack of information technologies, and time constraints.

The literature on awareness in CSCW has pointed to the notable lack of agreement on what is awareness and what about awareness is important to the understanding and support of cooperative work through technology (Carroll et al. 2006; Gutwin & Greenberg 2002; Heath et al. 2002; Kolfschoten et al. 2013; Schmidt 2002). There have also been debates in the field of human factors about whether situation awareness is a state that can be shared and maintained or a dynamic process of continually achieving understanding (e.g., Endsley 1995b; Salmon et al. 2007). In this research, **awareness is viewed as an ongoing and dynamic process that is constantly being shaped by emerging information and events**.

3.1.1 Awareness in Trauma Resuscitation and Ad Hoc Contexts

Among the many different facets of awareness that have been proposed and discussed in CSCW and, more specifically, in healthcare studies, six facets relate to the characteristics of awareness in the trauma resuscitation setting: social, temporal, spatial, activity, articulation, and process awareness. *Social awareness* has been described in contexts in which actors are often distributed but generally know each other. To coordinate work, actors require knowledge of who is around, where and how far in relation to each other they are situated, and what their current status and availability is (Bardram et al. 2006; Carroll et al. 2003; Prinz 1999). *Temporal awareness* has been discussed in studies focused on non-emergency settings characterized by long-term collaborations (Bardram 2000; Reddy & Dourish 2002; Reddy et al. 2006). To manage their work and facilitate scheduling in these settings, actors need to know the status of past, present, and future activities as well as the urgency of each activity. *Spatial awareness* refers to knowing what activities are taking place within a space and how people are interacting with the space itself in contexts in which actors or teams are distributed to varying degrees (Bardram et al. 2006; Gutwin & Greenberg 2002). *Activity awareness* has been described in both synchronous and asynchronous contexts as knowing what others did or are doing or knowing what needs to be done (Cabitza et al. 2007; Dourish & Bellotti 1992; Prinz 1999). *Articulation awareness* is characterized as knowing and communicating the information necessary for coordinating tasks and managing task interdependencies in collocated teamwork (Cabitza et al. 2007). Similarly, *process awareness* has been defined as knowing where the team is in the overall process in collocated, asynchronous, and synchronous contexts (Cabitza et al. 2009a).

While these facets of awareness have been described in detail with regard to collocated, distributed, synchronous, and asynchronous contexts, few studies directly examined the details of awareness in short-term, *ad hoc* contexts. Three main characteristics of such contexts introduce potential risks to providing meaningful and useful awareness information. First, there is a lack of information available *before* events to firmly establish common ground upon which awareness can be built (Argote 1982; Xiao et al. 2007). The amount and type of information available for supporting awareness varies depending on the available preparation time, urgency, and complexity of the event. Second, when team composition fluctuates, communication becomes less efficient (Lee et al. 2012). Team members arrive late and at different times and sometimes leave in the middle of events. Information must then be repeated, potentially resulting in communication redundancy, interruptions, or miscommunications. In some cases, team members might continue working without the information they need, which may lead to misguided decisions and errors. Third, there are temporal awareness issues unique to collocated, time-critical collaboration. Perceptions of time are skewed: clinicians often lose track of time, which makes maintaining temporal awareness during time-sensitive procedures challenging. It is also difficult to gain awareness of the timeline of events when arriving late. Furthermore, the short time period and rapidly changing information make continuous monitoring for trends in the data difficult. Considering these three main characteristics, it becomes important to understand the types of information that drive awareness needs and the ways in which awareness unfolds in short-term, *ad hoc* contexts. Further investigation of low-level details about awareness allows for the proposal of more meaningful and useful mechanisms to address interruptions and missed information for supporting the awareness of *ad hoc* teams.

The purpose of this research is not to define awareness, identify new facets of awareness, or conduct an extensive review of awareness (see Carroll et al. 2009; Salmon et al. 2007; Schmidt 2002 for more detailed discussion). We build on the understanding of awareness from other contexts by examining the awareness needs of trauma teams at the micro level. The analysis of awareness centers on understanding the details of what types of information are necessary to support the awareness of *ad hoc*, interdisciplinary teams in emergency medicine by designing and using information displays to present the required information.

3.2 Temporality and Coordination

The nature of temporality in cooperative work has been a continual topic of interest in CSCW. Early CSCW work defined "coordination mechanisms" as the different temporal artifacts that have been used for coordinative purposes in cooperative settings for centuries: timetables, schedules, checklists, routing schemes, catalogues, and classification systems in large repositories (Schmidt & Simone 1996). Seminal studies of time-critical work settings described other coordination mechanisms designed to reduce the time it takes to perform recurring tasks, such as flight strips that provide air traffic controllers with dynamic representations of each flight (Berndtsson & Normak 1999) or timetables to coordinate traffic flow in underground lines service (Heath & Luff 1992).

The CSCW studies reviewed in this section differ from the studies of temporality and temporal artifacts in the medical sciences due to their greater focus on teamwork and coordination. While these studies offer important design principles for coordination, they are based on a scale both temporally and spatially larger than the fast-paced, collocated trauma resuscitation context.

Several CSCW studies of medical work have looked closely at temporality (Bardram 2000; Bardram & Hansen 2010; Bardram et al. 2006; Bossen & Jensen 2014; Egger & Wagner 1992; Matthews et al. 2007; Reddy et al. 2006). This body of work is roughly divided into studies of temporal coordination and scheduling and studies of temporal rhythms. CSCW studies of coordination in medical work describe activities occurring over several hours, days, weeks, or even months. Bardram and colleagues discussed temporal coordination for scheduling of patient care, synchronization of actions, and time allocation (Bardram 2000; Bardram et al. 2006). Bardram and Hansen emphasized the importance of work articulation around scheduling in surgery called "situated planning" (Bardram & Hansen 2010). Egger and Wagner examined the social and cultural complexity of time management and creating schedules for surgeries due to the different work routines of clinicians (Egger & Wagner 1992). They discussed the inherent problems of collaborative time management in complex organizations: temporal ambiguity, conflicting temporal interests and requirements, and scarcity of temporal resources. To address those problems, Egger and Wagner developed a prototype, called "operation book," which resembles the document used in a clinic's daily planning sessions. The spatial and temporal scale of the medical work contexts described in these studies, however, is larger than that of trauma resuscitation: the activities described are being coordinated across a department rather than within a collocated team. We build on this work by discussing the role of temporality in coordinating highly time-sensitive tasks among a team of clinicians within the scale of minutes. In addition, scheduling and coordination in trauma resuscitation are not a primary concern because teams are collocated (though task coordination is still required) and their formation is *ad hoc*.

There are several studies of temporality in clinical and emergency medical contexts. A classic study by Zerubavel (1979) described the rhythmic structures of social organization in hospital life as characterized by five major social cycles: the year, the rotation, the week, the day, and the "duty period." Reddy and Dourish (2006) focused on the role of rhythms and temporal patterns in information seeking of clinicians in an intensive care unit (ICU). They found that temporal rhythms orient members of the ICU towards likely future activities and information needs, forming patterns that characterize the work in the unit. Such patterns include large-scale rhythms (e.g., nursing shifts, rounds) and finer-grained rhythms (e.g., lab results, medication administration). Some medications are ordered based on urgency and circumstances, as they are in trauma resuscitation; but because medications in the ICU are given on a known schedule, nurses can arrange their activities around this schedule. Temporal awareness has also been considered as an essential dimension of "achieving overview" in medical work, especially when achieving a shared overview of patient status requires convergence of multiple schedules (Bossen & Jensen 2014). In medical research, there is more emphasis on (1) the importance of time to measuring clinical performance (Spanjersberg et al. 2009; van Olden et al. 2003); (2) the completeness and accuracy of documentation for medical records, research, and cross-referencing events between different units (Ferguson et al. 2005); and (3) the accuracy and synchronization of timepieces, especially pre-hospital (on the scene or in the ambulance before arriving at the hospital) and across hospital departments (Cordell et al. 1994; Ferguson et al. 2005). Although not focused on the design of time-based features for medical work, these studies point to the importance of time and the need for considering temporality in systems design.

3.3 Information Displays in Safety-Critical Teamwork

A central technology design issue in emergency medical work is supporting clinicians' awareness of various types of information to improve team communication and coordination, ultimately for better patient care. An important challenge to implementing computerized support in this setting is the need to synthesize and present information effectively. One way to provide awareness support is through shared information displays (Wallace et al. 2011). Information displays and whiteboards have been proposed for augmenting communication, work coordination, and awareness in a variety of medical settings, including emergency departments (Wears & Perry 2007; Wears et al. 2007); operating rooms (Bardram et al. 2006; Bitterman 2006; Parush et al. 2011; Drews & Westenskow 2006); critical care units (Wilson et al. 2006); and even patient rooms. These displays and status boards have been shown to support both collocated and distributed work by facilitating task coordination, resource planning, communication, and problem solving. Integration and display of large amounts of data have also been used for improving awareness in other safety-critical settings, such as air traffic control (Hourizi & Johnson 2001; Hutchins 1995), subway line control (Christian Heath & Luff 1992), and nuclear power plant control rooms (Mumaw et al. 2000).

As a safety-critical, socio-technical system, trauma resuscitation remains one of the few medical settings without information technologies that support teamwork. Introducing large displays that include vital signs data augmented with contextual information about patient status, and team tasks could provide additional support for maintaining team awareness.

To maintain awareness while completing their work, clinicians would need to allocate a portion of their visual attention to viewing the information display. In the visual and cognitive attention literature, there are many studies of gaze patterns across a range of tasks, including car driving (Rogers et al. 2005), laparoscopic surgery (Law et al. 2004), and information searches (Heath & Luff 1992). Using eye-tracking equipment, these studies examined patterns and dwell times of individual participants engaged in visual problem-solving tasks while looking at a single display. A recent study of the distribution of visual attention in anesthesia providers has shown that 30% of visual attention was directed to the vital signs monitor, particularly during crises (Schulz et al. 2011). Few studies, however, have explored the distribution of visual attention that interdisciplinary medical teams use to gather the information for maintaining situation awareness in dynamic domains such as trauma resuscitation. The knowledge obtained through understanding teams' use of the vital signs monitor can offer valuable insight into the design of information technologies that support complex and dynamic teamwork processes.

3.4 Related Approaches to Designing Information Displays

Information displays have been developed in medical and emergency response settings using a variety of approaches. Parush et al. (2011) derived requirements for an information display during open-heart surgery by identifying team communications that reflected processes of building and maintaining team awareness. Wachter et al. (2003) developed a graphical pulmonary display for anesthesia by using rapid, paper-based usability testing. Holzman (1999) used observations, interviews, and evaluation data to develop a system for coordinating distributed emergency medical responses. In addition to these standard approaches, researchers have also used participatory design techniques. For example, Bardram et al. (2006) designed their AwareMedia system based on field studies and a series of design workshops with a group of clinicians. Kyng et al. (2006) used field studies and participatory design to develop interactive systems for emergency response. Kristensen et al. (2006) used field studies and "future labs" (workshops in highly realistic settings) to develop ideas for supporting emergency medical services during major incidents. Though informative about the end results of design efforts, these studies do not describe any design tensions that emerged from designing with interdisciplinary teams during the design process.

Studies of ambient and peripheral displays provide useful heuristics for designing and evaluating information displays that guide our decisions. Mankoff et al. (2003) adapted Nielsen's heuristics for evaluating ambient displays (e.g., conveys "just enough" information). Complementarily to Mankoff et al. (2003), Shami et al. (2005) developed a method for evaluating peripheral displays *in situ* that reflects "trade-offs" (e.g., must be noticeable yet allow users to divide their attention when performing a task). Matthews et al. (2007) discussed design and evaluation guidelines for peripheral displays with regard to the changing scope, criticality, and class of user activities. These studies provide several heuristics that informed our design of the display that is the focus of this study and that served as guidelines for developing the discussion questions used to evaluate the display.

The approach we take is bottom-up but relies on participatory design (PD) to understand the domain and elicit the information needs of individuals and teams. Where this research differs from other studies, however, is in using PD as a vehicle not only to understand the domain and develop ideas but also to manage design tensions that emerged during the design process. Design tensions and associated challenges are acknowledged in the HCI and CSCW literature (Fitzpatrick & Ellingsen 2013; Gross 2013; Gutwin & Greenberg 1998), but there are few discussions on how to address and balance them. In the Value Sensitive Design (VSD) literature, studies have described identifying and balancing tensions in human values and reflecting this balance in system design (Czeskis et al. 2010; Miller et al. 2007). Czeskis et al. (2010) discussed VSD as an approach for addressing the tensions in human values and the use of "value scenarios" for engaging participants in conveying their concerns about the potential effects of the technology proposed. Similarly, Miller et al. (2007) examined conflicts in human values held at the group level versus those held at the individual level and described how to address value tensions in the design to avoid issues with users having difficulty appropriating the system into their work practice. Both studies described identifying value dams and flows (system features or organizational policies that are opposed to or supported by stakeholders) and then balancing needs (e.g., privacy versus awareness) in the system design.

VSD is related to PD in its theoretically grounded approach to design, aiming not only to involve stakeholders throughout the design process but also to understand the stakeholders' social values and then incorporate those values into the way systems are designed and evaluated, such that the systems transform everyday activities and enact social change (Hendry & Friedman 2008; Friedman et al. 2008). VSD studies tend to have a wider scope—extending user values to all human values while focusing on values with moral and ethical implications, including contexts beyond the workplace, and involving broader sets of direct and indirect stakeholders (i.e., parents and teens, and software engineers in a large organization) than those normally involved through PD. These perspectives can supplement those of PD to incorporate user perceptions of using a system in real life. Denning et al. (2010) used semi-structured interviews to elicit human values with regard to using security systems for wireless implantable medical devices (wireless IMD's). Users described their perceptions of different types of security systems and indicated whether they "liked" or "disliked" each system. Based on participant feedback, Denning et al. (2010) developed a set of criteria for developing and evaluating IMD security systems.

3.5 Summary

There is a specific need for more research in CSCW and healthcare on designing information displays to support awareness during *ad hoc*, interdisciplinary medical teamwork. Three factors—the notion of awareness, what awareness means in this context, and how temporal factors in this environment affect the way clinicians maintain awareness—require further investigation and detailed description. While clinicians currently use information technologies such as stopclocks and vital signs monitors to maintain awareness, these tools lack contextual information produced by clinicians. Several studies have discussed different approaches to designing information displays that provide useful heuristics for designing and evaluating peripheral displays and have demonstrated that participatory design is an appropriate approach to design. We next describe the results from a study that showed the feasibility of implementing an information display in a trauma bay and explored the capacity that trauma teams have for allocating their visual attention to an information display during the trauma resuscitation process.

CHAPTER 4: A FEASIBILITY STUDY OF VISUAL ATTENTION THROUGH DETAILED VIDEO ANALYSIS OF VITAL SIGNS MONITOR USE

The feasibility study was published in the Proceedings of the 2013 Conference on Computer-Supported Cooperative Work (Kusunoki et al. 2013). The goal of the study was to examine the visual attention of trauma team members in order to determine the feasibility of supporting their awareness with a large wall display showing contextual information during resuscitations. The main research questions for this feasibility study were: Who are the most frequent users of the vital signs monitor? How often is the monitor used? How much time is allocated to the monitor?

We found that those in decision-making roles looked at the monitor longer than others and appeared to analyze data for diagnostic purposes. Those who were more involved in direct patient care looked less frequently and for shorter amounts of time. Finally, clinicians usually glanced at the vital signs monitor for 1-3 seconds but sometimes spent up to 26 seconds analyzing monitor data. These findings suggest that displays with more contextualized information may be viable in emergency medical environments.

4.1 Conceptual Framework: Feedback Loops in Trauma Resuscitation

Feedback loops are viewed as powerful mechanisms for augmenting human performance (Wickens et al. 2004). An example of a simple and successful feedback loop application is the driver-feedback sign—a speed limit sign coupled with a radar sensor attached to a large digital readout announcing “Your Speed” (Goetz 2011). Research in HCI and UbiComp has leveraged this concept by featuring technologies and applications that allow fast and easy collection of energy-usage data and personal health data to trigger behavior change (Froehlich et al. 2010; Froehlich et al. 2011).

In the context of medical work, feedback allows clinicians to identify and correct poor decisions before they lead to undesirable outcomes (Wickens et al. 2004). Drews and colleagues (2006a & 2006b) studied how anesthesiologists used visual display feedback for maintaining the level of anesthesia administered during surgery. They found that feedback helped anesthesiologists formulate drug-dosing strategies, particularly during critical moments. In contrast, our work views the entire trauma team involved in multiple feedback loops, with each feedback loop addressing a major physiological system (Airway, Breathing, Circulation, and Disability), as outlined by the ATLS evaluation protocol. We can view the resuscitation process as consisting of several independent feedback loops for two reasons.

First, although the body's physiological systems are interconnected, they are sufficiently independent from one another, allowing clinicians to treat each system independently. In fact, the ATLS protocol recommends that the evaluation of these systems be performed sequentially and independently of each other. During the primary survey of a new patient, the team diagnoses and treats complications in each physiological system by collecting evidence about its status, determining and administering treatments, and interpreting patient responses to those treatments (Figure 3). Each feedback loop originates with an event (e.g., injury or treatment) and continues with the team's observations of the effects of this event (e.g., injury symptoms or response to treatment). Based on the feedback obtained, the team decides whether to perform a

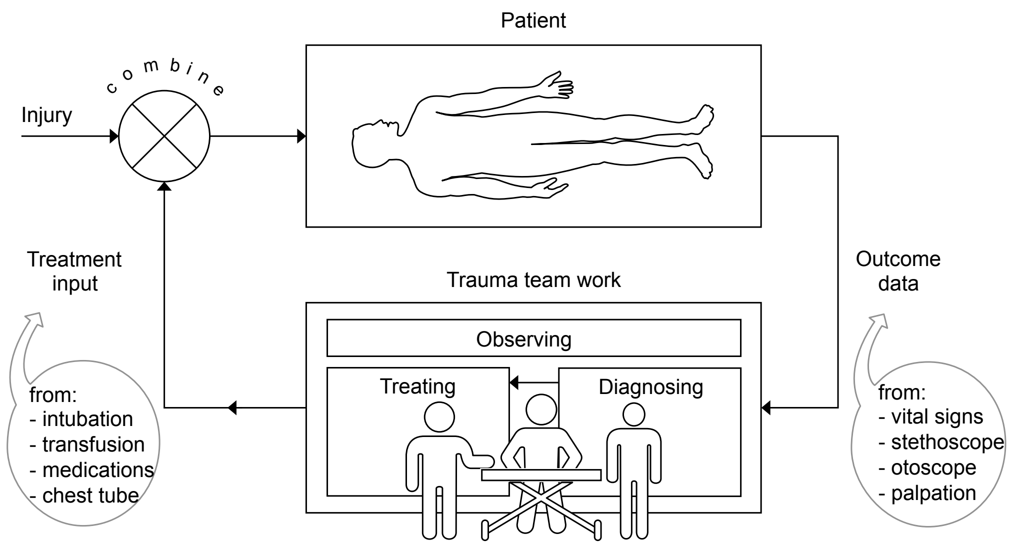


Figure 3: Feedback loop representation of the resuscitation process.

treatment; pause and temporarily switch to another physiological system (different feedback loop); or conclude the current feedback loop (Figure 3).

Second, all major interventions (e.g., intubation or chest tube insertion) are closely coordinated and supervised by a single person (team leader), making it difficult to perform two interventions simultaneously. In addition, each intervention is followed by a waiting period to evaluate the effects of the treatment (feedback). The timeliness of this feedback depends on how fast the team can perform treatments and how fast the patient reacts to those treatments. The team may start working on a different system while waiting for feedback but often cannot perform major work on more than one physiological system at the same time.

Viewing the resuscitation process using a feedback loop perspective allowed us to situate monitoring activities within the context of the work. This perspective yielded new insights into team dynamics and the role of vital signs monitor in supporting trauma teamwork. In short, we realized that understanding the dynamics of different feedback loops, as well as team activities associated with those feedback loops, will help inform what information to display, when in the process, and for how long.

4.2 Benefits of Conducting Detailed Video Analysis

Users and their contexts are important in designing information systems. Researchers strive to conduct research in natural settings to gain a holistic understanding of participant behavior within a particular context. Observation helps researchers to build a descriptive understanding of what actually occurs and to understand the world from the perspective of the observed (Blomberg et al. 1993). Detailed video analysis enables researchers to review the swift behaviors and teamwork of multiple actors against a timeline.

4.2.1 Understanding User Context and Behaviors through Observation

What people say they do is not always the same as what they actually do (Blomberg et al. 1993; Forsythe 1999). This phenomenon is related to ideal and manifest behavior—participants sometimes present distorted accounts of their behavior or may not be aware of what they are doing because they often do not have access to the tacit knowledge deeply rooted in their behaviors (Babbie 2010; Blomberg et al. 1993). When combined with other techniques like focus groups and surveys, observation is especially helpful in identifying and confirming participants' (and also researchers') tacit knowledge and assumptions (ibid).

Observation can help researchers uncover patterns of behavior and participants' "world views" in a flexible and unobtrusive manner (Blomberg et al. 1993; Randall &

Rouncefield 2007). Observing users in their own contexts is helpful because such observation reduces the pressure on participants to perform during a formal study and allows researchers to see how participants would behave on their own accord (Tourangeau 2004). Observing participants may reveal behaviors, factors, and barriers that the researcher had not considered or that are contrary to previous assumptions and findings (Willimack et al. 2004). Observations further assist researchers in distinguishing between what they already know and what they want to know about participants, thereby helping identify initial criteria and questions for information system design. It is important to note, however, that the perspective of the research approach taken can influence whether aspects of participants' work are visible or "invisible" to the researcher and that observation is just one method to help researchers develop a particular perspective that should be supplemented with other methods to gain different perspectives to create a fuller understanding of the behaviors taking place (Muller 1999).

4.2.2 Detailed Video Analysis as form of Unobtrusive Observation

Videos are useful for conducting unobtrusive observations—especially if the purpose is to analyze communication; work coordination; interactions; or behaviors like glances, gazes, and gestures in detail (Crabtree et al. 2012). The video format is suited for reviewing rare events, conducting multiple analyses, and allowing analysis by multiple people, which is helpful in situations in which it is difficult to get information from busy participants. Videos are also useful for identifying issues that users may have experienced and for analyzing events against a timeline (Marshall & Rossman 2011; Randall & Rouncefield 2007).

In this study, videos were analyzed *post hoc* to understand how participants used the vital signs monitor. We selected the video observation method because it allowed us to record durations and frequencies of looks more precisely than *in situ* observations and to conduct detailed analyses of behaviors and communication among the seven to eight team members observed. These video observations were closer to pure observation on a continuum from pure observation to participant observation. Because access to videos of live resuscitations was limited to five weeks after the event and used only within the hospital, we opted to use an existing dataset of simulated resuscitations that did not have these limitations on time and location. While video analysis is useful, it is also limited in the types of data it can capture from the moment and cannot be used alone as a replacement for engaging with participants (Crabtree et al. 2012). The main limitations of this technique are that researchers are not able to observe participants outside the frame of the video camera and time span recorded or ask follow-up questions during or after the event to confirm and clarify the behaviors observed.

4.3 Dataset

We analyzed 12 high-fidelity simulated resuscitations—each involving a unique trauma team with a team leader (senior surgical resident or emergency medicine physician), physician surveyor, anesthesiologist, primary nurse, nurse right, scribe nurse, respiratory therapist, and medication nurse. Team members were recruited from clinicians usually serving in these roles. The simulations were performed in an actual trauma bay with high-fidelity patient mannequins and the usual medical equipment and materials available.

We analyzed two scenarios performed by trauma teams. The first scenario (*Scenario A*) involved a 5-year-old female who was in a high-speed car accident. Teams needed to respond with interventions including intubation (a procedure in which a tube is inserted into the trachea to assist the patient's breathing) and fluid administration to stabilize blood pressure. The second scenario (*Scenario B*) involved a 3-year-old male who was hit by a car and dragged. Trauma teams were expected to perform chest decompression using a needle to release increased air pressure in the space between the lung and chest wall (tension pneumothorax) and fluid administration to stabilize blood pressure. The mannequins had features that allowed the teams to perform the resuscitation procedures required for each scenario (e.g., listen to breath sounds, insert tubes, and feel for injuries). The mannequins were also marked by artificial injuries for scenario realism.

4.4 Data Analysis

4.4.1 Transcription and Coding of Simulated Resuscitations

We conducted a detailed transcription of simulation videos and coding of team tasks and communication to enable subsequent analyses of tasks related to monitor use. We transcribed the simulations into a spreadsheet by recording the tasks in the order in which they were performed. The tasks included patient assessments, diagnoses, medication preparation, interventions, and references to information sources for both gathering data and obtaining feedback. We also transcribed team dialog to understand the context of the tasks—including sections for the role of the speaker, role of the listener(s), and the statements they made. A data dictionary was created to standardize the transcription and coding process; it included the tasks performed according to ATLS with a corresponding code (ABCDE). Two researchers coded the transcripts independently and applied multiple codes where necessary. Coding disagreements were minimal and were concerned mainly with tasks that had not initially been categorized based on the protocol. All disagreements were resolved through group discussion with another researcher, and codes in the transcripts were updated to reflect the decisions.

4.4.2 Analysis of Vital Signs Monitor Looks

Using the transcripts and videos, two researchers recorded the instances in which team members looked at the vital signs monitor, including how many times each individual looked and the amount of time he or she spent looking at the monitor. We used the time-stamping function in Transana, an open-source video transcription software, to record the start and end times of monitor looks by each team member. To manage multiple, overlapping looks at the monitor, the data were placed into a separate spreadsheet and sorted by start time and then by team member. Start times were then matched with end times, and lengths of looks were calculated. This process also allowed us to check for accuracy and missing data points.

Using this data, we created histograms showing the frequency and durations of looks across all simulations (see Figure 4 as well as the look durations for each team member in Figure 8). Based on the observed drop in the frequency of monitor looks over 3 seconds, we chose 3 seconds as a reasonable threshold to distinguish between short and long looks (see Figure 4). Monitor looks ≤3 seconds were considered glances, and looks that were >3 seconds were considered scrutiny (Sekuler & Blake 2006).

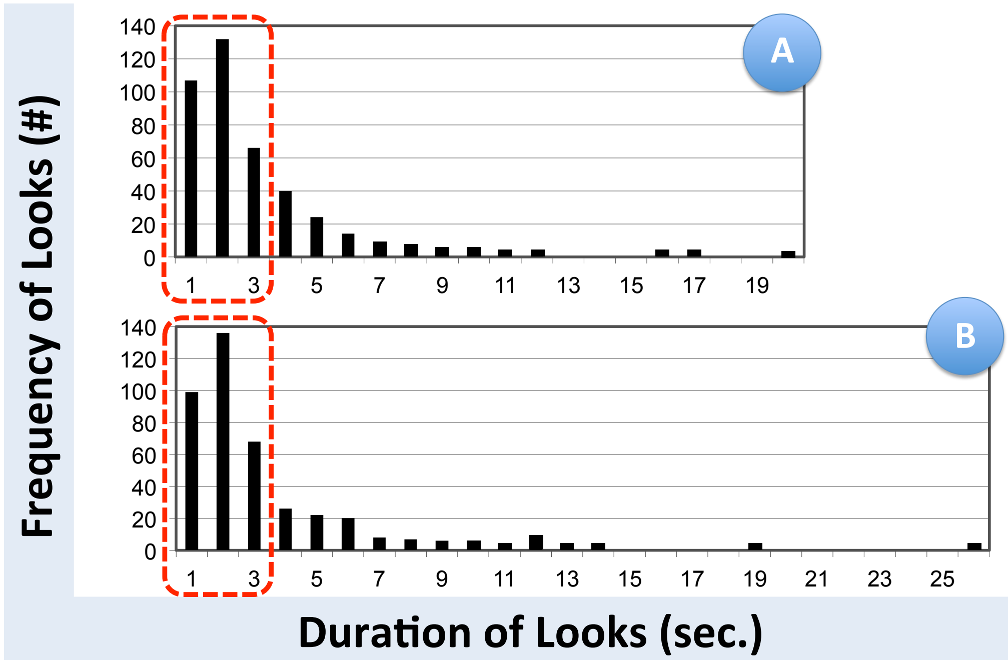


Figure 4. Frequency of vital signs monitor look durations across 6 simulations for Scenario A (a) and 6 simulations for Scenario B (b).

4.5 Results

We report our results in three parts. First, we describe the trauma team workflow from a feedback-loop perspective to help situate our analysis of monitor looks. We then characterize the use of the vital signs monitor within the context of trauma teamwork. Finally, we discuss team roles and how their work was distributed across feedback loops to gain further insight into team workflow and how best to support it with supplemental information displays.

4.5.1 Situating Vital Signs Monitor Use in Feedback Loops

Although we created three-part visualizations of tasks and monitor looks for all 12 teams, space constraints allow us to show visualizations for only two teams, one from each scenario (Figure 5 and Figure 6). Our observations showed that teams initially followed the resuscitation protocol (from A through C), starting with a quick survey of the Airway [A] (by stabilizing the neck and assessing the airway patency); Breathing [B] (by listening for breath sounds and providing supplemental oxygen); and Circulation [C] (by palpating for pulses), as shown in top charts in Figure 5 and Figure 6. After completing these initial evaluation steps, the teams focused on the feedback loop involving the most critical intervention: intubation of the trachea [A] in Scenario A and chest decompression or chest tube placement [B] in Scenario B. Critical tasks included monitoring oxygen saturation and blood pressure, as well as examining breath sounds and pulses.

We found that the frequency and duration of monitor looks varied over the course of resuscitation and depended on the tasks and team activities. The middle charts in Figure 5 and Figure 6 show the frequency of monitor looks over time for all team members. The bottom charts show the total duration of monitor looks. A possible explanation for this variability in frequency and duration of monitor looks may be that the types of information sought during periods of frequent scrutiny differed from those sought during periods of frequent glances. Alternatively, it may be that teams limited the duration of their looks because they needed to focus on the patient. We next discuss these observations in greater detail.

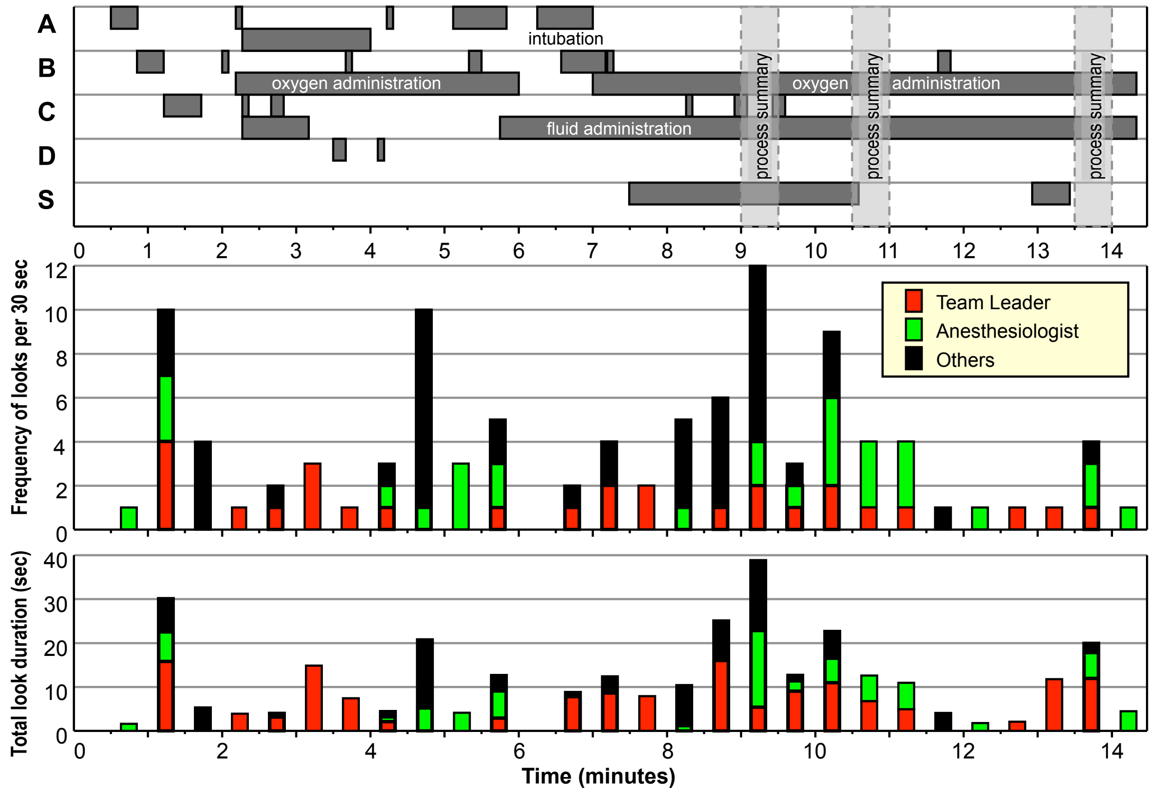


Figure 5: Top chart: Visualization of resuscitation tasks corresponding to feedback loops or ATLS steps for Scenario A, Team 1 (A stands for the Airway step or feedback loop, B for Breathing, C for Circulation, D for Disability, and S for Secondary survey). Bottom two charts: Distribution of frequency and total duration of monitor looks per 30-second interval.

4.5.1.1 Iterations of Feedback Loops

Teams continuously monitored the status of different physiological systems through corresponding feedback loops. Most of the time, teams were able to address the problems they diagnosed within a single iteration of a loop. For example, Team 1 in Scenario A decided that the patient needed additional oxygen and intubation based on decreased oxygen saturation and the lack of patient responsiveness at 2′15″ (Figure 5, top). They successfully completed intubation at minute 7 and then continued monitoring

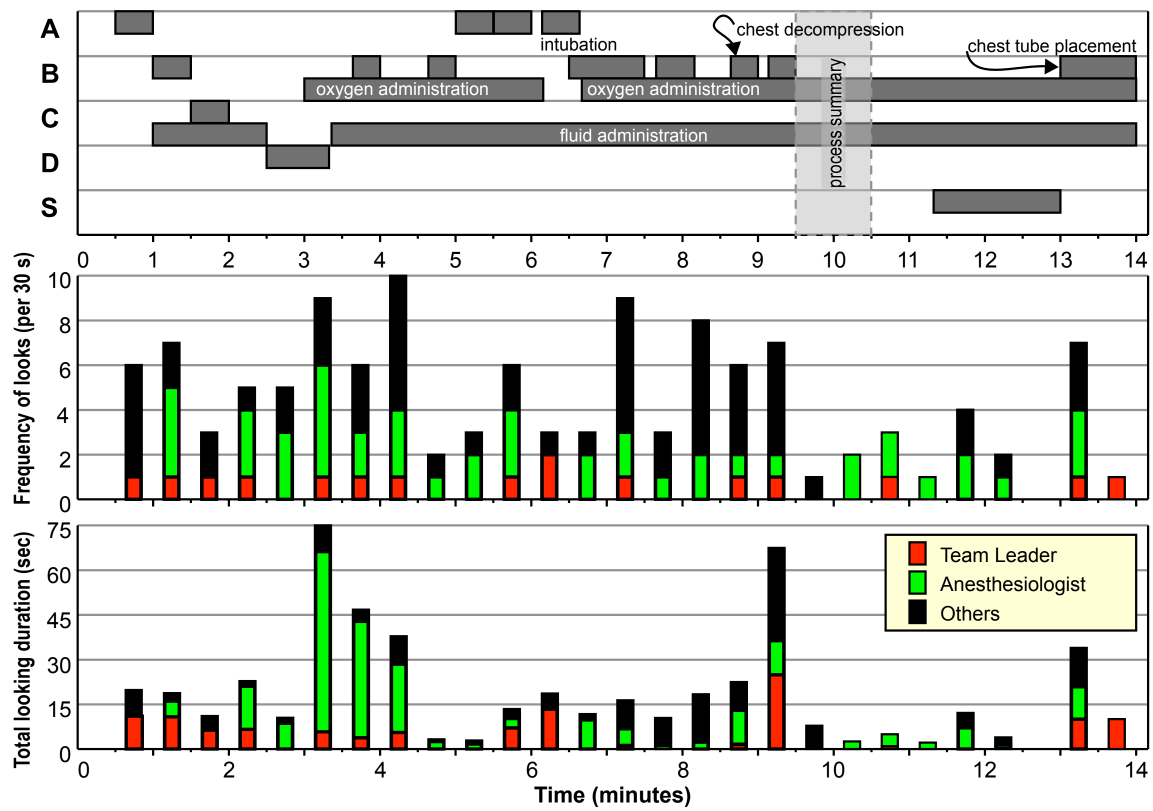


Figure 6: Top chart: Visualization of resuscitation tasks corresponding to feedback loops or ATLS steps for Scenario B, Team 5 (A stands for the Airway step or feedback loop, B for Breathing, C for Circulation, D for Disability, and S for Secondary survey). Bottom two charts: Distribution of frequency and total duration of monitor looks per 30-second interval.

the airway status through brief assessments and summaries of vital signs ("process summary" in Figure 5).

Teams sometimes reiterated one or two feedback loops several times until multiple interventions finally led to patient improvement. For example, Team 5 in Scenario B iterated the Breathing feedback loop three times before successfully addressing the tension pneumothorax (Figure 6, top). At minute 1, they first diagnosed diminished breath sounds [B] and ordered oxygen administration, which started at minute 3. They then assessed breath sounds several times to observe the effects of oxygen administration (at times 3′40″ and 4′40″). After seeing no improvement, the team decided to intubate the patient, believing that this intervention would help (note their switch to the Airway loop). Breath sounds, however, remained diminished, leading the team to diagnose the patient with a tension pneumothorax and perform chest decompression at 8′40″. Even this second iteration did not fully address the underlying problem, triggering the third iteration and chest tube placement at minute 13.

Summaries of vital signs and patient status served as a mechanism for maintaining team situation awareness and ensuring that all critical tasks were completed. Team leaders often provided a process summary (and in some cases multiple summaries) at the beginning, middle, or end of the resuscitation. As an example, the team leader on Team 5, Scenario B, summarized the process at 9′30″, including the mechanism of injury, interventions, and tasks in progress (Figure 6, top):

> While he's putting the tube in, let's summarize. 2 year old, MVC [motor vehicle crash] hit and drag. Came in with an airway. We intubated secondary to hypoxia, needle decompressed, followed along with chest tube and fluids. Otherwise, external marks include tire tracks on the left chest and abrasions on left lower extremity as well as the left head. Anything else?

4.5.1.2 Switching Among Feedback Loops

Trauma teams often switched among multiple tasks from different feedback loops. For example, all teams in Scenario A began by assessing the Airway and ordering intubation but temporarily switched tasks to the Circulation loop and prepared intravenous (IV) access for administering intubation medications. Another example occurred in Scenario B, when Team 5 switched from assessing breath sounds in the Breathing loop to intubating the patient in the Airway loop, and then back to Breathing, when they decompressed the chest, as described above.

Some tasks had sequential order requirements as well. Intravenous access [C] needed to be established to administer fluids [C] or medications necessary for intubation [A]. It was also important to assess for brain injury before medicating the patient by examining the pupils and assigning a GCS score, an indicator of the patient's neurological status [D].

Switching among feedback loops seemed to occur for three reasons: (1) the requirement to attend to overlapping tasks from different feedback loops; (2) the need to suspend major tasks in the current loop while preparatory work for that loop was being completed; and (3) the sequential task dependencies across different loops, when one feedback loop could not proceed without completing tasks from another feedback loop.

4.5.2 Monitor-Use Behaviors & Intensity of Looks over Time

Overall, the frequency and duration of monitor looks were relatively low during resuscitations, representing *background monitoring* of the patient's vital signs while focusing on patient care. These quick looks correspond to low bars in both frequency and duration—the bars with up to five looks in frequency and up to 10 seconds in total duration (see bottom two charts in Figure 5 and Figure 6). We selected ten seconds in total duration and five looks in total frequency as the threshold for representing background monitoring because each of the five looks would then be approximately two seconds long, representing a glance. The background monitoring behavior was prevalent across all resuscitations, accounting for more than 50% of monitor looks in 8 out of 12 events (Figure 7(a)).

We also observed peaks (high bars) in both the frequency and the duration of looks, representing *scrutinizing behavior*. These peaks occurred (1) while teams were diagnosing patient conditions; (2) before major interventions ("diagnosing" in Figure 3), and (3) during "process summaries." For example, Team 1 in Scenario A had two high-frequency peaks in the intervals 1′–1′30″ and 4′30″–5′ (Figure 5). The first peak occurred during initial evaluation of the airway, breathing, and circulation, when the team diagnosed the need for oxygen administration [B] and intubation [A]. The second peak occurred while the team was waiting for the start of IV fluid administration, which then enabled them to start treating the airway by administering intubation medications. The remaining peaks coincide with process summaries, during which teams continued monitoring and diagnosing. We observed that all team members looked at the monitor during summarization, especially when the leader noted any changes in vital signs, as shown in this example:

> Open to suggestions, guys. We're well ventilated and well oxygenated. Our heart rate has come down dramatically. Our blood pressure is up with the IV fluid.

Similarly, during the 1′–5′ interval, Team 5 in Scenario B had several high peaks in frequency and duration corresponding to the observation and diagnosing phases within the Breathing feedback loop (Figure 6). Another peak occurred during the interval 7′–8′30″, when the team diagnosed the patient with a tension pneumothorax after assessing the patient's breath sounds. Peaks were also observed after chest decompression from 9′–

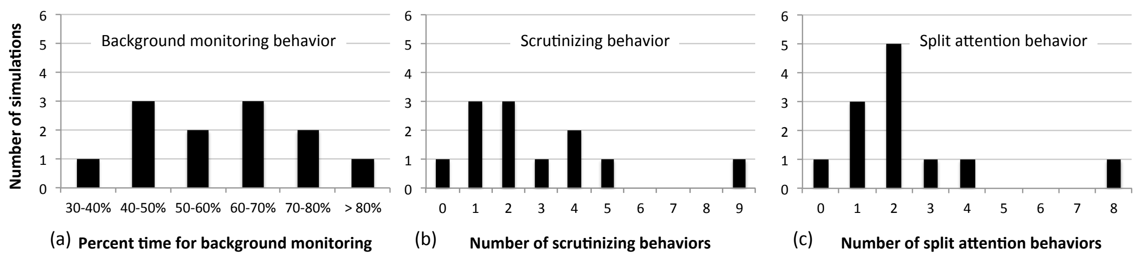


Figure 7: Vital signs monitor use behaviors across all 12 simulations. (a) Distribution of background monitoring behavior. (b) Distribution of scrutinizing behavior. (c) Distribution of split attention behavior.

9′30 and as the team performed chest tube placement between 13′–13′30″. During these interventions, the team needed to monitor the patient's oxygen saturation and carbon dioxide levels after intubation. They also needed to ensure that the chest tube was placed properly and that the patient's breath sounds were improving. On average, we found 2.8 scrutinizing behaviors per resuscitation (Figure 7(b)). This low number of scrutinizing behaviors overall can be explained by the fact that most teams succeeded in diagnosing the complications in one to two loop iterations. The outlier team with nine scrutinizing behaviors (Team 4 in Scenario B) had a less experienced physician surveyor but a proactive team leader who made diagnoses quickly and called out interventions promptly. Most of the monitor looks in this event came from the anesthesiologist, who monitored the vital signs for everyone and reported them aloud. The team leader noticed this behavior and used the anesthesiologist as a proxy so he could focus on the patient.

Finally, we observed that some high peaks in frequency did not have corresponding peaks in duration. We defined this behavior as *split-attention*, which occurred during complex procedures when the team needed to maintain attention on the patient while also monitoring the displayed vital signs.

For example, peaks in frequency during intervals 4′–4′30″, 5′30″–6′, and 7′–9′ for Team 5 in Scenario B (Figure 6, middle) do not have corresponding peaks in duration (Figure 6, bottom). During the first interval (4′–4′30″), the team was addressing a Breathing problem by frequently looking at both the patient's chest and the vital signs monitor. Similarly, during the 5′30″–6′ interval, the team was addressing the patient's deteriorating airway. The team was preparing for intubation and had to maintain attention on both the patient and the monitor. Shortly after intubation, the scribe nurse pointed out that the oxygen saturation was falling to dangerously low values. As a result, the team continued splitting attention between the patient and the monitor during the 7′–9′ interval, especially as they performed chest decompression. On average, we found 2.3 split-attention behaviors per resuscitation (Figure 7(c)). This low number of split-attention behaviors overall can be explained by the fact that the patients required only a few complex procedures. Team 5 in Scenario B was an outlier, exhibiting a total of eight split-attention behaviors. As described above, it took this team several loop iterations before diagnosing the problem, which required more time for both patient and for monitoring the vitals. The leader was also less proactive—mainly asking for information, reminding the team of protocol steps, and summarizing the process.

Although all team members looked at the monitor, the team leader and the anesthesiologist had more frequent and longer looks than others. This finding is not surprising, given their roles—the team leader is supervising the process and anesthesiologist is responsible for airway management, which involved one of the critical conditions that needed to be addressed. As seen in Figure 5 and Figure 6, the leader had a relatively low frequency of looks but was dominant in terms of the duration of looks.

4.5.3 Distribution of Looks across Teams and Scenarios

Our analysis of vital signs monitor looks showed that trauma teams used the monitor to identify conditions that could not be found through physical examination of the patient. The monitor was an integral part of the resuscitation process and provided an information source that team members used to establish common ground and maintain awareness. We further examined how teams used the vital signs monitor with a particular focus on (a) how much time was allocated to the monitor and how often team members looked and (b) who the frequent users of the monitor were.

4.5.3.1 Time Allocation and Frequency of Monitor Looks

Our data showed that most monitor looks were quick glances—3 seconds or shorter (75%) (Figure 4, Table 3). This large percentage of glances appears to be related to the prevalence of background monitoring behavior because clinicians allocate a portion of their visual attention to periodically updating their awareness without spending a lot of time analyzing the information on the display. The data also revealed many looks that were between just over 3 seconds and 26 seconds (25%) (Figure 4, Table 3). The monitor look ratio of glances to scrutiny is approximately 4:1. Although we examined 12 unique teams in two scenarios (6 teams per scenario), it appears that the total numbers of glances and scrutiny were highly consistent between Scenarios A and B. While scrutiny was not as prevalent as glances, we can infer that teams do have opportunities to look away from the patient and view the monitor in relative detail.

Five outlying monitor looks were longer than 15 seconds, all of which were made by team leaders or anesthesiologists (Figure 4). These unusually long looks at the monitor

Table 3. Distribution of glances and scrutiny across roles and scenarios, relative to the 3-second threshold.

Role	Scenario A			Scenario B			Total		
	Glances (≤3 s)	Scrutiny (>3 s)	Total	Glances (≤3 s)	Scrutiny (>3 s)	Total	Glances (≤3 s)	Scrutiny (>3 s)	Total
Anesthesia	88	16	104	120	41	161	**208**	**57**	265
Phys. Surveyor	18	7	25	13	9	22	31	16	47
Primary Nurse	32	15	47	31	8	39	63	23	86
Respiratory	12	2	14	50	11	61	62	13	75
Scribe	95	11	106	83	11	94	**178**	22	200
Team Leader	22	40	62	10	21	31	32	**61**	93
Technician	22	5	27	8	3	11	30	8	38
TOTAL	**289**	**96**	**385**	**315**	**104**	**419**	**604**	**200**	**804**
Percentage	75%	25%	48%	75%	25%	52%	75%	25%	100%

appeared to help team leaders and anesthesiologists track the changes in the patients' vital signs to determine the overall outcomes of the treatments. These looks occurred during diagnosis or following major treatments. For example, after intubation, the team leader on Team 5 in Scenario A looked at the monitor and reported, "*Okay. She's improving with the [fluid] boluses. […] We've secured our airway.*" Similarly, the anesthesiologist and team leader on Team 1 in Scenario A both looked at the monitor after the patient was intubated. The team leader reported, "*End-tidal [CO_2 exhalation level] is 33, guys, so from a respiratory point of view we're looking alright. Heart rate still coming down. Blood pressure is going up just a little bit, so that's good.*" The longest look (25.4 s) came from the leader on Team 5 in Scenario B. Scenario B was more complex than Scenario A, and team members had difficulty diagnosing problems with the patient's breathing.

4.5.3.2 Monitor Attention across Team Members

We were also interested in understanding the ways team members and teams as a whole used the monitor throughout the resuscitation process to identify design requirements for future displays. As our data showed, monitor use varied by team member role (Figure 8). Team leaders, anesthesiologists, and scribe nurses on all teams appeared to depend on the vital signs monitor the most, but they exhibited distinctly different patterns of use. Team leaders were not among those who looked most often, but they spent significantly longer amounts of time looking at the monitor than others (Figure 8). Based on our data, we concluded that most leaders relied on the monitor to maintain a high-level awareness of the patients' status and outcomes of the interventions performed. They appeared to analyze the monitor more deeply to determine the patients' conditions and the appropriate interventions. Team leaders also used the monitor to analyze trends in vital signs, which is demonstrated by the frequency of their scrutiny (Figure 8).

Anesthesiologists looked significantly more often but on average spent about the same amount of time as everyone else except the team leaders (Figure 8). Anesthesiologists used the monitor to ensure that the patients' vital signs were within a safe range and to detect any adverse reactions to medications or interventions, especially those involving the airway and breathing. For example, the anesthesiologist in Team 4 of Scenario B looked at the monitor often and reported the feedback to the team. Scribe nurses also looked at the monitor frequently, but only for a few seconds at a time to gather information for documentation.

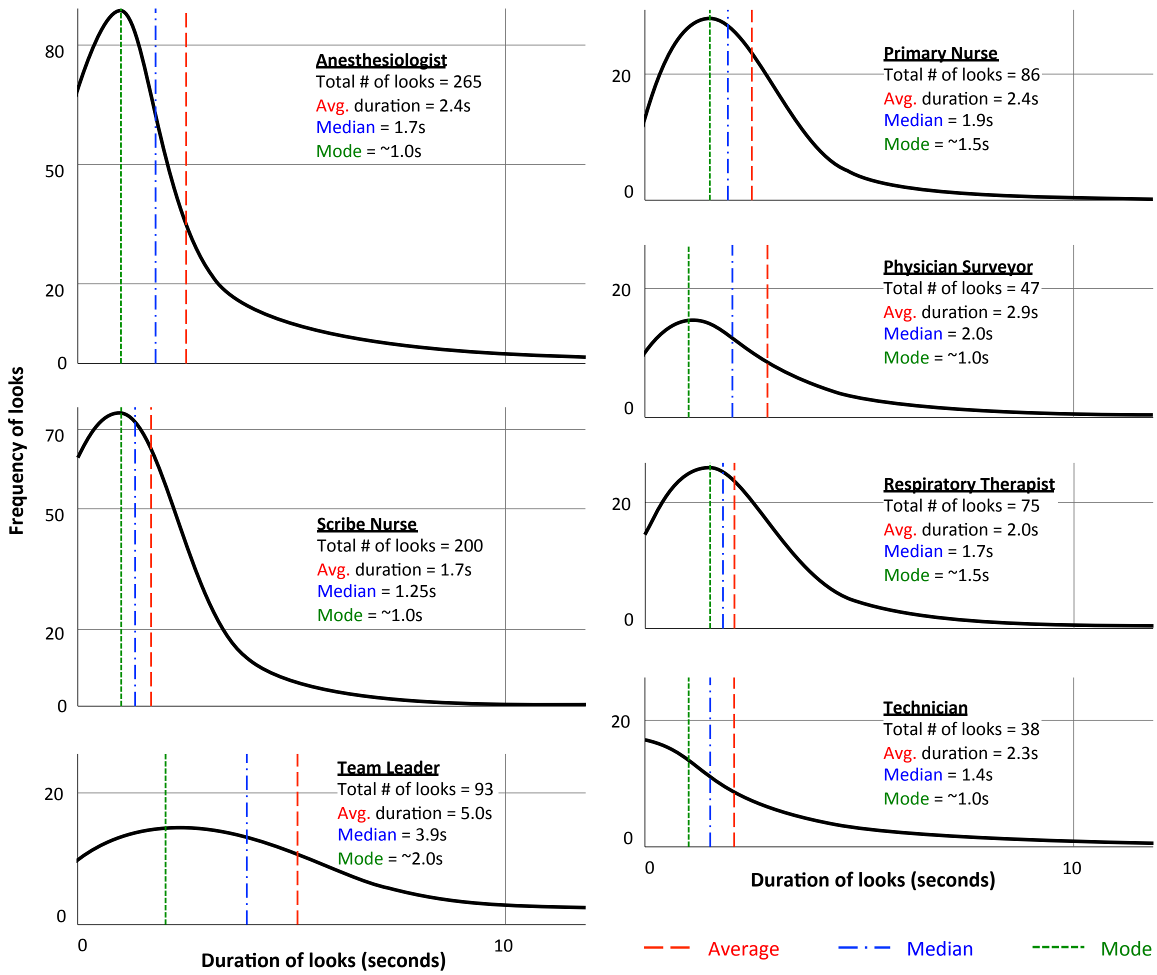


Figure 8. Curve-fitted approximation of the frequency of durations of the vital signs monitor looks for individual team members across all 12 simulations. Dashed lines mark the averages (red), medians (blue), and modes (green) of durations.

Physician surveyors and technicians looked at the monitor less frequently than the rest of the team (Figure 8). They looked at it most often when silencing monitor alerts or when everyone else was looking. Physician surveyors typically focused their attention on the patient rather than on the monitor. They spent most of their time examining the patient, relying on other team members to report vital signs. Technicians checked the monitor when connecting sensors to the patients. Their time was largely spent preparing

IV access and retrieving materials for the team. Moreover, the team and room configuration positioned the physician surveyor and technician facing away from the monitor. They had to turn around to view the monitor and did so mostly when their eyes and hands were not busy.

Primary nurses, like physician surveyors and technicians, were busy with patient care—removing the patients' clothing, administering fluids and medications, and retrieving materials for the team. Respiratory therapists sometimes checked the oxygen saturation on the monitor when administering additional oxygen to the patients but usually looked when other team members were also looking.

In short, those in decision-making roles (team leaders) looked significantly longer than others as they analyzed the vital signs data for diagnostic purposes. Team members directly involved in patient care looked least frequently and for the shortest times. It also appeared that a fraction of monitor looks were the result of other people looking at the monitor or reporting information currently displayed, representing confirmatory behavior for updating awareness of changes in vital signs.

4.5.3.3 Roles and Work Distribution across Feedback Loops

Understanding roles and work distribution across feedback loops helped us further determine how to support the work of trauma teams with supplemental information displays. We needed to know who is responsible for which tasks, what kinds of information they need for task completion, and how their work overlaps with the work of others. Established principles and guidelines for optimal trauma care published by the American College of Surgeons (2008) imply that there is a general division of labor defining specific tasks that each team member performs based on his or her role. We observed, however, that certain team members assumed the roles of others despite being "in charge" of particular tasks. This role-switching behavior depended on differences in level of experience, position around the patient, and availability to perform a task. For example, the physician surveyor was normally responsible for examining the patient across different feedback loops—such as assessing the airway [A], listening for breath sounds [B], palpating for pulses [C], and assessing the patient's pupils [D]. Our observations showed that anesthesiologists often took over these tasks due to their convenient positioning at the head of the bed. Anesthesiologists also helped independently confirm the physician surveyor's findings.

Our research site for this study is a teaching hospital where care providers frequently engage in on-the-job learning and where teams are dynamically composed of team members with varying levels of experience and expertise. Several physician surveyors did not have experience with performing chest decompressions or chest tube placement, and they followed directions from leaders and anesthesiologists. One anesthesiologist performed chest decompressions because the physician surveyor was uncomfortable with performing the procedure. Although the anesthesiologist's role is mainly to manage the patient's airway and oxygen administration, anesthesiologists are also skilled in performing other respiratory-related procedures. As confirmed by medical experts on our research team, these types of unpredictable circumstances also arise during actual resuscitations.

Primary nurses and technicians also frequently covered each other's tasks, filling in where the other left off on multi-stage tasks. For example, to complete the Circulation loop, technicians would place an IV access port; primary nurses would prepare the fluids, connect the IV line to the infuser, and then hand the line to the technician to connect it to the access.

These observations imply that team members are distributed across multiple feedback loops. Team leaders acted as overseers of the process and thus were involved in multiple feedback loops. They accounted for tasks completed and not completed, pushed for information to conclude feedback loops, and determined what feedback loops needed to be reiterated. Managing multiple feedback loops required the leaders to maintain a high-level awareness of all the tasks completed, in progress, and pending. Because team members switch roles and engage in multiple feedback loops, it is important that they maintain awareness of information important to all roles, especially when temporarily assuming different roles.

4.6 Discussion

During trauma resuscitation, teams collect evidence, diagnose, treat, and interpret patient responses, creating separate feedback loops for each component of the ATLS protocol. Our findings offer insights into how this feedback loop-driven process of trauma teamwork can be improved.

4.6.1 Supporting Monitor-Use Behaviors

We identified three distinct types of behaviors of teams using the vital signs monitor: (i) background monitoring to maintain overall awareness of the resuscitation process and patient status, as evidenced by periods with a low frequency of glances; (ii) split attention between the patient and the monitor, as indicated by periods with a high frequency of glances; and (iii) scrutinizing monitor trends and patient status over time, as demonstrated by periods with a medium frequency of scrutiny (Table 4).

4.6.1.1 Periods with a low frequency of glances (background monitoring)

Intervals with low numbers of glances occurred often and were distributed over the entire resuscitation (low bars in both frequency and duration charts in Figure 5 and Figure 6). During these intervals, the team was focused on their work, and monitor viewing was a background activity for maintaining overall awareness. To support this use, the display should be peripheral and simple and contain only essential information. Current vital signs monitors, which are meant mainly to provide a quick reference to current patient status, appear to meet the information needs during background monitoring.

4.6.1.2 Peaks with a high frequency of glances (split-attention behavior)

Intervals with high numbers of glances (high bars in frequency and low bars in duration charts in Figure 5 and Figure 6) occurred during critical moments in the resuscitation (diagnosis and intervention), when the team had to maintain attention on the patient while also checking for important information on the monitor. To support this behavior, displays should be peripheral and simple and should highlight information specific to the task at hand. Ideally, displays should be placed as near to the patient as possible to minimize the time spent switching between looking at the patient and at the monitor.

Table 4. Vital signs monitor use behaviors with frequency and duration of looks.

Behaviors	Description	Frequency	Look Duration
Background monitoring	Focusing on work and viewing the monitor occasionally to maintain overall awareness	Low	Glance
Split-attention	Maintaining attention on patient while also checking for important information on vital signs monitor during critical moments in the resuscitation	High	Glance
Scrutinizing	Analyzing the vital signs monitor to collect information to make diagnoses and after major treatments to determine changes in patient's status	Medium	Scrutiny (long)

4.6.1.3 Periods with a medium frequency of scrutiny (scrutinizing behavior)

Intervals with medium numbers of scrutiny (high bars in both frequency and duration charts in Figure 5 and Figure 6) occurred during diagnostic stages, when teams were collecting information and making diagnoses, and after major treatments. Because the monitor looks were relatively long (on the order of tens of seconds), the display could cease to be peripheral and provide richer information and perhaps even include simple interaction. Designing displays to support this information behavior is challenging in identifying which information to display, given the large number of information types relevant to the resuscitation process.

4.6.2 Providing Rich Contextual Information

Our data showed that a significant amount of time was spent on viewing the vital signs monitor. In particular, the leaders (those in decision-making roles) appeared to scrutinize the displayed information for relatively long time periods and may benefit from richer contextual information, including (1) details of the mechanism of injury; (2) highlights of changes in vital signs; (3) diagnoses, interventions, and outcomes; and (4) process-oriented information about the status of tasks for each feedback loop. This additional information may help the leaders manage the activities of multiple feedback loops from a high-level perspective by keeping track of the observations, treatments, and outcomes that occur in each feedback loop during the resuscitation. Their summarizing behaviors also suggest that a display providing a reminder of the "story" with contextualized details of the resuscitation may be beneficial. These reminders would support team leaders when they review critical information to ensure that all injuries were assessed properly and to help prevent or remedy inconsistencies in team awareness. The challenge here is enabling seamless switching from basic to more complex information, or from peripheral to focal modes of viewing.

4.6.3 Supporting Role Distribution across Feedback Loops

Despite being in charge of certain tasks, team members needed to be flexible to manage changing circumstances. Team members often performed tasks across different feedback loops, coordinated and shared work, covered other team members' tasks, and learned and taught new procedures. The nature of dynamic and tightly coordinated teamwork may necessitate a general information display for those in non-leadership roles to avoid tunnel vision for any particular role. Such a display could provide the status of tasks in each feedback loop to promote a shared awareness among the team. Multiple monitors displaying the same information in different positions around the stretcher would allow roles such as the physician surveyor and technician to view patient information easily and might also reduce the reliance on others to call out information.

4.7 Summary

Through extensive video analysis, we examined how trauma resuscitation teams are currently using vital signs monitors in our effort to inform the design of additional information displays. A major contribution of our work is that it establishes the empirical quantification of the length of a safe amount of look-away time from the patient in emergency situations. Our data showed that a significant amount of time was spent on viewing the vital signs monitor. Clinicians exhibited three types of monitor-use behaviors that suggest design requirements for supporting awareness of individuals in their particular roles: (i) periods with a low frequency of glances, to maintain overall awareness of the process and patient status; (ii) peaks with a high frequency of glances, to split attention between the patient and the monitor; and (iii) periods with a medium frequency of scrutiny, to monitor trends in patient status over time. These findings indicate that clinicians have the available visual attention to view a vital signs display and even at times to analyze it in depth.

In particular, the leaders appeared to scrutinize the displayed information for relatively long time periods and may benefit from richer contextual information. Physical examination, verbal communication, and use of the vital signs monitor all served as channels for receiving feedback to maintain awareness and support workflow. The vital signs monitor provides an overall summary of the patient's condition based on up-to-date sensor data but does not provide the rich, contextual information needed to support situation awareness fully during the resuscitation process. The challenge here is enabling seamless switching from basic to complex information and from peripheral to focal modes of viewing.

We hypothesize that trauma teams may benefit from additional displays to supplement the vital signs monitor with contextual information, provided that displayed information can be absorbed within a safe amount of look-away time from the patient. We have examined the frequency and duration of the vital signs monitor looks and demonstrated how these variables are influenced by role. Our study offers empirical evidence about the length of this look-away period, showing that medical teams have the time and cognitive resources to look at monitors in emergency situations.

Based on what we learned about the trauma resuscitation context and the types of information teams need and the behaviors they perform, we proceeded to develop a participatory approach to designing an information display that supplements the vital signs monitor. The following sections describe our approach, data collection methods, analysis, and findings from the iterative, participatory design process.

CHAPTER 5: METHODS

5.1 Overview

Over the past two years, we have performed multiple iterations of an information display design with a team of researchers and various trauma team members at two sites: Children's National Medical Center (CNMC) and Children's Hospital of Philadelphia (CHOP). This research is part of a larger research effort to develop a shared information display to support situation awareness of trauma resuscitation teams. Over several years of fieldwork and user-centered development activities, the team has used different methods to engage with the domain: observations of live and simulated resuscitations, interviews with trauma team members, micro-analyses of live video recordings (e.g., Sarcevic et al. 2012), and the feasibility study described above. As an important part of the participatory design process, these field studies revealed the problems of coordinating activities and of information overload, access, and retention. It was through this fieldwork that a display solution emerged to synthesize the information about patient status and team activities. The feasibility study then showed that supplemental displays might be feasible to implement in this setting.

Using the knowledge we gained about the trauma resuscitation context, we developed a total of 26 data collection sessions to engage with users: 6 participatory design workshops, 8 simulation sessions with entire resuscitation teams, 6 heuristic evaluation sessions, 5 video review sessions, and 1 focus group (Table 6). We gained an understanding of the domain and of clinicians' needs that helped us to develop 16 display design prototypes, of which eight versions were tested with clinicians. The data presented in this dissertation focus on describing the nature of awareness in a time-critical medical setting and how best to support awareness in such domains through the design of a shared information display. Institutional Review Boards at CNMC, CHOP, and Drexel University approved all research.

5.2 Research Team

The multidisciplinary team is comprised of ten researchers and practitioners at four institutions: HCI researchers and ethnographers, computer scientists, engineers, and clinical experts. My role on this team was multifaceted, allowing me to engage in every aspect of the design process. The most important aspects of my role on the team were (1) developing the formative design and evaluation activities to elicit clinician ideas, feedback, and concerns and (2) using the information elicited from clinicians to design the display. More specifically, I engaged in the following activities:

- Developing design and evaluation activities
- Preparing all materials for design and evaluation sessions
- Running design and evaluation sessions
- Recording and managing data collected
- Transcribing audio, video, photos, and surveys
- Analyzing the data
- Designing and redesigning the interface using Photoshop
- Working with a researcher to define the functional requirements for the display interface and data input interface
- Writing team reports and publications

- Supervising undergraduate researchers who helped with session preparation, transcription, and data analysis and management

5.3 Research Approach: Participatory Design (PD)

Our approach is grounded in participatory design (PD)—emphasizing the importance of eliciting, understanding, and addressing clinician needs while gaining long-term commitment from clinicians to the development of our system. PD approaches help researchers engage with users and actively elicit their knowledge through joint discussions (Randall & Rouncefield 2007). Many PD techniques have been developed over the years. Muller et al. (1993, 1997) present comprehensive taxonomies of PD activities and techniques—including ethnographic methods, semi-structured conferences, low-tech prototyping, mock-ups, storyboard prototyping, and envisioning future solutions. Muller and Druin (2012) also offer an extensive review of the PD literature, including techniques such as workshops, stories, games, and dramas. The most common setting for PD is the participatory workshop.

Muller and Druin (2012) describe PD as a method for building "third spaces," or "hybrid spaces," that are neutral and unfamiliar to both participants and researchers (p. 11). Workshops form this kind of hybrid space because participants and researchers "communicate in a mutuality of unfamiliarity" to reach mutual understanding (ibid, p. 20). Participants and researchers must engage in mutual learning, reciprocal validation, knowledge exchange, and idea synthesis for designs to emerge. It takes a skilled facilitator to manage discussions and design activities that will elicit useful information from as many of the participants as possible (Marshall & Rossman 2011). The most well-known type of participatory workshop is the "future workshop," consisting of three phases: critiquing the present situation to identify issues; envisioning the future (the fantasy phase) to brainstorm desirable attributes; and planning how the envisioned future can be implemented (Bødker, Grønbaek, & Kyng 1993; Muller et al. 1997; Muller 2003).

PD workshops are well suited for eliciting design requirements and ideas from diverse clinicians working on interdisciplinary teams to develop a shared information display. They are also valuable for gathering initial design requirements in a relatively short amount of time. By eliciting issues and desired attributes through participatory techniques such as workshops and group discussions, researchers also identify issues and concerns and aspects of the system that participants think are important to investigate. Taking a PD approach helped us to produce a system design that is tailored to the needs of unique types of users. This approach will also help strengthen users' commitment to using and improving the design over time after implementation.

5.4 Research Sites

We conducted our research at two sites. Our main research site was Children's National Medical Center (CNMC), where we completed a full design cycle, and our secondary site was Children's Hospital of Philadelphia (CHOP), where we initiated display development and included data from initial PD workshops for validating design requirements. CNMC is an independent pediatric hospital with a Level 1 trauma center in Washington, D.C. Level 1 trauma centers provide the highest level of definitive, comprehensive care for severely injured patients with complex, multi-system trauma. Each year, the center admits about 1,000 children with trauma and burn injuries. Patients are treated in two adjoining resuscitation rooms in the emergency department by dedicated specialists in trauma and burn care. CHOP is an independent pediatric hospital with a Level 1 trauma center in Philadelphia, PA. The emergency department at CHOP serves over 80,000 patients a year, of whom about 400 require trauma resuscitation.

5.4.1 Site-Specific Information Technologies

Our main research site contained three other technologies in addition to the vital signs monitor (Figure 2); temporal artifacts (Figure 9 a,b,c); and the paper-based trauma flowsheet described in Chapter 2.4. These additional technologies include the trauma checklist, the weight board (Figure 9(3)), and two large monitors (Figure 9(1,2)). The trauma checklist (Figure 10) includes lists for the pre-arrival plan, primary survey, vital signs, secondary survey, and plan of care after the patient leaves the room. The checklist is designed as a reference for leading the team through the trauma resuscitation protocol and is not included in the medical record. The checklist fits on a single sheet of paper and is held exclusively by the team leader. Team leaders occasionally write notes in the margins of the checklist as reminders about the mechanism of injury, temperature, initial vital signs, and laboratory and radiology orders.

The dry erase board (Figure 9(3)) displays the patient's weight as a reminder and notification for team members who missed the initial announcement. Patient weight is essential to decision-making for treating the patient in terms of medication dosages; voltage levels (for defibrillation and cardioversion); equipment sizes; and procedures. Usually a bedside nurse will write the weight on the board when it is reported to the team by an EMS or when the team estimates the weight using the height-based tape measure called a Broselow Pediatric Emergency Tape. The Broselow Tape is color-coded and provides recommended treatments according to different weight and age categories.

Figure 9. Information technologies in the trauma bay: (1) information display used in this research, (2) display for vital signs or overhead view, (3) weight board, (a) clock, (b) time since patient arrived and time of arrival, and (c) stopclock.

The main trauma bay used in this study has three 42" wall-mounted monitors installed for multi-purpose use such as augmenting vital signs information; showing the overhead view of the patient; and showing a live video feed from the anesthesiologist's laryngoscope, a tool used for visualizing and inserting an endotracheal ventilation tube. Two monitors are placed at the front of the room side by side (Figure 9(1,2)) and one monitor is placed in the back of the room for those positioned at the head of the bed (anesthesiologist, respiratory therapist, and sometimes bedside nurse) to view more easily without turning around. During our simulation studies, two of the displays at the front and back of the room presented our design (front display shown in Figure 9(1)). An auxiliary display to the right of our display was used to show the overhead view of the patient (Figure 9(2)).

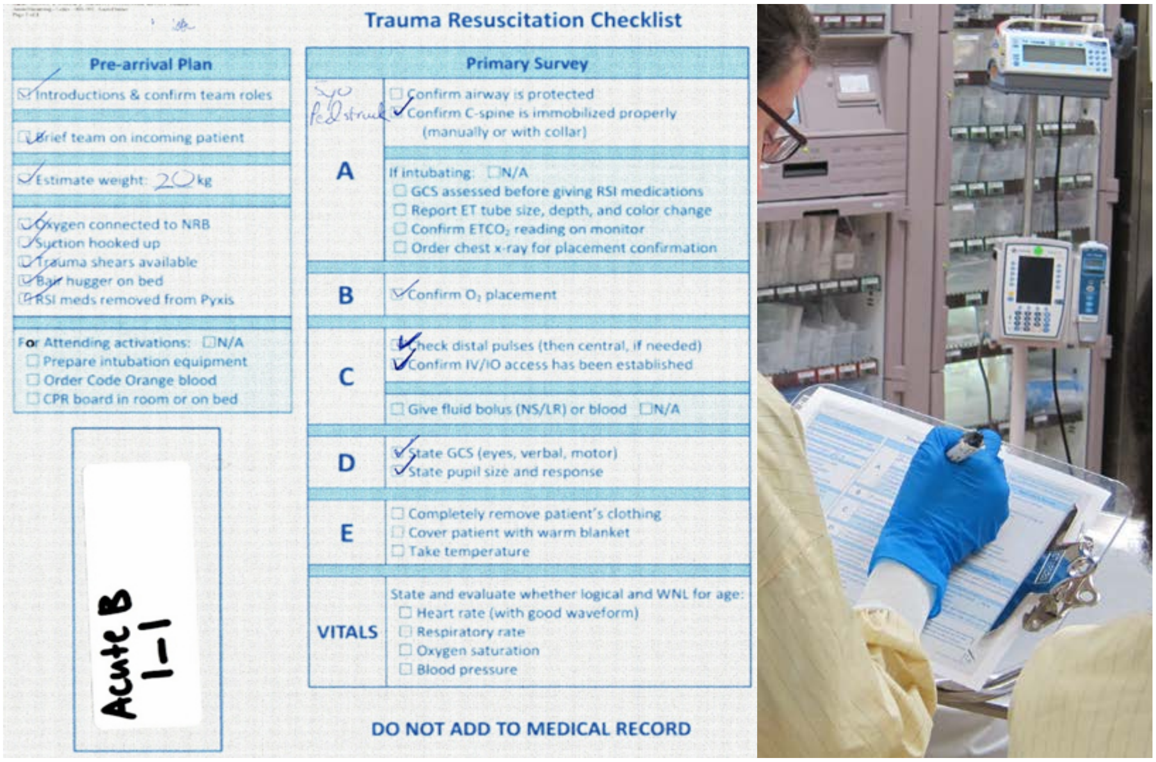


Figure 10. Trauma checklist used by team leaders.

5.5 Participants

For PD workshops and simulated resuscitations, participants were recruited to represent the core team member roles required during trauma resuscitations: anesthesiologist; bedside nurse; critical care physician or fellow; emergency medicine physician; physician surveyor (a surgical resident or nurse practitioner); respiratory therapist; scribe nurse; and team leader (surgical attending or fellow). Participants were asked to represent the roles in which they would normally serve on a daily basis.

A total of 62 unique participants with experience levels in emergency medicine ranging from several months to 30+ years signed up to participate in our research (Table 5). Several clinicians participated multiple times throughout the study. Repeated

Table 5. Participant counts from CNMC and CHOP. *Some scribe nurses also served as bedside nurses during simulations but were only counted once as scribe nurses.

Roles (N=62)	CNMC (N=49)	CHOP (N=13)
Anesthesiologist	6	1
Bedside nurse*	7	2
Critical care physician	0	1
Emergency medical physician	6	2
Physician surveyor	8	1
Respiratory therapist	6	2
Scribe*	7	2
Team leader	9	2

participation was allowed between but not within phases. One of the main benefits of continued participation was that we received feedback from those who saw the evolution of the design in addition to those seeing it for the first time. Moreover, the mixture and variation of participant roles and levels of experience represented in the group sessions replicated the real-world composition of *ad hoc*, interdisciplinary resuscitation teams. Participation was voluntary; participants received nominal monetary compensation for their time.

Recruitment was challenging in this setting because clinicians are busy and work long, odd hours. With assistance from research coordinators at both sites, we posted calls for participation using internal listservs and bulletin boards. Most participants dedicated an extra two hours before or after their work shifts or came in on their days off to participate in our studies.

5.6 Techniques Employed

Between November 2012 and July 2014 we conducted six types of activities through which we collected data: PD workshops, simulation sessions with entire resuscitation teams, heuristic evaluation sessions, video observations, video review sessions, and a focus group (Table 6). We next describe the protocols for data collection through each activity.

5.6.1 PD Workshops

PD workshops brought clinicians together to determine and discuss the requirements of the information display. Six workshops were conducted during the first four months—four sessions at CNMC and two sessions at CHOP between November 2012 and February 2013. We started with two workshops at CNMC and two at CHOP to create preliminary designs (Table 6) and followed up with another set of two workshops at CNMC focused on display functionality (Table 6). The main purpose of these workshops was to understand clinicians' perceptions of what information is critical to their work and how they need this information displayed. We adapted the PD technique called PICTIVE (Muller, 1993) to provide an environment in which users with diverse perspectives have equal opportunity to engage in the design process. Each workshop lasted two hours and was split into five different activities with a break in the middle.

We recorded discussions (audio and video) during each workshop and also took photographs of activities and outputs. Video records supplemented audio records by helping us distinguish who said what, see what people were doing or pointing at, and

Table 6. Display design and evaluation process: Timeline of data collection activities.

Activity	Location	Date of Session	# of Sessions	Session Duration	# of Partic.
Initial PD Workshops (PDWS1)	CNMC CHOP	Nov. 20, 2013 Feb. 6-7, 2013	4 workshops	2 hours	24
Simulation 1 (SIM1)	CNMC	Jan. 11, 2013	2 sessions	1 hour	14
Heuristic Evaluation/ Interviews (HE)	CNMC	Feb. 1, 2013	6 sessions	30 minutes	6
Simulation 2 (SIM2)	CNMC	Mar. 8, 2013	2 sessions	1 hour	13
Follow-up PD Workshops (PDWS2)	CNMC	Apr. 5, 2013	2 workshops	2 hours	8
Simulation 3 (SIM 3)	CNMC	Jun. 7, 2013	2 sessions	1 hour	13
Video Observation (VOB)	CNMC	Nov. 6-22, 2013 Dec. 10-15, 2013	7 resuscitations	20-45 minutes	N/A
Simulation 4 (SIM4)	CNMC	Jan. 17, 2014	1 session	1 hour	7
Video Review (VRS)	CNMC	Mar. 28. 2014	5 sessions	1 hour	5
Simulation 5 (SIM5)	CNMC	Apr. 18, 2014	1 session	1 hour	8
Focus Group (FG)	CNMC	Jul. 23, 2014	1 session	1 hour	4

match participants' roles from the transcripts. Photographs helped us analyze the design outputs in detail.

In the initial workshops, we used five carefully constructed activities to elicit participants' perceptions. Each built on the next, allowing us to validate findings within and across workshops. Participants were asked (a) to fill out a brief, individual survey and discuss as a group the most recent resuscitation in which they had participated (15 minutes, Appendix 1); (b) to create display sketches based on their individual needs (30 minutes); (c) to engage in a group design activity to create a shared display (30 minutes); (d) to rank the priority of the information features for their roles (5 minutes); and (e) to discuss any concerns with using the display (20 minutes).

The survey (Appendix 1) was implemented to prompt participants to think critically about their work. We asked participants to recall the most recent resuscitation in which they had taken part (sometimes only a few hours before the workshop) and to provide brief answers about what worked and what did not, what issues they encountered, and what they would change. Each participant was then asked to discuss his or her experiences with the group. Clinicians discussed their work challenges, information needs, time management, and the features they believed would support their work. Reflecting on their work in this way helped participants ground their design thinking in real, concrete scenarios that provided the basis for designing the display, evaluating their designs, and discussing their concerns (Carroll 2000).

Following the survey, each participant was given a sheet of construction paper on which to create a design for his or her personal information display. We asked participants to think about the critical pieces of information they would need and how the display would look. Participants used low-tech design objects such as pens, pencils, paper, and post-it notes to create design sketches (Figure 11; Figure 12, left). The objective was to understand which features of teamwork require support through information types needed by each role. Individual designs helped us to identify specific role-based

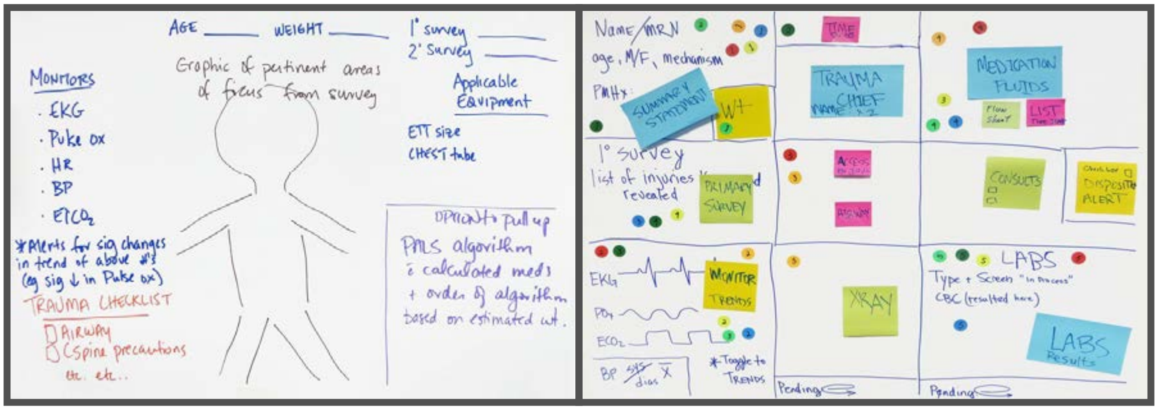


Figure 11. Examples of a participant's individual design (a) and a group design (b).

information needs and design ideas that might be lost through group design activities or in cases in which dominant participants exerted excessive influence on the design discussion. Participants discussed their individual designs with the group, and all the designs were posted on the wall for reference during subsequent workshop activities. Sharing their designs prompted participants to articulate their information needs and design rationales. Participants were encouraged to discuss each other's designs—an approach helped them further articulate their ideas, experiences, and from the perspective of each role.

In the third activity, participants worked together as a group to negotiate a display design that incorporated their initial ideas from the individual designs. In each workshop, one participant took charge and translated the ideas from the group into a display design (Figure 11, right). Designing displays as a group prompted participants to discuss their design decisions and priorities in detail and to reach consensus on the most important design features that would address the main information needs of all roles. Group designs

Figure 12. Workshop participants engaged in design activities—individual design activity (left) and ranking information features on the group display design (right).

helped us to understand which types and forms of information needs were shared among roles.

For the fourth activity, each participant was given color-coded stickers labeled 1 through 5 and asked to rank the information features on the group display design (Figure 12, right). This activity allowed each person to voice an opinion during the group activity (Muller & Druin 2012). The rankings also allowed us to discuss what participants believed were the most important types of information to include on the display and the priorities of each role. This activity, paired with the clinician-created designs, allowed us to systematically identify the key features to include on the display to optimize the use of screen space without causing information overload. It also helped us ensure that user input and concerns drove the design decisions we made.

Finally, we asked participants to write on individual post-it notes any concerns about using the display during emergency resuscitations. We grouped concerns into themes, drew circles around the post-it notes to show the boundaries, and asked participants to explain their reasoning for each theme that emerged. This discussion prompted participants to think critically about their display designs and the implications for actual practice. Eliciting clinicians' concerns was also important in enabling the researchers to understand the clinicians' values to be sensitive to during testing and development (Czeskis et al. 2010; Miller et al. 2007).

After nine display design iterations, three simulation sessions, and six heuristic evaluation sessions with clinicians, we conducted two follow-up design workshops at CNMC (Table 6). The format was similar to the initial workshops but the discussions focused on eliciting group designs and input on the display's functionality (Figure 13, left). We also used this time to conduct member checking to validate the findings gathered until that point in the process about (1) the critical pieces of information needed on the display; (2) the purpose of the display; and (3) their issues and concerns. Participants were encouraged to specify any information we should add to our findings and indicate any information for removal (Figure 13, right).

5.6.2 Simulated Resuscitations

High-fidelity simulations were developed to engage clinicians in realistic and challenging clinical scenarios both to gather design requirements and to evaluate the usefulness and effectiveness of our display. We conducted five sets of simulations with eight teams (Table 6). Simulations were conducted in the main resuscitation room of the emergency department using a high-fidelity simulation mannequin, equipment normally available to teams, and the existing wall monitors (Figure 9(1,2)). Prototypes were displayed using two of the wall-mounted monitors (Figure 9(1)), one on each end of the room) showing the same information and one monitor at the front of the room displayed an overhead view of the team (Figure 9(2)).

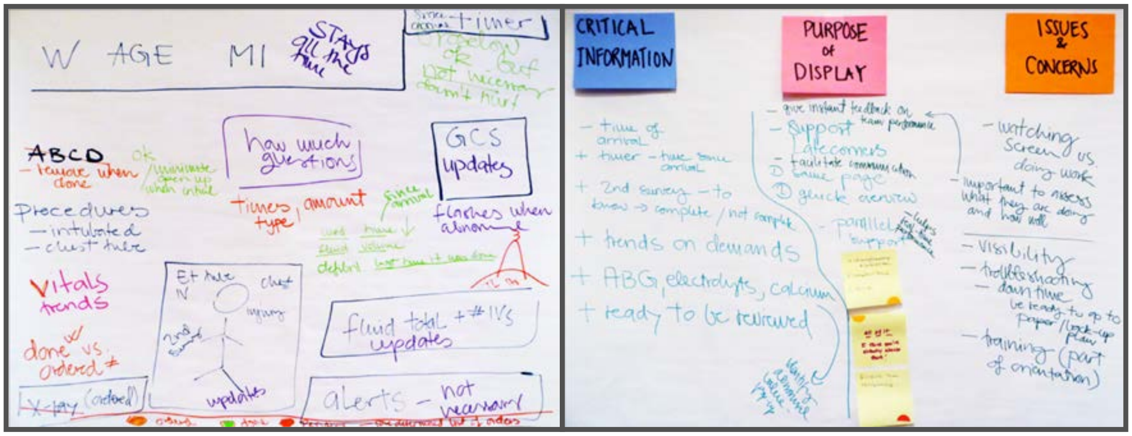


Figure 13. Example of a group design by participants (left) and a poster with member checking feedback on our findings (right).

Because one of the reasons for conducting simulations was to experiment with different data-capture mechanisms for system development, data input varied across simulation sessions. Initially, data was captured for the display using a digital pen and paper flowsheet used live by scribe nurses (Figure 14, left). During the second set of simulations, the prototypes drew data via digital pens from both the flowsheet and the paper checklist that trauma team leaders use. We encountered issues with handwriting recognition, the complexities of triggering the information that needed to be presented, and the limitations of information that could be derived from flowsheet input. Due to these issues, we decided to focus mainly on designing the display interface and developed a computer-based input interface that can later be used as the basis for the design of an electronic flowsheet. From our third simulation session on, a clinician acted as the "Wizard of Oz" and input information using the computer interface (Figure 14, right).

In each of the sessions devoted to testing and re-designing the display, we first oriented teams to the current display's functionality by using a brief clinical scenario.

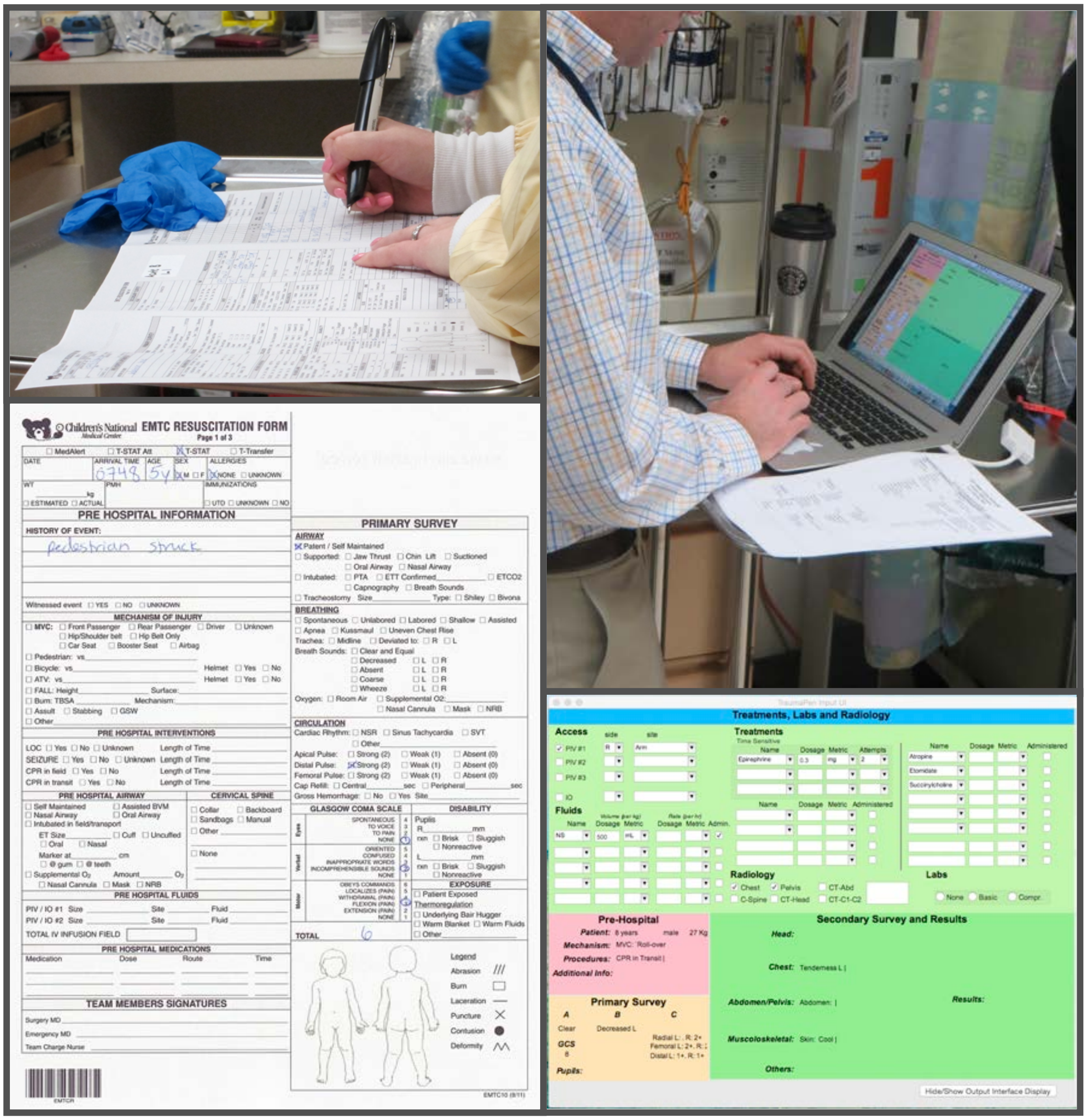


Figure 14. Data input mechanisms for the display: digital pen and paper (left) and computer-based "Wizard of Oz" user interface (right).

Then, using a high-fidelity mannequin, teams performed one to two resuscitations based on clinical scenarios ranging from moderate to demanding that had been developed by medical experts (Figure 15, top left). Following each scenario, we asked clinicians to discuss their experiences of using the display within the context of work (for discussion

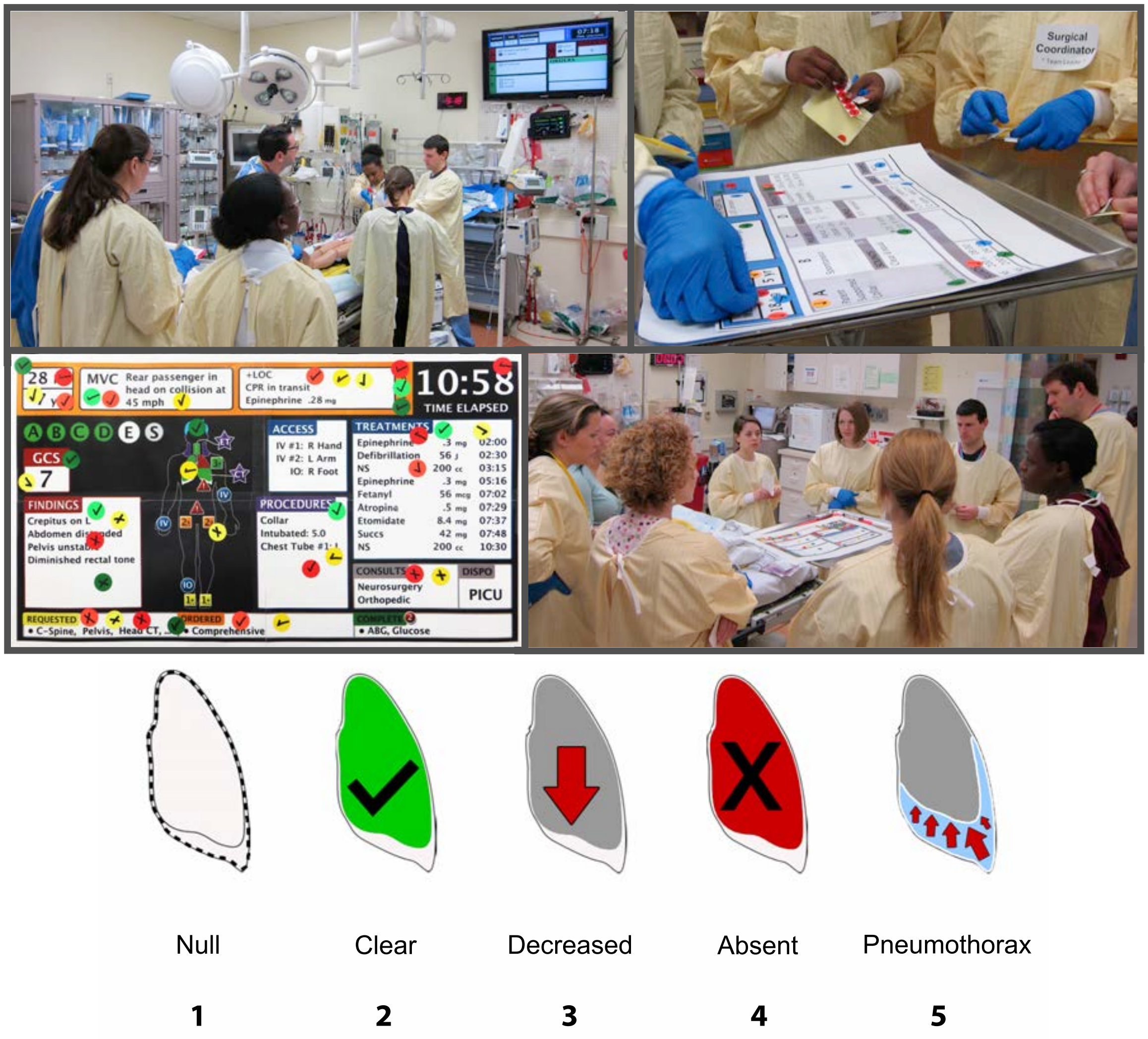


Figure 15. Simulated resuscitation (top left), participants annotating paper version of display (top right), annotated display (middle left), group discussion (middle right), lung icons evaluated (bottom)).

questions see Appendices 6-10). Participants were also asked to indicate up to five features they found useful (indicated by checkmarks) and up to five features they did not find useful (indicated by x's) on a paper copy of the display using stickers color-coded based on their roles (Figure 15, top right and middle left). If an information feature did not receive any sticker feedback, we considered it neutral. We also asked questions specific to the display features that were revised based on feedback elicited in previous sessions (Figure 15, middle right; Appendix 2, 3, 4, 5, 6).

In simulation sessions four and five, we included an activity in which clinicians discussed their perceptions about a particular display feature that represents the status of the patient's lungs (Figure 15, bottom). Participants indicated their interpretations of five different lung statuses on a sheet of paper numbered 1-5. This technique was used primarily to determine which icons clinicians had difficulty interpreting at the time of the simulation in order to promote discussion about ideas for improving the design of the icons.

We also experimented with an adapted Human Factors tool called the Situation Awareness Global Assessment Technique (SAGAT) to determine how the information display affected situation awareness in simulation sessions four and five (Endsley 1995a). At critical points in the resuscitation, a researcher paused the team and blanked out the display. Each team member was then given a packet of paper on which to record his or her answers to questions about information that emerged during the resuscitation included on the display (e.g., "What is the current GCS of this patient and which medications and fluids have just been administered?"). This activity allowed us to determine that the technique would be useful for future implementation during the summative evaluation phase of the project. Each session concluded with further discussion about team communication, information features, display design and functionality, and concerns.

5.6.3 Heuristic Evaluation with Interviews

Following the first set of simulations, we conducted six one-on-one heuristic evaluations with interviews (Table 6). The purpose of the heuristic evaluation sessions was to elicit detailed feedback from participants and their ideas for improving the display design. At the beginning of each session, we introduced the display by showing participants a paper version of the display and explaining the functionalities. We asked participants to rate the display on a Likert scale from 1-7 (Figure 16, left, Appendix 7) based on a set of criteria adapted from previous work on heuristic evaluation for ambient and peripheral displays (Mankoff et al. 2003; Matthews et al. 2007; Shami et al. 2005). Participants were instructed to explain the reasoning behind each of their ratings for the display, and the researcher noted the rating for each criterion as well as any comments. Participants were encouraged to annotate a paper version of the prototype to show us what they meant when providing specific design critiques or suggestions (Figure 16, right). At the end of each session, participants were asked to provide feedback about the metrics used to evaluate the display and to suggest additional metrics to consider, if any. Each session concluded with questions about concerns participants had about using the display and about what they believed its purpose was. All sessions were audio recorded.

5.6.4 Video Observations of Live Trauma Resuscitations

Detailed video observations and transcription of live trauma resuscitations were conducted over two weeks in November and December 2013. The purpose of conducting video observations of live events was to gain a better understanding of the trauma resuscitation process, challenges, and the nature of awareness in real-life situations as

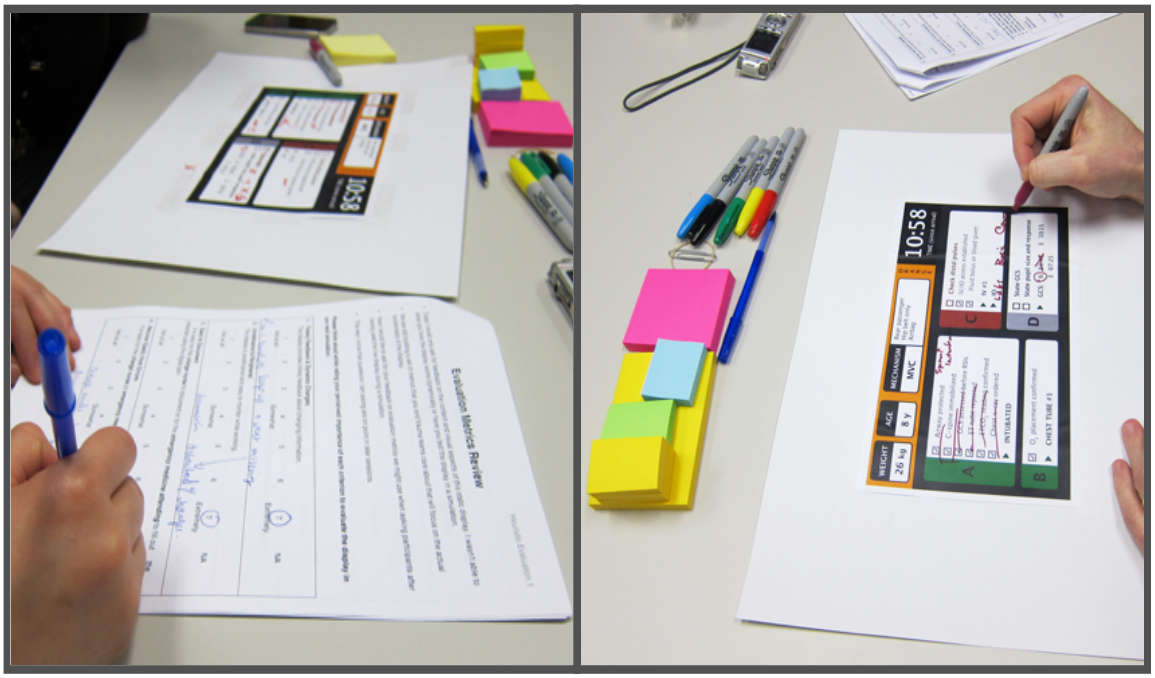


Figure 16. Heuristic evaluation sessions: rating the display

well as to develop more targeted questions to discuss with clinicians in subsequent sessions. One researcher was stationed at CNMC and transcribed videos from seven events that occurred during the month (Figure 17). Due to patient privacy and IRB restrictions, videos of live events could be stored only on-site and had to be deleted after five weeks. Videos therefore needed to be transcribed in detail—with all dialogue and activities recorded. Field notes about the nature of the event and prominent initial findings were also recorded to help the researcher remember the "big picture" of each event.

5.6.5 Video Review Sessions with Interviews

Five video review sessions each involved an individual clinician narrating a 10-minute video of a simulated resuscitation performed during Simulation session 3

Figure 17. Tools used for transcribing videos of live trauma resuscitations—video review software on hospital computer (top) and spreadsheet of transcribed activities and communication on researcher's computer (bottom).

(Figure 18). Questions had been developed through the previous video observations of live events, specifically regarding the nature of awareness and eliciting direct feedback about activities performed during a typical trauma resuscitation (Appendix 8). The clinicians were asked to pause the videos where appropriate and comment on things that seemed unusual or important about the resuscitation and about the teamwork involved. Examples of discussion points included what they thought about the performed tasks, the information that emerged, what the team did well or what needed improvement, and team awareness of what other team members were doing. During each session, we asked the

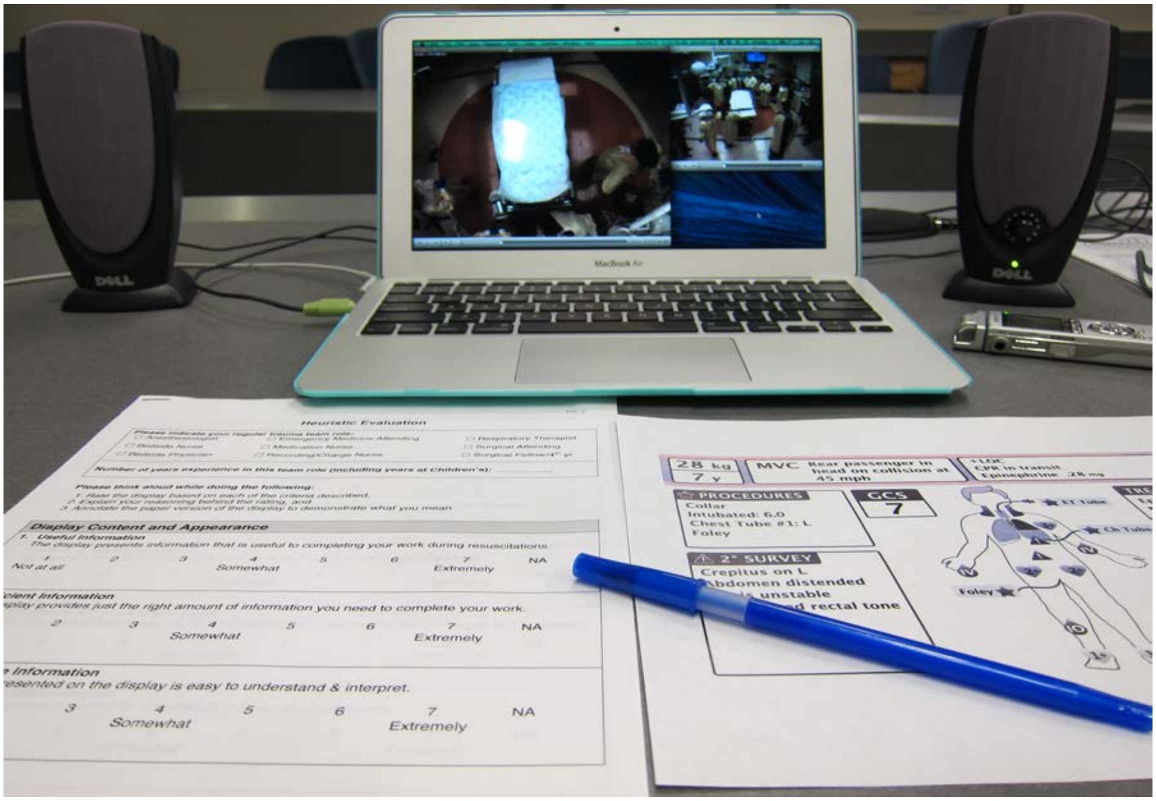


Figure 18. Setup for video review sessions with interviews. Video of a simulated resuscitation (top), evaluation instrument (bottom left), and display prototype for annotation (bottom right).

clinician how he or she adjusts and manages awareness in different situations (e.g., when arriving late to a resuscitation).

The purpose of conducting video review sessions was trifold. The main objective was to understand the perspective of clinicians in different roles about maintaining awareness during the resuscitation process. The second goal was to conduct member checking to verify our observations and conclusions from previous sessions. Finally, the third purpose was to elicit targeted feedback on specific features of the display that had been recently revised.

5.6.6 Concluding Focus Group

A focus group with four clinicians—an EM physician, a surgical coordinator, a bedside nurse, and a scribe nurse—was conducted at the end of the design cycle. The purpose of this focus group was to elicit feedback from clinicians on the previous design iteration to finalize the changes to the display design (Figure 19) in order to conclude the formative design process. We started with a detailed demonstration and explanation of the functionalities of the display based on a clinical scenario. Participants were asked to insert their comments and questions while the researchers demonstrated each display feature.

After the demonstration, participants indicated the features that they thought are useful (indicated by checkmarks) and not useful (indicated by x marks) on a paper-based version of the display using color-coded stickers based on their roles. Participants then discussed the reasoning behind their selections (Appendix 9). Participants reviewed the revised lung icons by filling out the corresponding blanks on a sheet of paper (Figure 15, bottom). The session concluded with a short discussion about participants' concerns about using this display and an invitation to provide their thoughts on possible future directions of the project.

5.6.7 Summary

The types of participant feedback differed with each design and evaluation activity. This mix of feedback types ensured a holistic approach to design while minimizing the methodological biases tied to each of the approaches. Each method has its strengths and limitations (Table 7).

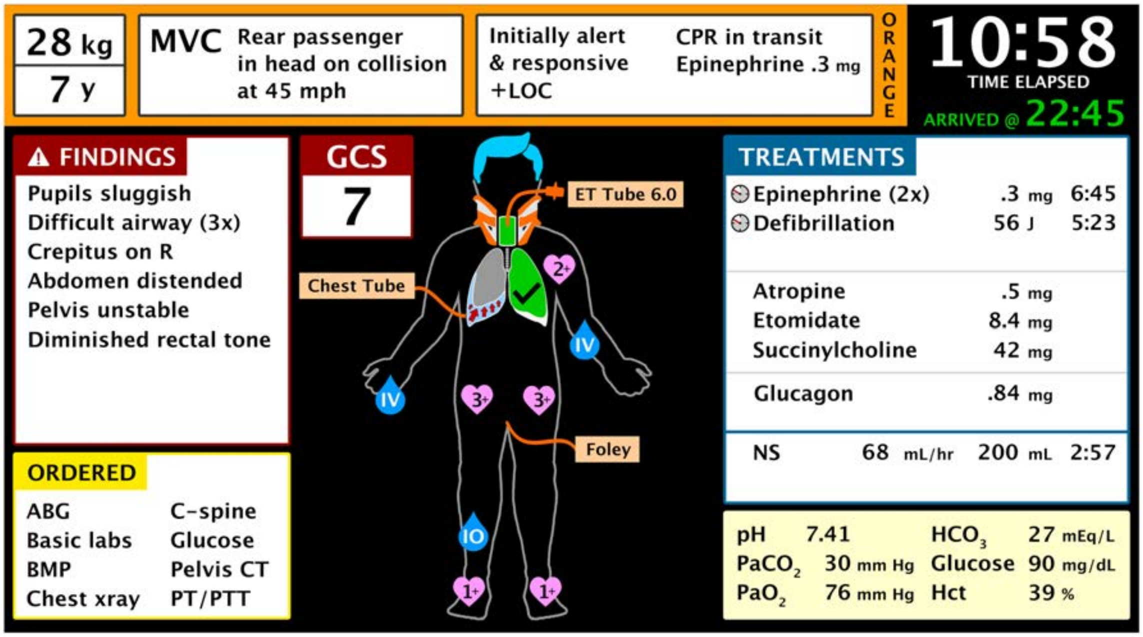


Figure 19. Display design version evaluated during the focus group.

We received feedback based on participants' own design ideas and perceptions of information needs through PD workshops. This technique promoted user engagement in system design and empowerment to speak about role-related needs that might otherwise be overlooked. Eliciting user-generated design ideas helped us to create a design that is driven by user input. The participatory design process also helped us to identify the key information features to include on the display to support shared awareness while also addressing the role-based differences in information needs. The two main limitations to using this method are that: (1) sometimes users idealize their designs or recall their behaviors and needs differently from reality and (2) it can be difficult to recruit full teams to participate in longer design sessions.

We elicited participants' feedback based on their experience using the actual display prototype in the context of work through simulation sessions. Clinicians were

Table 7. Summary of method strengths and limitations.

Method	Strengths	Limitations
PD Workshops	- Promoted user engagement and empowerment - Supported user-driven design - Helped in understanding role-based needs - Identified key information needs for shared awareness	- Users sometimes idealize designs or recall their behaviors and needs differently from reality - Difficult to recruit full teams to participate in longer design sessions
Simulated Resuscitations	- Targeted feedback on designs based on prototype use in context - Allowed users to comment on the usability and usefulness - Allowed researchers to test specific features by designing clinical scenario	- Users might act differently in a simulated environment - Difficult to recruit full teams to participate
Heuristic Evaluations	- Detailed one-on-one discussions between researchers and users - Targeted feedback on design revisions and issues - Survey helped guide discussion	- Designs were paper-based - Users cannot necessarily comment on usability without viewing a functional prototype
Video Observations	- Observed live events - Gained a better understanding of the process and issues that arise - Allowed researchers to observe current work practices as a baseline to compare with after implementing display in real events - Identified topics to discuss with users in subsequent sessions - Did not require user recruitment	- Unable to follow up with users observed in the video due to logistics - IRB restrictions on storage of videos - Limited field of view and sound
Video Review Sessions	- Detailed one-on-one discussions between researchers and users - Videos served as a point of reference for users when discussing awareness and information needs - Targeted feedback on design revisions	- Videos were of other people, not the users, so they could not comment on the mindset behind behaviors - Video users reviewed was of a simulated resuscitation, not a live event
Focus Group	- Finalized system design - Detailed and targeted feedback on design revisions	- There might be more vocal participants that can sway the discussion

able to comment on the display's usability and usefulness because they used it within the trauma resuscitation context. Simulations also allowed us to test specific display features that had been recently revised by presenting clinical scenarios that encouraged the use of those features. The limitations of simulations were that the simulated environment might cause participants to act differently due to necessary workarounds and, as with the PD workshops, that it can be difficult to recruit full teams to participate.

Heuristic evaluations using initial paper-based prototypes provided detailed, individualized feedback about the role of each team member. Engaging one-on-one with users helped us to get targeted feedback on design revisions and issues. The survey structured and guided the discussion so that all topics were covered in enough detail. The main limitation was that the designs presented during the sessions were paper-based: participants could not necessarily see how the display would function or what it would look from a distance on an actual display in the trauma room. The discussions were therefore focused more on the usefulness of the information included on the display than on the display's overall usability and reliability.

Video observations allowed us to understand the trauma resuscitation process and the information and activities necessary to support awareness. Observing live events of real patients revealed issues affecting awareness and coordination that may arise during real events. We also observed current work practices to set a baseline of how users normally conduct their work without interventions that we can compare with their work after implementing the display in real resuscitations in order to determine the impact of the display. Identifying issues with maintaining awareness allowed us to discuss these topics with participants in subsequent sessions. While this method did not require user recruitment, following up with clinicians who had participated in the observed resuscitations was challenging due to the logistics of tracking and setting up voluntary interviews with specific clinicians. The videos of live resuscitations with real patients could be stored for only four weeks on the hospital server, requiring the researcher to travel to the site to complete the video analyses. Because of limited funds and time, the researcher made two, one-week long trips to complete as many video analyses as possible. Finally, the video format also limited our field of view and sound, making it difficult to know the invisible work that might be taking place during the resuscitations (Muller 1999).

Through video review sessions with clinicians, we were able to get targeted feedback on the display's features and functionality as well as rich descriptions of awareness and the resuscitation process from the perspective of particular roles. Engaging one-on-one with participants helped us to get targeted feedback on recent design revisions. We were also able to discuss our questions that emerged from conducting video observations. The video of a simulated resuscitation served as a point of reference for discussing awareness and information needs from the perspective of clinicians. There were two limitations to using this method: (1) the video was of a simulated resuscitation, not a live event due to IRB restrictions on privacy; and (2) the video was of other people so the participants could not comment on the exact mindset behind the behaviors taking place. However, they could still comment on the possible logic based on their clinical expertise.

Lastly, a focus group helped us finalize the design revisions and conclude the formative design and evaluation aspect of the project. The format of the session was similar to the simulated resuscitation sessions but focused more on the design discussion. Walking the clinicians through the design, feature-by-feature, based on a clinical scenario helped us to lead a detailed discussion of the display's features.

5.7 Data Analysis

Two analysis techniques—thematic and content analyses—were employed to identify trends in the various types of data collected: discussions with participants, observed communication and behavior of clinicians, design artifacts created by clinicians, design feedback on display designs, and concerns written on post-it notes by clinicians. As previously noted, the outcomes of data collection and analysis ultimately depend on the perspective and assumptions held by the researchers (Muller 1999). Using two complementary analysis techniques helped us gain a holistic understanding of users in this context—their perceptions (i.e., of the display design, awareness, and coordination in this setting); the information needed to support their awareness; their current work practices; and concerns about using the display in real trauma resuscitations (Table 8).

First, we conducted *thematic analyses* on the transcripts of our discussions with participants in PD workshops, simulated resuscitations, and video review sessions.

Table 8. Summary of analyses by method.

METHOD	THEMATIC ANALYSIS	CONTENT ANALYSIS
PD Workshops	Discussion transcripts	Sketches, post-it notes
Simulated Resuscitations	Discussion transcripts	Design feedback
Heuristic Evaluations	Field notes	
Video Observations	Transcripts of communication/behavior & field notes	
Video Review Sessions	Discussion transcripts	
Focus Group	Field notes	Design feedback

Thematic analyses of the field notes from heuristic evaluation sessions, video observations, and the final focus group session supplemented these analyses. Field notes described the most salient issues, design suggestions, and descriptions of work that emerged during each session. Second, we conducted *content analyses* on the user-created design artifacts from PD workshops and the feedback indicated on paper-based versions of the display design from simulated resuscitations.

5.7.1 Audio and Video Transcription

Session discussions were transcribed in three ways: (1) a third party transcribed all PD workshop discussions, (2) the author and two other research assistants transcribed the discussions from all simulation sessions, and (3) the author transcribed the communication and behaviors from video observations and discussions from video review sessions. Digital field notes highlighting the key discussion points and design revision suggestions were also compiled for the video observations, heuristic evaluations, and the final focus group by reviewing the audio recordings from each session.

The author formatted the transcripts using the same format developed in the feasibility study to capture the nature of the topics being discussed according to trauma team role. A statement was considered as one conversational turn in which one person was speaking. Video transcripts of live trauma resuscitation observations included extra information to capture the nature of the activities performed by clinicians (Table 9, activity analysis) and the salient characteristics of the event (Table 10). One conversational turn or one activity was recorded per row and numbered in the order of occurrence to maintain the contextual flow of the discussion.

Table 9. Video transcription and analysis fields. *Fields used only for video analysis. ***Codes applied during analysis.*

TRANSCRIPTION ORGANIZATION	
#	Numbers to indicate the order of events.
Timestamp*	The time that the communication or action took place.
Notes	Additional notes to provide context of the communication or activity.
COMMUNICATION ANALYSIS	
Speaker	Role of the person making the statement (Table 11).
to	Role of the person(s) being spoken to (Table 11).
Dialogue	Transcription of the statement made if intelligible.
ABCDES, pre-hospital	Resuscitation step to which the statement refers or the step during which the communication occurs (Table 12).
Code**	Content of the statement (Table 13; Table 14).
ACTIVITY ANALYSIS*	
Actor	Role of the person performing the action (Table 11).
Action	Description of the action being performed.
ABCDE, pre-hospital	Resuscitation step during which the action occurs (Table 12).
Code**	The type of action being performed (Table 13; Table 14).

Table 10. Salient characteristics of the event.

CODE	DESCRIPTION
ID	Unique resuscitation event ID for cross-referencing with other data collection tools.
Injury severity	Level of severity of the injury (stat, transfer, attend., other)
Patient summary	Summary of the mechanism of injury.
Major clinical events	Events and interventions (none, CPR, intubation/re-intubation, needle/CT, blood transfusion, emergent operating room, death, other)
Other characteristics	Anything else that describes the event (upgrade, under-triage, multiple activations, two patients in one bay, late scribe, patient screaming, too loud, no leader, conflicting orders)

Speaker roles were indicated on all transcripts to determine the perceptions of clinicians in each role (Table 10). Roles to whom the statements appear to be directed were included for video analysis to infer the intention of the speaker (Table 11). Relevant resuscitation steps to which the statement or action refers helped organize statements into categories to determine the perceptions and information needs related to each resuscitation step (Table 9 and Table 12, transcription organization and communication analysis). For video analysis, the relevant resuscitation steps were used to organize the communications and behaviors in relation to the resuscitation process. Codes were applied in separate columns for communication and behavior.

5.7.2 Thematic Analysis of Transcripts of Discussions from Sessions

Transcripts were analyzed using a thematic analysis approach (Joffe & Yardley 2004; Braun & Clarke 2006). The purpose of conducting the thematic analysis was to develop a rich narrative characterizing the broad themes that reside across the study's large and diverse dataset. Codes were developed inductively and iteratively. An initial set of codes was created from analyzing PD workshop transcripts and was then used for subsequent analyses. Codes were added to the code set and used from the point at which they emerged in the design process in an effort toward sequentially deeper analyses of the data.

We analyzed PD sessions to understand the details of teamwork, information and awareness needs, and concerns in this domain. Each transcript was reviewed for the context and flow of the discussion before codes were applied to each statement. Multiple codes were allowed to describe any one statement (one conversational turn) as appropriate. The following aspects of the statements were considered during coding: type

Table 11. Team member roles and other possible actors.

TRAUMA TEAM ROLES		OTHER
Anesthesiologist	Physician surveyor	All
EM physician	Respiratory therapist	Family
Med nurse	Scribe nurse	Paramedic
Bedside nurse left	Surgical coordinator	Patient
Bedside nurse right	Technician	Multiple

Table 12. Trauma resuscitation steps.

RESUSCITATION STEPS			
A	Airway	**E**	Exposure
B	Breathing	**S**	Secondary survey
C	Circulation	**PH**	Pre-hospital
D	Disability	**NA**	Not applicable

of statement (e.g., if it was about a perception, experience, concern or design suggestion); timing of the statement within the design process; role of the person making the statement; and nature of what was being discussed. For example, a statement in which a surgical team leader discussed a blood transfusion and his need to know how much fluid has been administered, whether fluids were still running, and whether blood had been ordered was coded as ‘surgical team leader,’ ‘fluids/blood,’ ‘task/process awareness,’ ‘orders,’ and ‘quantity awareness.’

The codes were discussed by a group of three researchers on the team to determine which codes to keep, remove, or merge. This process led to the development and grouping of 89 codes for characterizing the resuscitation environment, different

Table 13. Initial set of codes developed to describe the resuscitation environment, aspects of teamwork, concerns, and purpose of the display.

ENVIRONMENT	**TEAMWORK ISSUES**
ad hoc	**Communication Issues**
amount of people involved	can't hear information
chaotic	missed information
complexity/ difficulty	redundancy
fast-paced	**Coordination Issues**
interruptions	decision-making
known/ unknown information	latecomers
noise level	leadership
pediatric vs. adult trauma	role distinction
short notice	teamwork
stress and anxiety	people unfamiliar with each other
CONCERNS	rotations
accuracy/ reliability	**PURPOSE OF THE DISPLAY**
data capture/ input	efficiency
dependence/ fixation on display	feedback
distracting	patient management/ outcomes
dynamic response	quality improvement
communication degradation	quantity awareness
information overload/visibility	quick overview
new technology	reminder
reassessment	situation awareness
responsibility	summary/ review
training	task/ process awareness
troubleshooting/ system down time	team awareness
	time awareness

aspects of teamwork, concerns, the purpose of the display (Table 13), critical pieces of information to display, and design issues (Table 14). The researchers then updated the transcripts with these final codes in their second pass through this data.

Upon completing the inductive coding process, participants' statements were analyzed by code similarity to identify predominant concepts and their relationships. Relevant quotes were extracted to illustrate themes across discussions. The codes were

Table 14. Codes developed to describe the critical information features to display and design issues.

CRITICAL INFORMATION FEATURES	DESIGN ISSUES
ABCDE	**Appearance and Functionality**
abnormal/ normal	alerts
consults	checklist
defibrillation	colors
disposition/ transfer	data input/ capture
family	display design
fluids/ blood	display functionality
interventions/ procedures	display position
IV access	documentation
labs	information overload
medications	multiple monitors
orders	pictures/ images
patient demographics	visibility
patient history	**Dynamic and Adaptable**
pre-calculated	case by case
pre-hospital/ pre-trauma bay	critically ill
radiology	dynamic changes
relevant information	multi-modal
secondary survey	real-time
trends	**Tech Integration**
tubes, lines, drains	EMR
vital signs	existing technologies

grouped and organized into higher-level themes—including the resuscitation environment, teamwork issues, clinician concerns, critical information features, purpose of the display, and design issues.

Thematic analysis was performed on transcripts from the simulated resuscitations and video review sessions using the initial codes to further identify and characterize themes in the data while allowing additional codes to emerge. To supplement the thematic analysis, we analyzed the field notes to identify the most salient issues, design suggestions, and descriptions of work that emerged during heuristic evaluations, video observations, and the focus group. While these sessions were not transcribed in full, the author reviewed the audio recordings shortly after the sessions were completed and noted the most salient aspects of each session. The notes were then grouped into categories, allowing the author to identify themes across sessions and retrieve relevant quotes to support the findings from thematic analysis of the other sessions. The researchers used transcripts from video observations to supplement the field notes in order to understand teamwork through the clinicians' communication and behaviors. Through these analyses, we identified patterns in participants' comments that demonstrated how clinicians perceive their work, the coordination challenges of their domain, the information needed to support their awareness, and their concerns and feedback on display designs.

5.7.3 Content Analysis of Design Artifacts, Concerns and Design Feedback

Content analysis (Joffe & Yardley 2004; Babbie 2010) was conducted on the design artifacts, participants' concerns, and design feedback on the display. Individual and group design artifacts created by participants in PD workshops were analyzed to identify the main information features needed to support their awareness and to compare individual information needs by role. The post-it notes with concerns created by clinicians in PD workshops were also analyzed to identify major concerns about using the display in real resuscitations. Design feedback indicated on the paper-based versions of the display from simulations, heuristic evaluation sessions, and data from the focus group were analyzed to determine clinicians' perceptions of the display over time. Content analysis supplemented the thematic analysis of discussions with participants.

5.7.3.1 Analysis of Participants' Sketches

We first analyzed participants' sketches by extracting the critical types of information to support awareness from individual and group designs and then grouped them into larger categories (e.g., pre-hospital information, treatments, orders). Information included on the individual designs was transcribed into a matrix to analyze the information features each role included in designs. The features were then grouped by type and sorted by the number of times they had been included in designs. The frequencies of information types included on designs were analyzed across sessions to identify the most salient information needs to support awareness.

Data related to group designs were transcribed in a similar manner by grouping information features by type and recording the top-ten ranks that members of each role assigned to the features. The ranking for each feature was determined by the frequency of the rank assigned to the feature. Rankings helped us determine the most prominent information needs from participants' perspectives.

5.7.3.2 Analysis of Clinician Concerns

The same analysis technique was used to extract and group issues and concerns into larger themes. Each post-it note containing a concern was transcribed into a matrix to analyze the concerns voiced by each role in PD workshops. The groups that emerged from clustering the post-it notes during the design sessions were used to organize the concerns into themes. The themes were then ordered by frequency to determine the predominant perceptions held by users. We then analyzed issues and concerns by frequency per role to identify which issues and concerns were most important to each role. Concerns voiced during subsequent sessions were added to the list of concerns.

5.7.3.3 Analysis of Clinician Feedback on Information Features

Feedback indicated on paper versions of display designs during simulation sessions and the concluding focus group was calculated to analyze trends in clinicians' satisfaction over time. The information features of each display design implementation tested in the simulation sessions were partitioned into main categories (e.g., header, ABCDE, treatments, and orders). The percentages of participants who found features useful and not useful to supporting their awareness in these categories were then calculated as:

$$\frac{\text{\# of votes}}{\text{\# of items in category}} \times \frac{1}{\text{\# of people who voted}} \times 100$$

Only one vote per category per participant was counted. These analyses helped us to determine clinicians' satisfaction with the display and the individual design features over time. Visual analysis allowed us to identify features dynamically to discuss with participants.

5.7.4 Summary

In summary, two types of analyses were conducted on the data from design and evaluation activities. First, we conducted a thematic analysis of discussions with participants and transcripts from video analyses—helping us understand the details of teamwork, information and awareness needs, and concerns in this domain. Field notes from heuristic evaluations, video observations, and the final focus group supplemented this analysis. Second, we conducted detailed content analysis on design artifacts from the PD workshops using the frequency of information features included in individual and group designs and the rankings of information features by participants on group designs to identify the most important features to include on the display to support awareness as well as the role-based differences in information needs. Categories to describe clinicians' concerns with using the display during real events were also identified through content analysis of issues and concerns collected on post-it notes and identified through other discussions. We analyzed the feedback on the category of information features obtained through printed versions of the display annotated with stickers in simulation sessions and the focus group. We next present the findings from these analyses.

CHAPTER 6: FINDINGS

6.1 Overview

This chapter comprises four sections that draw from three publications. First, we use participants' perspectives to characterize teamwork during emergency resuscitations and identify features of *ad hoc*, interdisciplinary, and collocated teamwork that require support through information technology. We first presented these results in the *CSCW Journal* paper "Sketching awareness: A participatory study to elicit designs for supporting emergency medical work," co-authored with Aleksandra Sarcevic, Zhan Zhang and Maria Yala (Kusunoki et al. 2014b).

Second, we highlight three main concerns clinicians expressed about using the display in emergencies—including the real-time adaptability to dynamic changes, information overload and visibility, and replacement of verbal communication—which they perceived as directly related to awareness and the extent to which the display may affect it. These findings were also published as part of the *CSCW Journal* paper (Kusunoki et al. 2014b).

Third, we describe the role-based differences and tensions around the information features included on the display. These findings were published in the ACM CHI 2014 paper "Balancing design tensions: Iterative display design to support *ad hoc* and interdisciplinary medical teamwork," co-authored with Aleksandra Sarcevic, Nadir Weibel, Ivan Marsic, Zhan Zhang, Genevieve Tuveson, and Randall S. Burd (Kusunoki et al. 2014a).

Finally, we examine the role of temporality in trauma teamwork and how trauma resuscitation teams experience and perceive time, construct their own time-keeping mechanisms, communicate temporal information, and respond to different presentations of temporal information. The results of this study led to the ACM CSCW 2015 paper “Designing for temporal awareness: The role of temporality in time-critical medical teamwork,” co-authored with Aleksandra Sarcevic (Kusunoki & Sarcevic 2015).

Our process for understanding information and awareness needs was threefold. First, we used participants’ perspectives to characterize teamwork during emergency resuscitations in order to identify and validate features of collocated teamwork that require support through information displays. We used our understanding of participants’ perspectives and of *ad hoc*, collocated teamwork to create and validate prototypes of the information display. Second, we analyzed clinicians’ individual and group sketches to uncover the differences in both awareness needs and priorities for different information types based on clinicians’ roles. Finally, we examined the features of awareness in this context and focused specifically on the role of temporality due to its prevalence in time-critical work. We discuss the features of awareness in more detail in the Discussion.

6.2 Features of Trauma Teamwork Requiring Support

Based on our analysis of discussions, individual sketches, and group designs, we identified five features of emergency medical teamwork that require support: (1) accessing patient information and pre-hospital data, (2) identifying leaders and other roles (Chapter 2.3), (3) monitoring patient status in real time and trends over time, (4) keeping track of tasks and team progress, and (5) managing orders and coordination with other hospital units (Table 15). We observed that needs and priorities for different information

Table 15. Summary of information types, roles favoring those types, and position on the display for each feature of teamwork.

Features of Teamwork		Priority Information Types	Roles Favoring this Information	Position on Display
Accessing patient information and pre-hospital data		• Demographics (age, weight) • Mechanism of injury • Pre-hospital interventions • En-route changes in patient status	• Scribe, bedside nurses • Leadership roles • Physician surveyor	Top left
Identifying leaders and other roles		• Names of supervisory roles • List of team roles present in the room	• Leadership roles • Scribe, bedside nurses • Anesthesiologist • Respiratory therapist	Top center
Monitoring patient status in real time and trends over time		• Raw vital signs • Vital sign trends	• Leadership roles • Anesthesiologist • Respiratory therapist • Scribe, bedside nurses	Right or middle center
Keeping track of tasks and team progress	*Sequential dependency of tasks*	• Medications (name, dosage); IV access (type, placement); fluids (type, amount)	• Scribe, bedside nurses	Bottom center or right
	Elapsed time	• Timestamps for medications, fluids • Timer	• All roles	Top center
	Abnormal patient findings	• Abnormal findings from patient evaluation (ABCD protocol steps)	• Leadership roles	Bottom left
	Periodic checklists	• Completed tasks, tasks in progress and remaining tasks	• Leadership roles	Bottom left
Managing orders and coordinating with other hospital units		• Lab orders and results (e.g., blood gas level) • Radiology orders and results (e.g., x-rays, CT scans)	• All roles	Bottom right

types varied across roles. These needs provided us with insights into how clinicians achieve awareness. The sketches also revealed the differences in both information needs and priorities based on role.

We saw a pattern in information arrangement across different design layouts. One participant nicely described the flow of the information on the display using her sketch:

> So this is information that's known. This is information we're discovering. This is what's actual and then this is what's revealed. So left to right, just like you would read, what you know and then what you're discovering… The things that we find most important are on the top left and the things that we're going to eventually act on are in the bottom right. (Critical Care Specialist, CHOP-PDWS2)

Analysis of the individual and group designs revealed that they generally fit this higher-level theme (Figure 20 and Figure 21). We next discuss each feature of teamwork in greater detail.

6.2.1 Accessing Patient Information and Pre-Hospital Data

Critical information about the patient is reported at the beginning of the resuscitation, as the Emergency Medical Services (EMS) team hands the patient over to the resuscitation team. Patient information includes demographics (e.g., age, weight); mechanism of injury (i.e., how the patient got injured); pre-hospital interventions; and en-route changes in patient status. Most of the individual sketches and all four of the group designs had patient information and pre-hospital data in some form, usually at the top left (Figure 20 and Figure 21). Participants emphasized the importance of including this information on the display for two reasons. First, because patient information is reported early in the event and only once, team members have difficulty accessing this data later as they evaluate and treat the patient. For example, bedside nurses insisted on displaying age and weight to reduce the need for questions about these parameters when they drew medications or prepared fluids (medication dosages and fluid volumes depend on the patient's age and weight). Leadership roles and physician surveyors agreed with nurses

Figure 20. Examples of individual sketches from CNMC (a, b, c) and CHOP (d, e, f), Six out of 23 designs. Roles are (a) emergency medicine fellow, (b) scribe nurse, (c) anesthesiologist, (d) surgical resident, (e) critical care specialist, and (f) bedside nurse.

and also added a brief summary of the injury mechanism to be able to anticipate treatments and diagnoses. A physician surveyor explained:

> Usually, I would like the weight and age of the patient, the mechanism of injury, what was done from the scene to the hospital. So that would be basically all of the extraneous stuff on top. As soon as the patient gets in, the story changes a lot of times… I've noticed that at least four times since I've been here. But the paramedic would tell us a story, and that would often not pan out towards the end. So I would just like to know the actual mechanism [of injury]. (Physician Surveyor, CNMC-PDWS1)

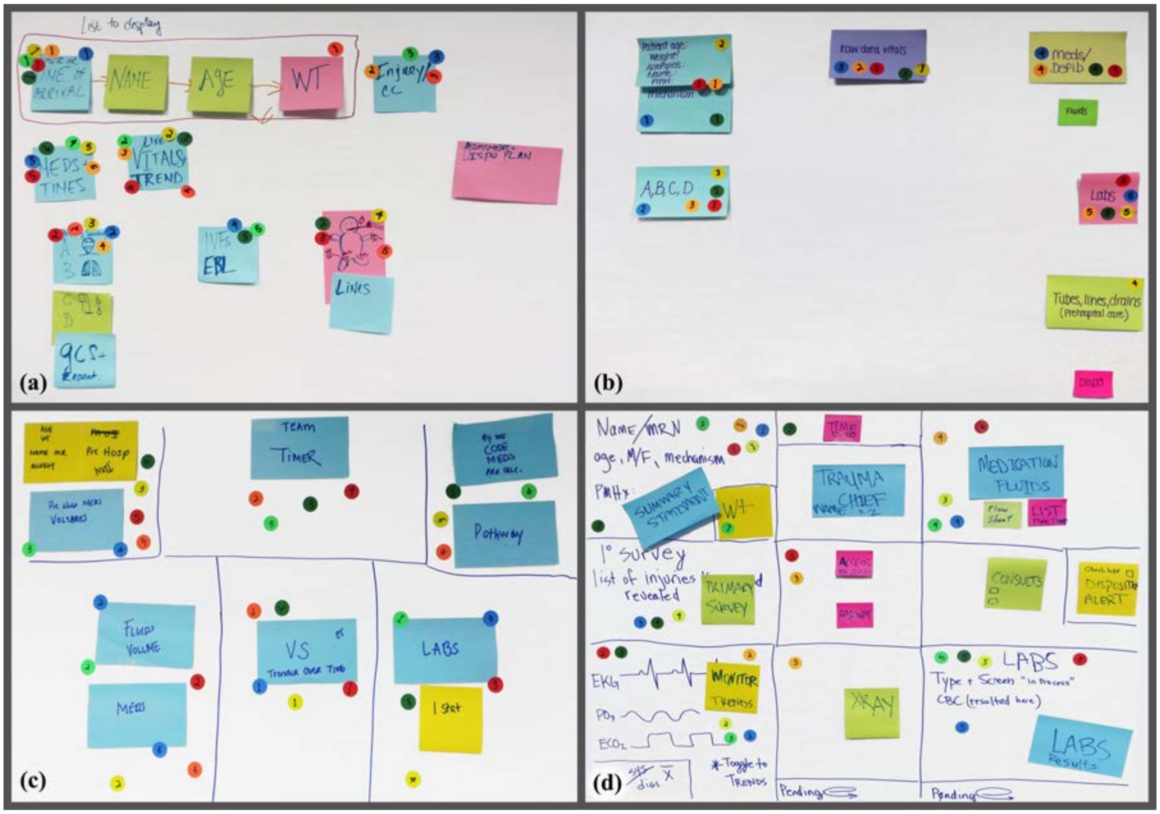


Figure 21. Group designs from CNMC (a, b) and CHOP (c, d).

Participants provided concrete examples of *why* they needed patient information and pre-hospital data and *when* in the process this information was important. There are insights we could not have obtained by observing team communications and activities alone.

Workshop participants further commented that information about the patient's name, allergies, and past medical history would help teams get a better sense of how to treat the patient but noted that this information was not essential. This insight revealed that it is just as important to decide what information will not be on the display as what information will:

> I think that just overall, not having [the top part of the display] be just a summary of the flowsheet is really important because there is a lot that you need for documentation, but it's not going to affect your decision-making. (Scribe Nurse, CNMC-PDWS1)

Second, *ad hoc* team formation makes it common for some team members to arrive later than others and miss important information (Lee et al. 2012). When team members arrive late, the team leader must temporarily shift his or her focus to update latecomers about the patient's status. Patient age, weight, and especially mechanism of injury were therefore seen as important pieces to display to fill in clinicians who were coming in late, as explained by participants across workshops:

> [In] the major traumas, the problem is that every time someone new comes on the scene, like the ICU attending or the surgery attending, I have to tell the story again. It kind of throws everybody off of the already-in-progress resuscitation. That's my main problem. (Surgical Fellow, CNMC-PDWS1)

> This is supposed to be a quick overview if I walked in the room ten minutes late because I was doing something somewhere else. (Respiratory Therapist, CNMC-PDWS1)

> It could decrease repetitive questions because every time a new person walks into the room you have to say the whole thing all over again. (Emergency Medicine Physician, CNMC-PDWS2)

> There's certain information that just gets buzzed around that room. People come in and say, "What's the mechanism [of injury]? What do we do? What's this? What's that?" That [weight] could be there [on the display]. Just look there for weight. (Scribe nurse, CHOP-PDWS2)

Patients and family members were also noted as an important source of pre-hospital and medical history information. Patients are often able to respond to questions (i.e., what happened, what level of pain they are in) or provide some feedback through sounds, movement, and facial expressions that allow teams to adjust their care. Family members are especially helpful when the patient is unconscious, cannot speak, or does not have a record at the hospital:

> Usually I have a team member talk to the family, and they come back to me and tell me what the history was. And then whatever's pertinent I try to announce to everyone so that they know. (Emergency Medicine Physician, CHOP-PDWS1)

Patient information and pre-hospital data are important contributors to clinicians' awareness when completing tasks, similar to *activity awareness* and *articulation awareness* as discussed in the CSCW literature. This information helps clinicians understand how they should approach treating the patient and coordinating their activities. Having this information on the display throughout the resuscitation process can be particularly useful to clinicians who arrive late by establishing activity awareness without having to interrupt the team.

6.2.2 Identifying Leaders and Other Roles

Organizational practices at CNMC and CHOP recommend that both surgical and emergency medicine physicians share leadership during trauma resuscitations. Depending on the severity of the patient's injury, assistance from additional specialists (e.g., critical care, neurosurgery) may be necessary. In most cases, surgeons lead trauma resuscitations while discussing decisions with emergency medicine physicians and other specialists. Clinicians in these supervisory roles usually stand at the foot of the bed, overseeing the rest of the team. Even so, the presence of multiple leaders may make others in the team unsure of whose orders to follow, especially if the leader is not clearly identified. An emergency medicine physician commented:

> A lot of times when it's more difficult, it's because there are multiple attending [physicians] in the room and that can work well when they're standing together and working together, but sometimes, when there are so many people in the room, it's just much harder and it feels a lot more chaotic. (Emergency Medicine Physician, CHOP-PDWS1)

The *ad hoc*, interdisciplinary nature of team composition highlights the importance of understanding, at the very least, who the leaders are, what roles are present in the room, and leaders' levels of experience to facilitate teamwork among clinicians who may not have worked together before:

> It's helpful when we know each other and that's why I feel like… if we can all come into the room and say I'm so and so, I'm the fourth-year surgical so we know that's different from the seven-year rotator, and we'll be like "okay what you [surgical

> fellow] say stands better than what a seven-year surgical rotator is going to tell me." So I think there are differences when you know and are comfortable with people. (CNMC-2 Emergency Medicine Physician)

> I agree with all of that. I think in the end it's going to come down to who's liable or who's running the show. (Surgical Fellow, CNMC-PDWS2)

Team member introductions are now common across US trauma centers to help teams establish role delineations, understand the levels of experience of teammates, and even learn each other's names. Teams are typically notified of the estimated time until EMS arrives with the patient. Depending on how quickly the EMS team is able to transport the patient, teams usually have between five to 20 minutes to prepare and do a round of introductions. Often, however, patients arrive unannounced, leaving little or no time for team introductions (Sarcevic et al. 2011b).

Although all four groups discussed these teamwork challenges, only participants from CHOP expressed the need for specifically identifying leaders and other roles on the display, usually at the top center of their sketches Figure 20(d,e) and Figure 21(c,d)):

> Just a little area where it says who's who, who the leader is, the nursing roles, the surveyor… there's the swipe machine when you walk into the trauma bay where people swipe their ID. So if it was possible to connect the display so that it automatically displays who's in the room, because there are times when another person walks into the room and starts giving orders or giving recommendations and you have no idea who they are. (Emergency Medical Physician, CHOP-PDWS1)

Furthermore, participants from CHOP proposed a technological solution to this challenge: using their badges equipped with radio-frequency identification (RFID) sensors to automatically identify team members as they walk into the room, displaying their names, photos, and the typical roles they assume. Team members would then be shown on the information display to support the team's social awareness of who is present in the room, what roles are filled, and what roles are missing.

Two explanations may account for the difference in role-identification needs between CNMC and CHOP participants. First, there are two large sign-in boards situated near the entrance to the trauma bays in CNMC where team members write their names, roles, and arrival times. Second, a few years ago, CNMC instituted the practice of role-tagging—attaching a self-adhesive paper tag indicating each member's role—to assist teams with role identification (Sarcevic et al. 2011b). None of these mechanisms exists at CHOP. Note, however, that even with these solutions, clinicians at CNMC continue to face the challenge of identifying leaders and other roles in the room: sign-in boards proved to be of little help when situated outside the rooms, and role-tagging proved to be ineffective when there was insufficient time to put on the tags.

Identifying leaders and team roles contribute to clinicians' awareness when coordinating their work, similar to *social* and *spatial awareness* described in the CSCW literature. Clear role distinction and leadership promote better *social awareness* during resuscitations, especially in the cases when more people are needed in the room. Physical positioning around the patient based on role supports clinicians' *spatial awareness* of where each role is generally located and their *activity awareness* of where each role's activities usually take place.

6.2.3 Monitoring Patient Status in Real Time and Trends Over Time

Physiological parameters such as heart rate, blood pressure, and pulse are the most commonly used indicators for monitoring and assessing the patient's status. It was no surprise, then, that almost all the sketches included patient vital signs in some form, mostly in the center or on the right side of the display (Figure 20). Two findings stand out in relation to patient monitoring.

First, four out of 23 sketches did not include any information about the vital signs; they were created by two surgical leaders and one physician surveyor at CNMC and one physician surveyor at CHOP. Although vital signs are important to these roles, it appears that these participants conceptualized their information displays as an addition to the current vital signs monitors rather than a replacement:

> So the first thing to note is I have zero vitals on [my design] because there's a tele[meter] separately. I'm assuming this [display] is not replacing a tele[meter]. (Surgical Fellow, CNMC-PDWS2)

This finding suggests that some participants saw information distributed across the room, whereas most assumed that the new display would synthesize all the information they needed. Respiratory therapists and anesthesiologists were concerned about the placement of the vital signs and how easy would it be for them to see the display from the head of the bed. This concern was also manifested through their sketches, which prominently featured the vital sign data (e.g., Figure 20(c)):

> If I have a head injury, and I'm trying to trend my vitals, and if I can't see that, because there's one screen here, and there's one screen there. But I'm going to

> assume that they're doing the same thing, so whoever is at the head of the bed can still see what's at least on one of them. (Respiratory therapist, CNMC-PDWS2)

Second, participants who included vital signs in their sketches suggested two ways in which this information can support patient monitoring: (1) showing raw vital signs with live waveforms and values like those on the vital signs monitor (e.g., Figure 20(e)) and (2) showing vital sign trends over the course of the event (e.g., Figure 20(f)). Respiratory therapists and anesthesiologists requested raw vital signs because they provide immediate feedback on the effectiveness of their treatments:

> I like the raw data because it truly tells me if my bagging is effective, or if it's not, just a large verification of if I'm doing something right or if I'm doing something wrong, or what's going on with the patient. (Respiratory Therapist, CNMC-PDWS2)

Scribe nurses, by contrast, expressed the need for the vital sign trends. Although vital signs monitors can display trends over time, they are rarely set to that mode. To help teams keep track of trends, part of the scribe nurse's role is to document patient vitals every few minutes and provide alerts when there is a change (Sarcevic 2010). With the amount of information they are managing, however, it is difficult for scribes to recognize and announce trends while keeping up with other aspects of the resuscitation:

> I actually like the idea of having previous vital signs to be able to compare because I feel like that's a huge responsibility that I have. I'm the only person in the room that has right in front of me all the vitals. I'm trying to document all the other things but at the same time look at the vitals when I'm writing it down and compare it to what they

> were before, and notify someone if something's changed. But it would be helpful if everyone could see more of that information. (Scribe Nurse, CNMC-PDWS2)

Monitoring the patient's status through vital signs actively supports clinicians' awareness when deciding on, completing, and determining the effectiveness of tasks. This awareness is similar to *activity awareness* and *process awareness* as discussed in the CSCW literature. Vital signs provide critical feedback for deciding on interventions and for determining if they were effective, which is essential to *activity awareness*. Vital signs trends also help clinicians detect changes in patient status to support *task awareness*. Trends support *process awareness* by providing an overview of the progress made in treating the patient.

6.2.4 Keeping Track of Tasks and Team Progress

Participants' sketches and workshop discussions revealed four task-determining factors that play an important role in helping teams keep track of tasks and team progress: (1) sequential dependency of tasks, (2) elapsed time, (3) abnormal patient findings, and (4) periodic checklists. Together, these factors determine the order of the steps or tasks that the team will perform and are thus critical for team coordination.

6.2.4.1 Sequential dependency of tasks

There are a number of tasks that are dependent on other tasks being performed first. For example, nurses cannot administer medications before IV access is established; anesthesiologists cannot start patient intubation before medications are administered (in fact, any tasks that require sedation cannot begin before IV access is established and neurological status is assessed); and x-ray technicians cannot take images before the initial survey is completed. To plan and coordinate their work, team members need to know the status of these sequentially dependent tasks—that is, whether these tasks have been completed. Participants articulated this need in their sketches, noting needs for information about administered medications (name, dosage, and time); administered fluids (type, amount, and time started); established IV access (type and placement); and completed protocol steps (Figure 20). Clinicians who were particularly interested in this information included nurses, airway physicians (respiratory and anesthesia), and team leaders:

> Medication and what we've given, what time it was given, and the dose that was given. […] The conversation between [emergency medicine physician] and I doesn't need to be on the screen. But what does need to be on the screen is the fact that it's been three minutes since [epinephrine] or this is the time you are inside [the trachea]. Because the time is so skewed in the midst of all of this, you lose track. (Bedside Nurse, CNMC-PDWS1)

> It's just fluids, blood, pressors [medications to elevate blood pressure such as epinephrine], meds if they're given, because sometimes we miss that or we are not sure is it still running. Is it in? When was it given? And those things are very important. (Surgical Fellow, CHOP-PDWS1)

6.2.4.2 Elapsed time

Time is an important dimension related to keeping track of tasks and team progress. Clinicians often lose track of time and of how long it has been since the patient arrived or since time-dependent interventions were performed. For example, certain medications need to be administered in time intervals. Teams often need to know when defibrillation was last performed and at what voltage to determine the next set of defibrillations until normal cardiac rhythms are reestablished. Leaders have to keep the big picture in mind, making it difficult to keep track of other resuscitation dimensions:

> The biggest thing I think, as the leader, is that you're trying to put everything, the whole picture together all at once and you sometimes lose the little things like the timing of medication. Epinephrine, the last dose that was given, or when the last fluid bolus was given. (CHOP-2 Emergency Medicine Attending)

In addition, knowing how much time has elapsed since the patient arrived gives a sense of how the resuscitation is progressing:

> Three minutes can feel like five seconds, or three minutes can feel like three hours, just depending on the situation that you're in. (Respiratory Therapist, CNMC-PDWS1)

The need for time keeping was expressed on both individual and group designs, which included timestamps next to the administered medications and fluids (to keep track of time-dependent interventions) and timers (to keep track of time elapsed since the patient's arrival) (Figure 20 and Figure 21). As we observed earlier, wall-mounted timers in the rooms currently serve this second function, but teams often forget to turn them on.

6.2.4.3 Abnormal patient findings

Emergency medicine physicians, surgical leaders, and physician surveyors noted that information about each of the ALS/ATLS protocol steps (ABCDE) does not need to be shown in great detail; instead, a display should show whether each step has been completed and what abnormal results, if any, emerge from an examination of the patient:

> We [referring to the group of design participants] shouldn't forget the ABC's. That's a major portion of what we're doing in the first few minutes. (Emergency Medicine Physician, CNMC-PDWS2)

As discussed by different groups, abnormal findings help teams (especially leaders) localize patient injuries, which in turn helps determine what tasks to perform and in what sequence. For example, asymmetrical breath sounds may be a sign of internal chest injury and usually require chest decompression or chest tube insertion. Other abnormal findings include obstructed airways, weak pulses, and deteriorating neurological status. We found these findings consistent with those reported in Sarcevic and Burd (2008), who found that questions about evaluation steps and abnormal findings ranked first, comprising 33% of all questions asked during ten real resuscitations. The current study helped uncover why teams, and leaders in particular, inquired frequently about abnormal findings, offering concrete insights into awareness needs and how best to translate them into design solutions.

6.2.4.4 Periodic checklists

Those in leadership roles want information about what tasks have been completed so they can move onto the next task (especially sequentially dependent tasks); what tasks are in progress; and what tasks remain to be done. As we previously observed, their practice is to provide short verbal summaries to the team periodically by listing major findings, critical vital signs, treatments and interventions, tasks in progress, and incomplete orders (Kusunoki et al. 2003). Teams can then take a brief step back and revisit the "big picture." Most leaders conceptualized these verbal summaries through digital checklists on their display sketches, providing a good example for what the display should present and the potential benefits:

> The best-run scenarios are the ones that have multiple summaries throughout the resuscitation because that allows the whole team to just realize where we are at that particular point in time, what has been done, what needs to be done. Just, it's a really important thing. (Emergency Medicine Physician, CHOP-PDWS2)

Completed tasks and steps were even conceptualized through a visualization of the body with all the tubes, lines, and drains depicted (Figure 20(a,d)). Participants in one workshop described the idea of using an image of the patient as follows:

> I think there is some method too, to having an image of the patient because there are so many numbers and other information being displayed. (Emergency Medicine Physician, CNMC-PDWS1)

> If you had an image, your lines could just be a picture [with] a tube that comes out of the mouth. (Bedside Nurse, CNMC-PDWS1)

> You could sort of highlight where there was a pertinent finding from survey on a graphic of the patient. Then that would help people to remember don't grab that arm if we think it could be broken. (Emergency Medicine Physician, CNMC-PDWS1)

Keeping track of tasks and team progress requires awareness of the sequential dependency of tasks, elapsed time, abnormal patient findings, and an overall summary of the resuscitation. The awareness required is much like a mixture of *activity and articulation awareness*, *temporal awareness, social awareness,* and *process awareness* as described in the CSCW literature. *Activity awareness* and *articulation awareness* are important for understanding the sequential task dependencies and keeping in mind any abnormal findings from the physical examination. *Temporal awareness* complements activity and articulation awareness with the elapsed time of tasks and major interventions. *Social awareness* also supplements activity and articulation awareness by helping clinicians know who is working on various tasks to plan and coordinate work. Finally, *process awareness* gives clinicians an overview of the progress and "big picture" of the resuscitation by providing the important findings, events, and tasks.

6.2.5 Managing Orders and Coordinating with Other Hospital Units

Most participants viewed the display as a way to manage many laboratory and radiological studies performed during resuscitations—that is, to show what should be ordered, what has been ordered, whether the results are back, and what the results are. Nurses fulfilling these orders saw the benefits of seeing orders on the display instead of asking and interrupting the team. Being able to pull up the results quickly for everyone to see was important to nurses, respiratory therapists, and leaders because they currently have to go to another computer (sometimes outside the room) and look them up:

> Right now, we have to walk out of the room, go to the computer, log into the computer, and wait for all that to happen to see an image. Even once we've intubated, let's see what the chest x-ray is like just to confirm [tube] placement. If it's something that would be easy to put up and kind of take away again very quickly. (Emergency Medicine Physician, CNMC-PDWS2)

Nurses call out the results to the team when they arrive, but some results may not become relevant until later. An option to toggle among radiology images, lab results, and other content on the display would address this situation.

Facilitating communication with other hospital units and people outside the room was also emphasized because of the need to coordinate with clinicians waiting at the next hospital unit:

> And [the next] destination is alerted so that the PICU knows we're coming or the OR knows we're coming or CT scan knows we're coming, so that we've made the decision for our next stop and we've alerted that stop. (Team leader, CHOP-PDWS2)

> My biggest thing is, we get yelled at all the time for not having the proper equipment set up upstairs. But if we know what room number [the patient is going to], we can just have a ventilator sitting in the hallway…and I can just call my [respiratory therapist] upstairs saying "go set it up." (Respiratory Therapist, CNMC-PDWS2)

To manage orders and coordinate with other hospital units, clinicians require awareness similar to *activity awareness*, *social awareness*, *spatial awareness*, *articulation awareness*, and *process awareness* as described in the CSCW literature. Clinicians coordinating from other units need *activity awareness* of the tasks being performed as well as *spatial* and *social awareness* of the tasks taking place in the trauma room. *Articulation awareness* is necessary for communicating orders and results among units. *Process awareness* is also important to clinicians in other hospital units for knowing how far the team is into the resuscitation so they know what to prepare and how much time they have left before the patient is transferred to their units.

6.2.6 Summary

Our early identification of these five features of trauma teamwork that require support allowed us to understand more clearly the nature and challenges of trauma teamwork from the perspective of clinicians. Accessing patient information and pre-hospital data is important because it is common for some clinicians to arrive later than others due to the nature of *ad hoc* team formation and because it is often difficult to access this information without interrupting team members. Identifying leaders and other roles on *ad hoc* teams is also difficult. Clinicians need to be able to monitor patient status in real time and to track trends over time to assess the effectiveness of their treatments. Finally, assistance in keeping track of tasks and team progress is also important: support could assist clinicians in monitoring the sequential dependency of tasks, elapsed time of tasks, overall progress, abnormal patient findings, and periodic checklists of tasks that have been completed. Trauma teamwork requires support for process awareness, social awareness, activity awareness, and temporal awareness, as reviewed in the CSCW literature. Later in the discussion section, we describe in further detail what awareness means in *ad hoc*, interdisciplinary emergency medical teamwork.

The PD workshop discussions helped us to develop design requirements on which to begin building our display. In the following section, we discuss the main information features identified in the PD workshops and examine the role-based differences and tensions that emerged around each information feature based on clinician feedback during the initial simulation sessions.

6.3 Role-Based Similarities, Differences & Tensions Around Information Features

The hierarchical nature of trauma teams and the multiplicity of responsibilities, disciplines, and training levels naturally lead to a diversity of information needs. Patient data that is meaningful to one team member might go unnoticed by other team members. While each role has particular information needs, we also observed several overlapping needs among roles that must be met in order to coordinate tasks. This mix of information needs also became evident as we were designing and evaluating display prototypes, revealing both role and design tensions.

Eight categories of information emerged from participants' group designs during the initial workshops. The categories include (ranked by perceived importance):

1. Patient demographics and pre-hospital information
2. Vital sign values, waveforms, and trends
3. Findings from ABCDE
4. Medication names, dosages, and administration times
5. Procedures: types and locations of tubes, lines, and drains

6. Laboratory and radiology orders and results
7. Fluid types and amounts
8. Disposition plan.

This overall ranking of information categories was based on individual rankings across both sites (Table 16). Role-based differences in information needs emerged through analyzing the information features in individual designs, the rankings of features on group designs, and clinicians' satisfaction with the functionality and information features on the prototypes tested in the simulations (see Table 17 for a summary of the information features and sub-features).

6.3.1 Patient Demographics and Pre-Hospital Information

All individual designs included a portion at the top with patient information such as age, weight, mechanism of injury, name, pre-hospital interventions, medical history, timer, arrival time, and allergies (Table 17). For group designs, this "header" included all information from individual designs except pre-hospital interventions, name, and timer. Although suggested initially, patient name, gender, allergies, and medical history were found least useful and did not propagate to the initial prototypes. All but two participants ranked the header information as most important during the workshops. Similarly, throughout simulation testing, the header was the most popular feature of the display, stabilizing with an increasing percentage of likes and a decreasing percentage of dislikes (Table 18 and Figure 22).

The most debated portion of the header was pre-hospital interventions. During the first set of simulations (v4, Figure 22 and Figure 23), EM physicians, physician surveyors,

Table 16. Individual rankings assigned to each information category.

Role	Site	Work-shop	Patient info	Vital signs	ABCDE	Meds & fluids	Lab results
Anesthesiologist	CNMC	W1	1	2	3	4	--
		W2	1	2	3	4	5
Bedside Nurse	CNMC	W1	1	2	--	3	--
	CHOP	W1	3	--	--	2	1
		W2	1	2	--	3	4
Critical Care	CHOP	W2	1	2	--	3	--
EM Physician	CNMC	W1	1	3	2	4	--
		W2	3	2	1	4	5
	CHOP	W1	4	1	--	2	3
		W2	1	2	--	3	4
Physician Surveyor	CNMC	W1	1	3	2	--	--
	CHOP	W1	2	1	--	3	--
Respiratory Therapist	CNMC	W1	1	2	3	4	--
		W2	2	1	3	--	4
	CHOP	W1	3	1	--	2	4
		W2	1	2	4	3	5
Scribe Nurse	CNMC	W1	1	2	--	3	--
		W2	1	3	2	4	5
	CHOP	W1	2	1	--	--	3
		W2	1	2	3	--	4
Team Leader	CNMC	W1	1	--	2	3	--
		W2	1	3	2	4	5
	CHOP	W1	4	1	--	2	3
		W2	1	2	3	4	5

scribes, and team leaders disliked pre-hospital information because it was not as useful as the other header features. The design tested in the second set of simulations omitted pre-hospital information (v6, Figure 22 and Figure 23), and this header received only one negative comment from a respiratory therapist. Pre-hospital information, however, emerged as important again during the second set of design workshops. Users preferred

Table 17. Role-based preferences for information features and sub-features from individual designs.

Header	
Patient demographics	All team roles
Pre-hospital information	Anesthesiologist, bedside nurse, physician surveyor, scribe, respiratory, leader
Vital Signs	
Numeric values	Respiratory, anesthesiologist
Live waveforms	Scribe, respiratory, anesthesiologist
Trends	Scribe
Patient Evaluation Findings (ABCDE)	
Checklist of steps	Physician surveyor, EM physician
Findings & procedures under ABCDE	Leader 1, leader 2, scribe, respiratory, EM physician
Findings & procedures by type	Anesthesiologist 1, anesthesiologist 2, respiratory, bedside nurse, scribe
Body with representations of findings	Physician surveyor, EM physician
Treatments	
Medications & fluids separated	Bedside nurse, scribe, respiratory
Medications & fluids combined	Anesthesiologist, respiratory, leader
Laboratory and radiology orders/results	
Radiology tests ordered	Bedside nurse
Labs and radiology tests ordered	Leader
Labs ordered & results	Anesthesiologist, scribe, EM physician
Lab results	Respiratory
Lab results & radiology tests ordered	Scribe, respiratory

the third design tested, which included pre-hospital information with a more efficient layout (v10, Figure 22 and Figure 23). The header remained the same from version 10 to the final version 16 (Figure 24).

6.3.2 Vital Signs

Individual designs suggested three ways of monitoring the patient's vital signs: *numeric values*, *live waveforms*, and *trends* during resuscitations (vital signs, Table 17). Only leaders and a physician surveyor did not include vital signs in their designs, noting

Table 18. Attitudes toward major components of the display expressed through the percentage of checkmarks (✓) and x marks (✗) during simulations and the focus group (N/A = not included in display).

Information Features	SIM 1 v4 ✓	✗	SIM 2 v6 ✓	✗	SIM 3 v10 ✓	✗	SIM 4 v13 ✓	✗	SIM 5 v14 ✓	✗	Focus Group v15 ✓	✗
Header	34%	13%	39%	1%	44%	0%	38%	3%	28%	5%	40%	0%
Vital signs	N/A											
Patient evaluation findings (ABCDE)	21%	43%	21%	20%	20%	14%	25%	38%	42%	13%	33%	0%
GCS	36%	7%	64%	0%	30%	0%	25%	0%	13%	13%	50%	0%
Treatments	55%	2%	N/A		70%	0%	13%	17%	25%	4%	42%	25%
Laboratory and radiology orders/results	14%	14%	14%	30%	30%	30%	38%	13%	50%	13%	13%	25%
TOTAL	**29%**	**24%**	**30%**	**14%**	**30%**	**11%**	**29%**	**14%**	**32%**	**8%**	**36%**	**9%**

they were keeping in mind that a separate monitor for vitals was present. The vital signs feature was ranked as second most important in both group designs, and most participants liked it. Scribes noted that they need both waveforms and trends to record this data and alert the team about changes in vital signs. Respiratory therapists and anesthesiologists highlighted the importance of numeric vital signs for real-time feedback on the effectiveness of their treatments.

Vital signs are currently omitted from our display prototype until we can determine how to incorporate them efficiently into the design and stream data to the display. Vital signs are critical to patient care, so we made sure to have a vital signs monitor when testing our display during simulations. Throughout the project, we have been working with the biomedical engineering department at CNMC to develop a

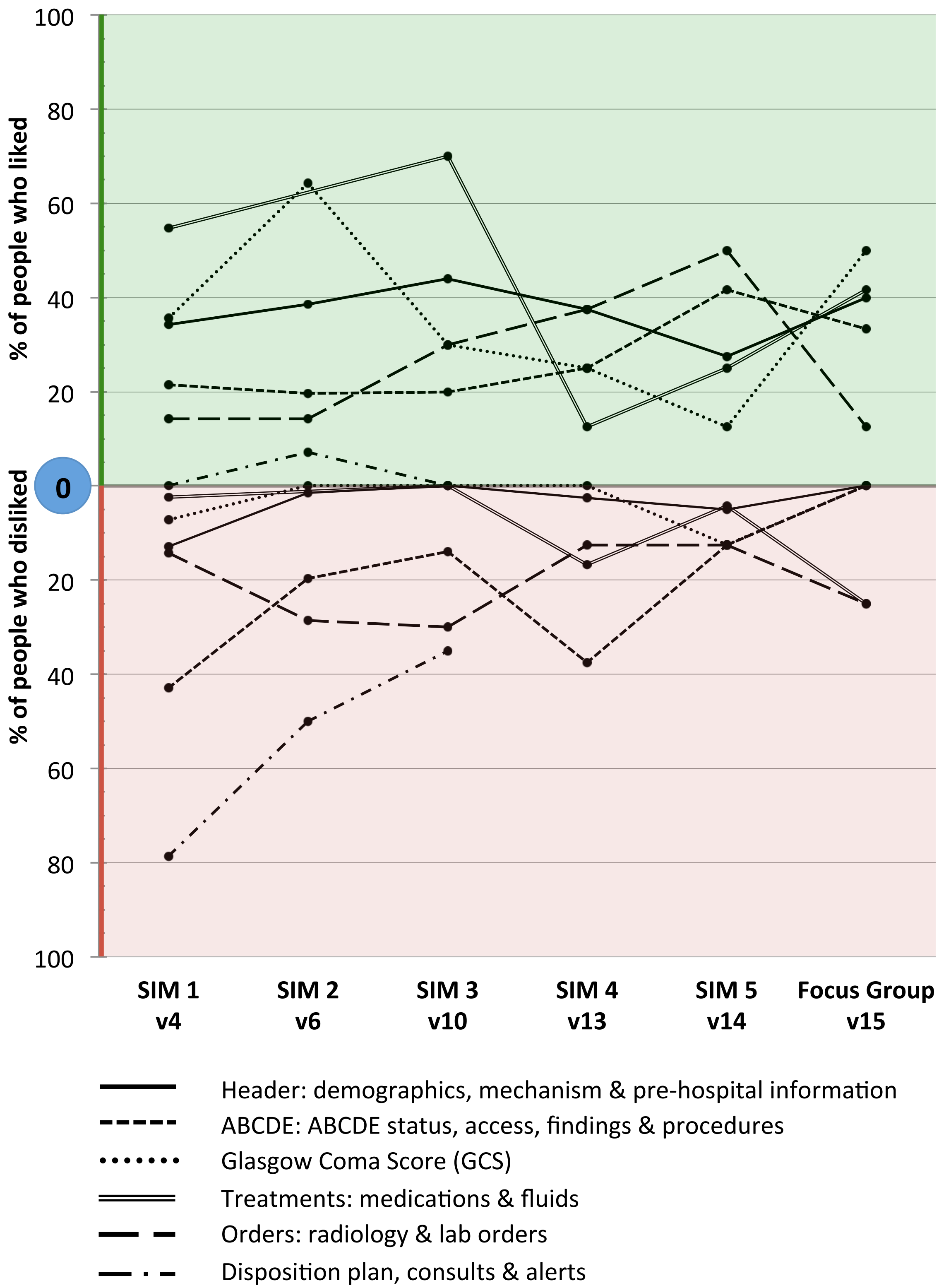


Figure 22. Evolution of participants' attitudes toward different components of the display evaluated in the first three sets of simulations.

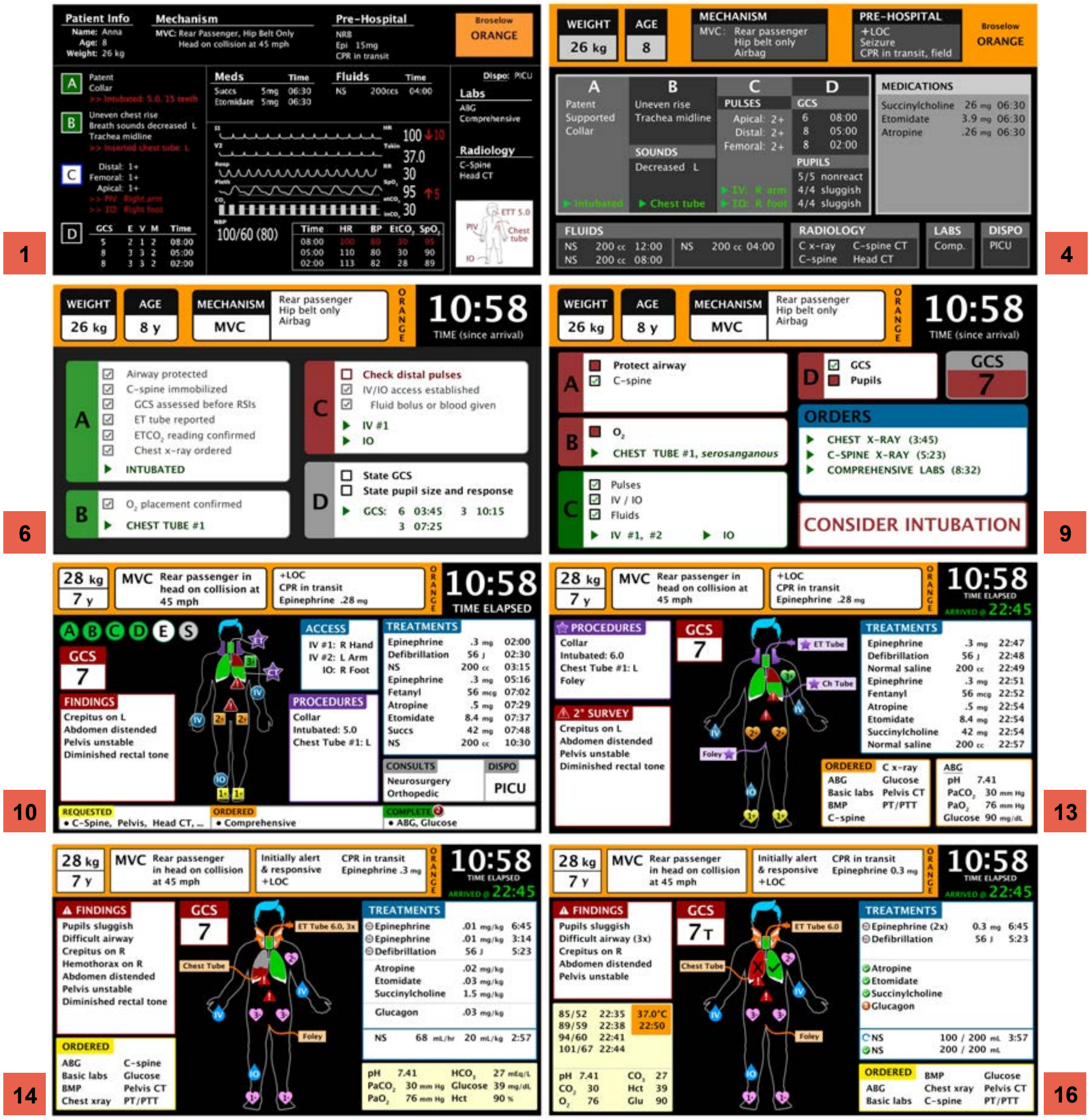


Figure 23. Evolution of display designs, versions 1-16.

technical solution so teams can view both vital signs and our information display. Several options were discussed, including (1) splitting the screen with vital signs and resuscitation information; (2) feeding vital sign data into a section within the information display; (3) displaying resuscitation information on the front screen for leadership roles

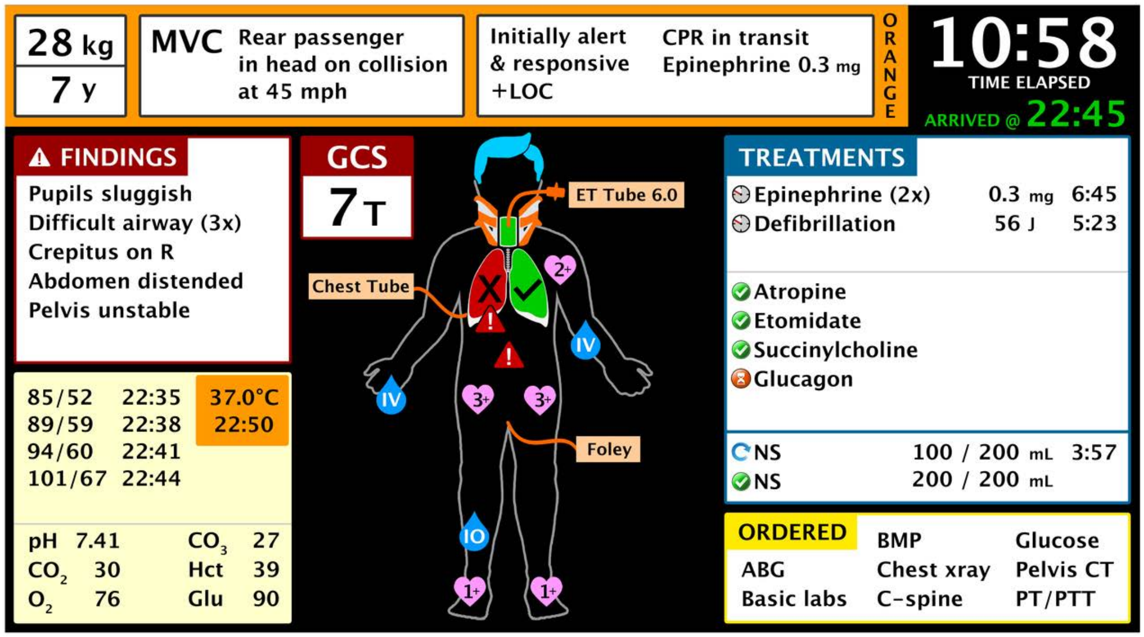


Figure 24. Final display design, version 16.

and vital signs on the back screen for the anesthesiologist and respiratory therapist; and (4) adding a second set of screens for augmenting vital signs.

6.3.3 Patient Evaluation Findings from ABCDE Protocol Steps

Information about ABCDE ranked third overall (patient evaluation findings, Table 18). Individually, all participants from both initial workshops incorporated elements of ABCDE in their designs using four methods (Table 17). The *first* method is a basic checklist of the steps: once a step is completed, it turns green or is checked off. The *second* method is a list of abnormal findings and procedures under each ABCDE step. The *third* method involves extracting the elements of ABCDE (e.g., a neurological exam score [Glasgow Coma Score], abnormal findings, and procedures) and then separating them into different display sections. The *fourth* method is an image of the body with visual representations of abnormal findings and procedures. This feature was part of a physician surveyor and an EM physician's designs in conjunction with a basic checklist. A respiratory therapist's design also followed the fourth method but included abnormal findings and procedures under each step. Both groups used the second method in their group designs; the first group also added an image of the body.

We grouped these four methods into two types of information structures: (1) *process-based* (first and second methods of presenting information organized by the order of activity) and (2) *state-based* (third and fourth methods of presenting information about patient and teamwork status). After experimenting with these different ways to organize ABCDE information, we found that the state-based combination of the third and fourth methods (v10-v16, Figure 22 and Figure 23) was the most effective, as indicated by an increasing percentage of likes and a decreasing percentage of dislikes in the first three simulations (Table 18 and Figure 22). In the fourth simulation, we observed an increase in likes and large increase in dislikes, due to the to lack of clarity of the patient body icons (i.e., pulses, procedures, and lungs) and the connection between the patient body icons and the findings and procedures boxes. Percentages of likes increased and dislikes decreased significantly in the fifth simulation after improvements were made to the icons and the connection to the text boxes. A slight decrease in likes and decrease in dislikes was observed in the focus group but was probably due to a greater focus on treatments in this discussion.

The most discussion surrounding ABCDE from both participants and research team members emerged during a major shift from using a list of abnormal findings and procedures under each step (second method, v4, Figure 23) to using the checklist-driven method in versions 6 and 9 (Figure 23). Emergency medicine physicians generally did not find the information about ABCDE useful to their particular role because it relates to the responsibilities of another role (surgical team leader). A physician surveyor noted after a simulation that the checklist-driven information was not helpful because the primary survey assessment (ABCDE steps) is his main focus: with all this information already in his mind, having it on the display is distracting. A leader had similar feelings about the checklist-driven method, noting in heuristic evaluations that the display just mirrored the information from the paper checklist in his hand. Participants' notes on paper prototypes from the heuristic evaluations suggested that we could simplify each step and remove the less critical checklist items (v9, Figure 23). Scribe nurses in the heuristic evaluations and simulations suggested providing numeric values and descriptive findings to make the checklist format more useful. The checklist items were removed and converted into graphical representations of ABCDE in the form of the patient's body with a short descriptive list of findings (v10-16, Figure 23).

6.3.4 Treatments: Medications and Fluids

All participants, with the exception of a physician surveyor and two EM physicians, included treatments such as medications, fluids, and defibrillation in their individual designs. Medications and fluids were also included in both group designs. Participants responded positively to having treatments on the prototype even though medications ranked as fourth and fluids ranked as seventh most important. Despite these positive reactions, we had to remove fluids and medications in design versions 6 and 9 due to technical difficulties until we could capture and display this information accurately in versions 10-16 (Figure 23).

Participants differed in the ways they suggested treatments should be formatted (Table 17). Some did not find it necessary to have fluids on the display because it is possible to look at the physical bag to see how much fluid has been given. Some participants needed only the ordered amount of fluids or dosage of medications, while others (e.g., scribe nurses) preferred the amount that has actually been received by the patient or the time medications were administered. After reviewing this issue with participants in the second set of workshops, we decided to combine medications and fluids into one running list called treatments (v10, Figure 23). Participants in the third set of simulations responded positively to having this single, detailed list (Table 18 and Figure 22). In the fourth and fifth sets of simulations and the focus group, participants helped us to make detailed adjustments to the treatments section: it evolved first into partitions for time-sensitive treatments, intubation medications, other medications, and fluids (v14, Figure 23) and then to time-sensitive treatments, all other non-time sensitive treatments, and fluids (v16, Figure 23). We observed a significant decrease in likes and increase in dislikes in the fourth simulation (Table 18 and Figure 22) most likely due to our decision to use absolute time for administration time. After changing absolute time to elapsed time, we saw slight improvement in positive perceptions in the fifth simulation and a significant increase in likes in the focus group. There was an increase in dislikes as well, however, but this was probably due to the focus of the discussions on fine tuning the treatments section and asking participants to use the stickers to indicate their points for discussion. Their comments were minor, suggesting that dosages and fluid rate should be removed for a cleaner display.

6.3.5 Laboratory and Radiology Orders and Results

Participants needed a way to manage their orders and results for laboratory ("labs") and radiology studies, ranking this information as sixth. Information about lab orders made it to only one group's design. There were, however, different perceptions about the ways in which this information should be configured on the display (Table 17). The design evolved from separate lists of radiology and lab orders (v1-5, Figure 23); to a combined list with timestamps when ordered (v6-9, Figure 23); to a scrolling list divided by status of requested, ordered, and completed labs (v10, Figure 23); to a final small list of orders with a separate section with lab results (v11-16, Figure 23). In the first three simulations, participants were not very receptive of the way orders were presented with a decrease in likes and increase in dislikes. In the fourth and fifth simulations, likes started to increase when we included lab results. It appears that in the focus group likes decreased and dislikes increased, but their comments were minor, suggesting that we remove the metrics for results for a cleaner display).

6.3.6 Summary

While there was general agreement on the information features that should be included on the display, there were several role-based differences in how participants wanted each information feature to be displayed and the types of content presented for each feature. Eight categories of information features were determined through clinicians' rankings of perceived importance. The evolution of each information feature was analyzed to understand the changes in clinicians' attitudes toward the ways in which each feature was presented and to provide the rationale for redesign choices. Toward the end of the design process, when we could focus on more fine-grained aspects of the display, we were able to articulate the role of temporality in trauma resuscitation and refine the time-related features of the display. In the next section, we discuss the nature of temporality and how the display design was developed to address temporal awareness.

6.4 Role of Temporality in Trauma Teamwork

The main aspects of the display design began to stabilize after version 10, which allowed us to review our designs and experiment with different representations of temporality in the simulation setting. Elapsed time was identified as one of the features of trauma teamwork requiring support for keeping track of tasks and team progress. Building on this finding, we further examined how trauma resuscitation teams (a) experience and perceive time, (b) construct their own time-keeping mechanisms, (c) communicate temporal information, and (d) respond to different presentations of temporal information. As an outcome of this process, we defined three types of time-representation techniques to facilitate the design of time-based features in time-critical, collocated teamwork: (1) timestamps based on absolute time, (2) timestamps relative to the process start time, and (3) time elapsed since task performance.

Temporal awareness is central to time-critical teamwork. Teams must analyze and maintain awareness of information according to various time dimensions that range from individual task duration to overall resuscitation duration. In this section, we describe how clinicians perceive and manage their work in relation to time. We present our results in two parts. First, we describe the perceptions and experiences of time discussed in the PD workshops, simulations, and video review sessions. Second, we describe how these perceptions and experiences materialized during simulations when clinicians used the display and time features within the context of their work.

6.4.1 Experiencing and Communicating Time

A major theme that emerged from analyzing discussions, particularly from the PD workshops and video review sessions, was how clinicians experience and communicate time during resuscitation. Three aspects of maintaining temporal awareness in trauma resuscitation emerged as particularly important: (1) perceiving and representing time, (2) monitoring continuously to identify trends, and (3) conveying speed and urgency.

6.4.1.1 Perceiving and Representing Time

Clinicians' perceptions of time during these high-intensity situations are often skewed. Each person's experience of time passing is different—whether one experiences time as being shorter or longer than its actual duration may depend on the tasks one is performing. It is therefore important that teams have time presented accurately and in a way that lets them grasp it intuitively so they can pace themselves accordingly. A respiratory therapist (RT) commented in one of the workshops about how perceptions of time can be warped during an event:

> Three minutes can feel like five seconds, or three minutes can feel like three hours just depending on the situation that you're in. (Respiratory Therapist, CNMC-PDWS1)

Most clinicians agreed that the existing stopclock showing the resuscitation time is useful for their overall temporal awareness because it helps them gauge the progress of the resuscitation. An emergency medicine (EM) physician highlighted the importance of having the stopclock in the room (Figure 9(c)):

> Just starting a zero clock is important.… So it's like a stopwatch. (EM Physician, CNMC-PDWS1)

A respiratory therapist also noted the value of the stopclock in helping teams maintain temporal awareness:

> Honestly, if you tell me he showed up at 6:10, I don't remember what time I came downstairs. I'd rather just know for the minute, like when the patient arrives, "click," and now there's a running stopwatch saying we've been running for ten minutes. (Respiratory Therapist, CNMC-PDWS1)

These comments also imply that resuscitation time can be used as a feedback mechanism for assessing team performance. An entire resuscitation should be completed generally within 20-30 minutes, with the initial evaluation completed within the first 7-10 minutes (Spanjersberg et al., 2009). The amount of time necessary to complete an intervention or perform the initial survey can give the team a sense of how they are performing, so they can adjust their pace as necessary. Awareness of resuscitation time can help teams interpret their actions and progress regardless of the way they individually experience time during resuscitations.

While teams are instructed to start the existing stopclock manually upon patient arrival (Figure 9(c)), participants suggested integrating this feature into the display (Figure 9(b)). This was a plausible suggestion because team members often forget to start the manual stopclock; no specific role is assigned to this task, making this approach somewhat unreliable. Implementing a stopclock that starts automatically would help teams by reducing the cognitive load of remembering to turn on the stopclock.

Time was also discussed in the context of time-sensitive, multi-step tasks, when team members must keep track of how much time has passed since one step so they can proceed with the next step. Administering the medication epinephrine (epi) was a useful example for discussing these types of tasks because it needs to be performed every 3 minutes until the patient's status improves. A bedside nurse commented that supporting awareness of the time elapsed since epi was administered would be helpful because clinicians often lose track of time due to the hectic nature of the process:

> What does need to be on the screen is the fact that it's been three minutes since [epi], or this is the time of your RSI's [Rapid Sequence Intubation medications, which are time-sensitive]. Because the time is so skewed in the midst of all of this, you lose track. (Bedside Nurse, CNMC-PDWS1)

6.4.1.2 Monitoring Continuously to Identify Trends

Trends in patient data can also provide clinicians with feedback on the effectiveness of their treatments and the big picture of what has occurred during the event. Maintaining awareness of the status of the patient, such as monitoring vital signs, is important; but subtle changes over time can be easily missed if there is too much information and if only recent information is displayed. A bedside nurse described:

> I think the trending is important.… The most recent, of course…and then the initial maybe always needs to be up there, because we don't notice trends if they're casual.… If I'm taking a heart rate every minute, I'm only going to have room for like

> five sets [on the trauma flowsheet], so I'm not going to see a trend. I'm just going to see an increase of five, whereas maybe an increase actually of 40 from when they got here, that would be important. (Bedside Nurse, CNMC-PDWS1)

Presenting trends from a short period (i.e., 20-30 minutes) in a form useful for supporting awareness is challenging. Scribes document vital signs data on a paper flowsheet, but this information is not visible to other team members. A scribe noted that she is often responsible for alerting the team when there are noticeable changes in patient status:

> I mean, we rely so much on whoever is documenting to notice all the trends and to notice when it's three minutes from medication [epi]. But I think that other people need to also be aware. (Scribe, CNMC-PDWS2)

There are built-in alerts and functions in the vital signs monitor to help teams continuously track vital signs. These alerts and functions, however, require manual setting for individual patients and are rarely activated due to time limitations. Instead, scribes and bedside nurses monitor trends in vital signs and indicate to the team when there is a change. A scribe participating in a video review session commented:

> If you have a really good [bedside nurse], they're really keeping track because they're either hitting the button or they're the one that has set it up for "cue 5." … The good ones will keep an eye on the vital signs. Every five minutes, like blood pressures and all. (Scribe, VRS5)

Bedside nurses set timers to automatically run the blood pressure cuff, and these timers also function as reminders for the team to review vital signs. These reminders present important information for promoting temporal and task awareness.

6.4.1.3 Conveying Speed and Urgency

Conveying expectations for speed and a sense of urgency—and communicating in general—is challenging in the resuscitation context due to the pace, noise, and intensity of the trauma bay. A bedside nurse described the nature of communication during severe trauma cases as follows:

> Communication tends to be very good when kids aren't sick. They just seem to stay quiet, and then you can move slower.… It's when something, a rare event happens. Somebody needs a chest tube. Even intubating, that will throw a wrench. But the more rare opportunities hit, the more panicked the room gets, the less communication happens, and the more the occasion tends to fall apart a little bit. (Bedside Nurse, CNMC-PDWS1)

Managing tasks that are similar in urgency and priority is difficult for teams, especially when more complicated procedures such as endotracheal intubation to treat an obstructed airway dominate the team's focus, as described by an anesthesiologist during a video review session:

> The other thing is [they're] so focused on the airway now.… I would be looking up at the blood pressure, making sure my fluids were hung.… [The leader] doesn't need to wait until after intubation to hang fluids. They're not going to risk the intubation by

> just hooking up an IV.… Blood pressure was dropping, so I would've expected one of these nurses already to be hanging fluids instead of feeling for pulses and finishing taping up the IV. (Anesthesiologist, VRS1)

The relative urgency of tasks can also be lost, especially when there are competing tasks that require immediate attention. Expectations of speed can vary greatly depending on different people's perceptions of time and urgency as well as their backgrounds and work styles. The need for clinicians to specify clearly the necessary speed of tasks became apparent during a video review session when a participant described how the team leader in the video managed competing demands:

> The team leader is asking for fluids to go in as fast as possible. Well something I think he could do better would be how he wants those fluids to go in. What that means. There's a couple of ways to get fluids in fast. One is a pressure bag. But in what seems like probably a 20-kilo kid, you probably want to do a push-pull method. To be able to specify that would be better because you get [fluids] in faster that way.… Just to kind of up the ante too by "let's get fluid going through both IVs." (Emergency Medical Physician, VRS4)

It is therefore important for clinicians to specify what they mean by "fast" such as the rate at which fluids should be administered or indicate a specific time frame during which a task should be completed. Knowing how long fluids have been running and at what rate can help clinicians gauge whether the treatment is effective by monitoring the trends in blood pressure. If the blood pressure does not increase within a certain time frame, they may choose to increase the fluid administration rate, or start another bag of fluids if the patient shows no sign of improvement after the first bag.

Having learned these important aspects of experiencing and communicating time that clinicians described, we iteratively designed and evaluated the time-based features for our information display to better support temporal awareness during trauma resuscitation, as described next.

6.4.2 Supporting Temporal Awareness

We now describe how the design of the time-based features evolved during the iterative design and evaluation of our information display to support temporal awareness in the high intensity, fast-paced environment of trauma resuscitation. To illustrate this process, we review the five designs (out of 16 iterations) that were evaluated in simulated resuscitation sessions (Figure 25 and Figure 26).

In the early stages of the design, the emphasis of discussions was mainly on determining which information features to include on the display. Participants in general responded positively to the inclusion of initial time-based features such as administration times for medications and fluids (v4 and v6, Figure 25). As the design progressed through testing in a simulated resuscitation environment, clinicians were able to see how different time presentations function within the context of their work, allowing us to focus on fine-tuning specific features to support temporal awareness. We experimented with three methods of presenting temporal information: (1) timestamps based on resuscitation time, (2) timestamps based on absolute time, and (3) time elapsed after critical tasks or treatments.

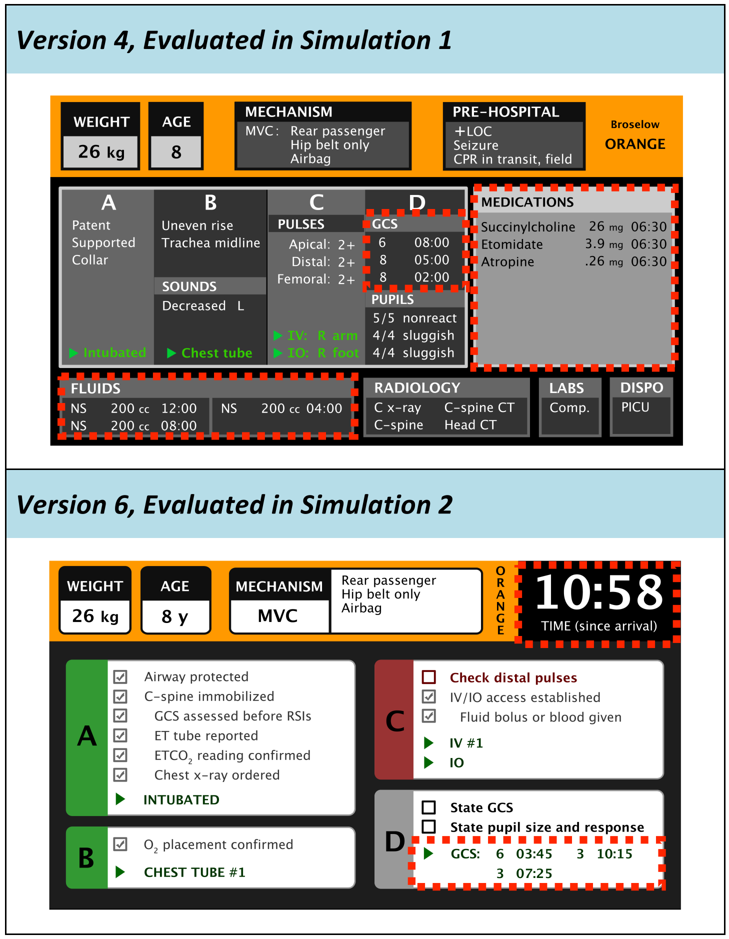


Figure 25. Time-based design features on display versions 4 and 6. Timestamps (outlined by dashed red boxes) indicate time reported or administered relative to resuscitation time.

6.4.2.1 Timestamps Based on Resuscitation vs. Absolute Time

Indicating treatments according to resuscitation or absolute time was debated throughout the design process. In the PD workshops, clinicians discussed their individual display designs in terms of timestamps for treatments, such as medications and fluids, relative to patient arrival time or absolute time (i.e., exact time administered). The first nine of 16 display designs incorporated temporal representations using timestamps for

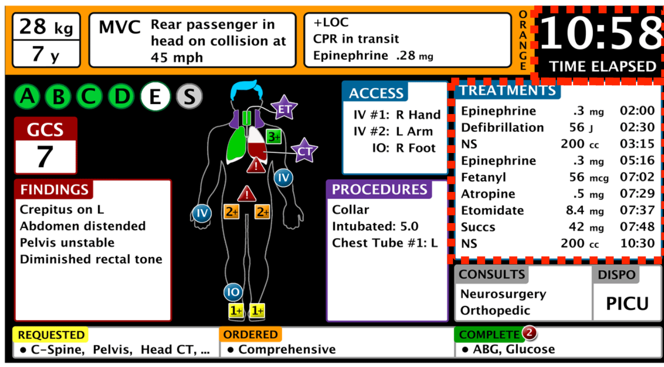
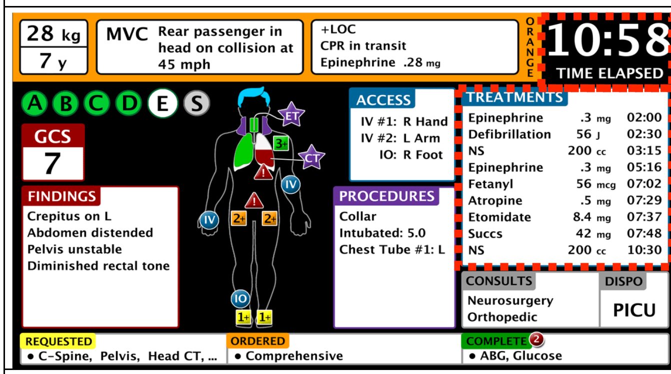
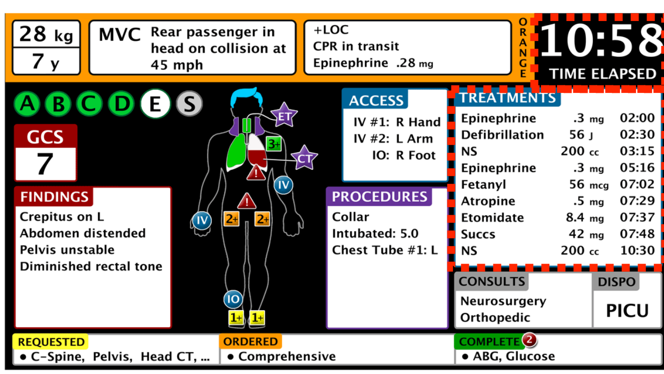
<table>
<tr><th>Design Version</th><th>Time-based Design Feature</th><th>Type of Time Representation</th></tr>
<tr><td rowspan="4">
</td><td colspan="2">Version 10, Evaluated in Simulation 3</td></tr>
<tr><td>Treatments (medications, fluids, cardiac treatments)</td><td>Timestamps based on resuscitation time</td></tr>
<tr><td>Stopclock</td><td>Resuscitation time (Time elapsed since patient arrived)</td></tr>
<tr><td colspan="2">+ Medications & fluids
+ Cardiac treatments (defibrillation & cardioversion)
– Time from Glasgow Coma Score (GCS) assessment, which indicates the level of cognitive function. GCS is assessed several times during a resuscitation. Display now shows only the most recent score.</td></tr>
<tr><td rowspan="4">
</td><td colspan="2">Version 13, Evaluated in Simulation 4</td></tr>
<tr><td>Treatments (medications, fluids, cardiac treatments)</td><td>Timestamps based on absolute time</td></tr>
<tr><td>Stopclock</td><td>Resuscitation time (Time elapsed since patient arrived)</td></tr>
<tr><td>+ Patient arrival time</td><td>Timestamp based on absolute time</td></tr>
<tr><td rowspan="6">
</td><td colspan="2">Version 14, Evaluated in Simulation 5</td></tr>
<tr><td>Treatments (medications, fluids, cardiac treatments)</td><td>Time elapsed since treatment was last administered (only for fluids & time-sensitive treatments)</td></tr>
<tr><td>Stopclock</td><td>Resuscitation time (Time elapsed since patient arrived)</td></tr>
<tr><td>Patient arrival time</td><td>Timestamp in absolute time</td></tr>
<tr><td>+ Rate of fluid administration</td><td>mL per hour</td></tr>
<tr><td colspan="2">Separated treatments: time-sensitive, intubation related fluids</td></tr>
</table>

Figure 26. Time-based design features (outlined by dashed red boxes) on display versions #10, 13, and 14. Plus and minus signs ('+' and '–') indicate the features added to or removed from each display design version.

treatments based on resuscitation time (v4 and v6, Figure 25; v10, Figure 26). The stopclock on the display prototypes started automatically when the clinician serving as the "Wizard of Oz" began inputting patient information into the display input interface upon patient arrival. Treatment timestamps for display design versions 1 through 9 were automatically recorded when the "Wizard of Oz" began inputting information about a treatment, which generally happened when a treatment was first ordered.

Although participants did not express dissatisfaction with timestamps being relative to resuscitation time in the first two simulations, conflicting views on presenting temporal information about treatments emerged in discussions starting from simulation session 3. It was confusing for clinicians to calculate how much time had passed since a particular task when looking at the timestamps while also considering the overall stopclock for resuscitation time as a reference. If they have to calculate time, clinicians prefer to do it in terms of absolute rather than relative time because they are used to working with absolute time (e.g., documentation is in absolute time). A bedside nurse noted:

> Knowing if it's been more than three minutes, you have to like do some subtraction too, right, so you have to say that it has been four minutes since the last epi, you can't just tell like how long ago it was. (Bedside Nurse, CNMC-SIM5)

Scribe nurses generally preferred absolute time because it is the standard format for recording time information on the paper flowsheet ("Should be just time it was given 'cause that's when I am documenting" CNMC-*SIM 3*) even though they also keep the team aware of time elapsed for time-sensitive treatments. An emergency medicine physician agreed:

> Yeah, so the absolute time is your reference time… whatever time you walked through the door, because if you go back and try to review, you could learn the times it was given, not how long it would take to give it. (Emergency Medical Physician, CNMC-SIM3)

Representing events according to absolute time, then, seemed to be the most straightforward way to present temporal information for tasks and treatments. We therefore experimented by using absolute time for timestamps in simulation session 4 (v13, Figure 26).

6.4.2.2 Time Elapsed Since Critical Tasks or Treatments

While some clinicians continued to value information as a log of time-stamped tasks based on absolute time, the majority of participants in simulation session 4 found it more important to have awareness of time elapsed since the previous task. For time-sensitive treatments in particular, clinicians preferred to interpret time according to the amount of time elapsed since the treatment had been completed, not as a timestamp given in absolute or resuscitation time. Participants noted that the amount of time elapsed since treatment administration would be most accurate if it were based on when treatments are actually administered rather than automatically recorded when the "Wizard of Oz" begins inputting the treatments as they are ordered. In design versions 10 through 16, selecting an "administered" checkbox on the input interface triggered the treatment administration times. As we learned through further discussion, clinicians currently calculate elapsed time based on absolute time but would prefer a stopclock feature that shows the interval since the last treatment:

> Even when we do epi, we don't say, "At minute five epi was given." We say, "Epi was given two minutes ago" based on the actual time. (Bedside Nurse, CNMC-SIM3)

Some time-sensitive medications turned out not to be critical for displaying with "time elapsed since administered" because their effectiveness wears off quickly (within a minute or so). Displaying "time elapsed since" for medications that were not time-sensitive was also unnecessary because the need for additional doses is apparent based on the patient's response to the treatment. Using this feedback, we implemented stopclocks for presenting temporal information (v14, Figure 26) and tested them in simulation session 5, the final simulation. Participants overall responded positively to using a stopclock feature instead of absolute timestamps to convey time elapsed since the last treatment. Showing time in this dynamic form (i.e., the time is counting up) proved to be an important mechanism for coordinating future tasks. As participants commented, awareness of time elapsed since the last treatment assists in managing the complexity of tasks and remembering to check whether the patient needs more medication or additional time-sensitive treatments.

We also found that having a log of all the times for repeated treatments was not necessary for planning or remembering future treatments. Given the number of treatments administered in a typical resuscitation, the list would become long—making it take longer to find the last treatment given. Most participants suggested that only the recent instance of time-sensitive treatments was important to display. A respiratory therapist commented:

> Is there any way you can roll it from the last epi instead of "having done"…when you give the next one, the other one moves off? It rolls off so then you won't have so many. (Respiratory Therapist, CNMC-SIM5)

Participants noted that this presentation would be enough to understand what the team has done and make decisions about the next step. In a future iteration, we plan to modify the display to present the count of times the same treatment was previously performed. The decision about when to administer the next dose is based on the time elapsed since the most recent dose was administered. Furthermore, the dosages are likely to be the same because they are weight-based, so there is no need to show all instances for each treatment.

6.4.2.3 Getting the Terminology for Temporal Features Right

We did not notice until simulation sessions 4 and 5 that the terminology for time features may not have been clear to participants and even to all the research team members. When discussing how to program the functionality of the display within our research team, we recognized confusion about whether the time representation for treatments (e.g., fluids and medications) would be a "stopclock" measuring time by counting *up* from zero or a "timer" measuring time by counting *down* from a specified amount of time (e.g., 3:00, 2:59…0:01, 0:00). In some cases, the term "timer" was used to describe both the functionalities of a timer and a stopclock, a problem that was discovered after reviewing transcripts, even in the initial PD sessions:

> See, like for me, I think of it more of a time of arrival or a *timer*.… I'd rather just know for the minute, like when the patient arrives, "click," and now there's a running

> *stopwatch* saying we've been running for ten minutes, we've been running for fifteen. I like the *timer* idea versus time of arrival. (Respiratory Therapist, CNMC-PDWS1)

This participant described the functionality of a stopclock and used the terms "timer" and "stopwatch." Clinicians were familiar with the idea of the stopclock at the top right of our display because it assumed the metaphor of the physical stopclock already in use.

6.4.3 Summary of the Role of Temporality

Experimenting with different methods to present temporal information on the display helped us to gain a deeper understanding of what role temporality plays in how clinicians in this context experience and perceive time, construct time-keeping mechanisms, and communicate temporal information. Timestamps based on resuscitation time caused confusion because clinicians needed to calculate elapsed time using the stopclock. Timestamps based on absolute time were preferred over timestamps showing resuscitation time but also required clinicians to calculate elapsed time using the wall clock. Timestamps based on elapsed time, especially for critical tasks or treatments, were the most efficient and understandable method of presenting time because they did not require clinicians to make any calculations. The need for defining the terminology to describe time features also became evident as a technique for reducing confusion and clearly discussing design features with participants and within our research team.

6.5 Clinicians' Concerns about Using the Display in Emergencies

Participants expressed concerns about various topics. Here we highlight four main concerns that teams perceived as directly related to awareness and the extent to which the display may affect it: (1) the accuracy and reliability of the display and data input; (2) the display's real-time adaptability to dynamic changes; (3) information overload and visibility of the display; and (4) the display becoming a visual distraction and substitute for verbal communication. These four concerns highlight the need for information prioritization and process-dependent adaptation of the display.

6.5.1 Accuracy and Reliability of the Display and Data Input Mechanism

Early in the design process, clinicians were concerned about trusting the display to support their activity awareness, about the accuracy of the person inputting the information, and about their teammate's reliability in producing the information from assessing the patient. A team leader explained:

> It would have to be completely accurate, completely reliable and never second guessed. So it depends on the recording but it also depends on who's doing the assessments—which a lot of times boils down to people who aren't as experienced as the other people who are standing and watching the whole thing, the whole resuscitation. So it'll probably take some time for everyone to believe in it completely to be able to look at it and say this is true and now I don't have to ask any more questions. It's still going to be at least in the first several weeks to months, that "Oh is that right? Is that true? It's not up there. Is it supposed to be up there? Does that mean it's negative or positive?" (Team leader, CNMC-PDWS2)

Over time, however, clinicians became less concerned with the accuracy of the display as improvements were made to the digital input interface:

> I don't have any concerns about looking at it, and you're working at how the information's gonna get put in [the display]. [Researcher: “Mainly accuracy then?”] Yeah, it's accurate. It's a lot different than when we did the [digital pen] thing and the [input] was [based on] writing. This is very clear. (Scribe Nurse, CNMC-VRS5)

This particular scribe nurse had participated in the first PD workshop and several sessions thereafter throughout the design process. Her feedback was especially helpful for reflecting on the evolution of the display design.

Initially, the main concerns about using the display had been about the technical accuracy and reliability of the display and issues with inputting data. It appeared that clinicians were also hesitant to trust the information on the display to support their awareness and coordination. These concerns were mitigated after the display design evolved and data input improved.

6.5.2 Real-Time Adaptability to Dynamic Changes

Emergency medicine physicians, physician surveyors, and respiratory therapists were concerned about the display’s ability to update or adapt to different types of patient injuries or resuscitations, as trauma resuscitations sometimes turn into medical resuscitations in which teams need to treat patients for preexisting and chronic illnesses. Teams must reassess each patient’s status throughout the resuscitation, and information captured three minutes earlier may no longer be accurate. The display would need to help clinicians dynamically update their activity and process awareness in changing clinical scenarios, as this emergency medicine physician described:

> If a trauma turns into a medical resuscitation, [the display] needs to be an adaptable screen that can now become support for the [medical alert]. (Emergency Medicine Physician, CNMC-PDWS1)

Teams follow a similar protocol when responding to medical alerts called the Advanced Life Support (ALS, or PALS for resuscitating children) protocol (Ludwig & Lavelle 2011). While medical alerts are similar to trauma resuscitations, they are more complex because teams must treat underlying medical causes (e.g., cardiac arrest or seizure) that can complicate the dynamics of the patient's illness. Designing the display to adapt to medical alert scenarios is beyond the scope of this research and would require a new design process that could be considered in future research.

Participants also expressed concerns about the mechanics of how the information will be updated, the efficiency of updating information, how often the information will refresh, and whether there will be a time delay. Any of these issues could delay clinicians' ability to update their awareness. As a bedside nurse described, the display should dynamically adapt to the severity of the patient's injury:

> Is it feasible to say that this [display] could change depending on the patient? And so as a [scribe], if it's something that was important to this patient, there would be a box I could hit that says "display"? … If I had a kid that was very routine, maybe just some routine stuff went up on there…. If it was a kid who was much sicker… we could say, "Let's display this, it's important for people to know." (Bedside Nurse, CNMC-PDWS1)

This design suggestion further implied that clinicians should still have control over which information to display and when it is displayed to be most useful for supporting their awareness.

There was also the question of how fast the display could respond. After using the display in the third simulation session, a respiratory therapist commented on the need for rapid responsiveness, especially in situations that require the team to act quickly:

> I just want to see it in like a real trauma…something that's fast moving. [A patient is] coding and how fast [the display] would work. That's absolutely critical. (Respiratory Therapist, CNMC-SIM3.1).

As previously discussed, how fast the display can adapt to a new scenario might actually depend more on how quickly the designated clinical expert acting as the "Wizard of Oz" can input information rather than the technical abilities of the display. Training clinicians on how to articulate information and training the "Wizard of Oz" on how to input information effectively is therefore essential. The "Wizard of Oz" role is fundamental to not only to the dynamic functionality of the display, but also to the other team members' trust of the information being displayed.

6.5.3 Information Overload and Visibility of the display

Participants were concerned about encountering information overload if the display design were cluttered with too much information. They felt it would be difficult to make critical information stand out on the display without causing "alert fatigue." The use of images was also related to visibility: if images are used in the design, they must be large enough to be useful, such as x-ray and scan results or an image of the patient indicating where tubes, lines, and drains are placed. Those in leadership roles were particularly concerned about the visibility of the information:

> If you put too much, then everything gets smaller so you can't read it and then it's messy and jumbled, and where's my information? This needs to be so simple and so convenient as to not provide too much information and get distracted on it. (Team leader, CNMC-PDWS2)

> I think simple is better in my eyes because if you get too much information in one place, then it's going to kind of distract people. Obviously, we need a lot of information, but I think trying to keep it to what we really need to know is important. (Emergency Medicine Physician, CHOP-PDWS2)

Spending time looking at the display because there is too much information to sift through or because it is too small to read would take clinicians' time and attention away from the information and activities that are necessary to support their awareness.

Positioning of the display with relation to where team members normally stand in the trauma bay had a large influence on how participants discussed visibility. Respiratory therapists and anesthesiologists were particularly concerned about the location of the display and how easy would it be for them to see the display from the head of the bed. Splitting information into multiple displays was mentioned as a way of increasing visibility, but some team members objected:

> I would caution against having [the display] split up into different parts only because I feel like that makes you lose the whole picture. So even though it is helpful for the airway [anesthesiologist and respiratory therapist] to have specific things, I think it's

> still more helpful to have the whole picture so that the person at the head of the bed knows, "Oh, the blood pressure is this." I just feel like it is better or more useful to have that whole synthesis than to have split portions for different roles. (Emergency Medicine Physician, CNMC-PDWS2)

It appears that supporting the "whole picture" of the resuscitation (i.e., process awareness) and the critical information for all roles (i.e., activity and articulation awareness) is more important than splitting the display into different sections or tailoring multiple displays to support individual roles.

6.5.4 Display as a Visual Distraction and Substitute for Communication

Early in the PD workshops, both leaders and nurses were concerned that the team would become distracted by the display. This already happens with the vital signs monitor, and they worried that another type of display would introduce a new stimulus that draws their attention and awareness away from the patient:

> You have to remember, because it's a pediatric patient, there isn't much space along the bed and so you're usually relying on other people to tell you what's going on and you may not be able to see the patient as well. So you rely on the things like the screens to kind of supplement your vision as well, but you have to remind yourself to keep your eyes on the patient consciously. (Emergency Medicine Physician, CNMC-PDWS2)

Participants also agreed that the display should not replace or decrease verbal, person-to-person communication critical to social awareness—a view that has been supported by previous literature. Coiera (2000), for example, discusses two categories of building common ground: “just-in-time grounding” and “pre-emptive grounding”. He suggested that in contexts in which team actors must engage in “just-in-time grounding,” a higher amount of communication is required to establish common ground at the beginning of teamwork or a particular task. There are many times, however, when technological interventions cannot replace verbal communication. Participants worried that, if people became visually distracted by and dependent on the display, they might defer verbalizing important findings to the team that promote activity and articulation awareness:

> When they’re doing the airway, the entire room needs to shut up. And I need to know if you (the anesthesiologist) can see the airway, whether you anticipate difficulty, if you have the right equipment, because I’m going to feed that back to other people, whether it means someone runs out to go get a correct tube, or I’m telling the medication nurse we’re going to drop (administer) this med instead. They are the people that I care the most about. And I don’t want any screens, any papers, anything between us. We just need to talk. (Emergency Medicine Physician, CNMC-PDWS1)

Providing information in advance for “pre-emptive grounding,” as suggested by Coiera (2000), can reduce the costs of future grounding. In the case of team members who come later, the display can act as a pre-emptive measure to reduce the need for redundant verbal communication about such matters as pre-hospital information and patient demographics.

In the second simulation sessions, a respiratory therapist voiced her concerns about less-experienced clinicians also relying on the display to update their awareness or becoming preoccupied with what information is (or is not) on the display:

> I think people are gonna rely on it. Well, I guess if you say inexperienced people, they may be looking at that and not concentrating on what they have to do. And they're gonna be so worried about, "Is that checked, oh you didn't check that, or that's not highlighted," instead of looking at the patient and seeing what's going on. (Respiratory Therapist, CNMC-SIM2.1)

Similarly, an emergency medicine physician noted that clinicians who do not use the display often might find it distracting from consulting important sources of information to update their awareness:

> In some ways it's a little bit of a concern for anyone who doesn't use it frequently enough.… It's a distractor, in many ways, from what we actually should be looking at, in terms of clinically assessing the patient, other than the [physical] exam.… It's easy to miss that vital signs are changing when everybody's focused on [the display]. (Emergency Medicine Physician, CNMC-SIM4).

Familiarizing clinicians with the information they can expect to see on the display through training could help reduce the risk of the display becoming a distraction.

6.5.5 Summary of Concerns

Clinicians expressed four main concerns about using the display in real trauma resuscitations and, as a result, we concluded several things. First, it is most important that clinicians trust the accuracy of the display and how the data is input to support their awareness. Second, the display should adapt to real-time to dynamic changes in the situation and be positioned to maximize visibility to all team members. Third, clinicians' concerns about becoming distracted and overloaded by the information on the display argues for design measures that can alleviate these potential problems. Finally, clinicians' concerns that team members would become reliant on the display and start replacing verbal communication necessary for articulation awareness to coordinate teamwork argues for the necessity of training to use even the most "intuitive" displays. Examining clinician concerns allowed us to understand how to design the display and to develop questions to elicit feedback about the display. Eliciting clinician concerns about the potential effects of the technology in real resuscitations was also important for understanding the barriers to system appropriation (Czeskis et al. 2010; Denning et al. 2010; Miller et al., 2007).

6.6 Summary of Findings

The knowledge we gained about the domain and clinician needs helped us to develop a final prototype that will be implemented "in the wild" during the summative evaluation phase of this research. Our findings showed that, in this context, awareness is ongoing and dynamic—emerging from the tasks performed, patient response, and information coming from various sources. As we described earlier, the need for patient data and pre-hospital information, vital sign data, and information about medications and fluids also confirmed the observations of real resuscitations reported in Sarcevic and Burd (2008). Coordination issues that arise from having multiple clinicians leading a trauma resuscitation team and the lack of strong social awareness of the roles present in the trauma bay confirmed previous observational studies of leadership structures (Sarcevic et al. 2011a) and coordination among roles (Sarcevic et al. 2011b). Similarly, prior work also identified the challenges in information retention (Sarcevic and Burd 2009). These previous studies, however, were limited in that we could see only what information or issues were emerging from the process.

We were able to elicit the details and examples of how clinicians want information to be presented through clinicians' sketches, feedback on paper versions of the display, and discussions throughout the design process. For example, we had known from previous studies that trauma team members need information about medications, but we did not necessarily know the specifics of how to address this need through design—the order in which medications should be displayed, the format to use for dosages, and the kind of time representations to use. Iteratively developing the display with clinician feedback also demonstrated the importance of the role of temporality in teamwork, as initially found through the PD workshops. We experimented with the ways in which designs can be developed to support temporal awareness and identified the most efficient and easily perceived time representations for users in this setting. The debates that came out of the PD workshops helped us determine the similarities and differences in how representatives of each role wanted information presented and then to reach a preliminary design that addresses the greatest needs for all roles. Most of the clinicians' main concerns emerged through content analyses of clinicians' post-it notes with concerns and thematic analyses of discussions throughout the design process. The concerns clinicians expressed also highlighted the challenges of the space, indicated the expectations for the display design, and provided information about how the display would impact their work.

PD and user-centered design techniques used in this research added new insights by allowing us to obtain contextualized examples of awareness needs, to gain a deeper understanding of users' concerns in relation to their work, and to brainstorm the specific design solutions that can address their needs. PD techniques played an important role in eliciting the nuances in the similarities and differences in awareness needs of team members by providing the structure for collaboratively addressing design issues with clinicians. Although there are differences in institutional norms and practices, as well as in perceptions about awareness among roles, we found little variation in perceptions within roles across institutions.

There were several benefits to conducting both content and thematic analyses. Content analyses of artifacts from the design process (i.e., clinicians' sketches, post-it notes with concerns, and feedback on paper versions of the display design) allowed us to gain both qualitative and quantitative perspectives on participants' perceptions. In the early stages of design, detailed content analysis of the information features presented on individual and group designs and the individual rankings on group designs allowed us to identify the most important information features overall and by role. Further analyses of how participants conceptualized he different information features served as the basis for how we designed each information feature. Through content analyses of design feedback, we were able to identify quantitative trends in participants' attitudes toward the display designs over time. Breaking down analyses by sections of the display helped us to further analyze how each section was received by participants in relation to the changes made to the different information features within each section.

Conducting thematic analyses enabled us to extract themes from discussions and to draw connections across a diverse set of data collected using different methods. Through thematic analysis, we identified the features of trauma teamwork that require support; that information served as part of the foundation of the display design early in the design process. We were able to form narratives around the patterns of role-based differences in needs regarding the information features of the display that we found through content analysis. Similarly, while content analysis helped us to identify the main concerns clinicians have at the beginning of the design process, we were able to build richer descriptions of each concern by employing thematic analysis and drawing on quotes from clinicians throughout the process. Most importantly, examining the corpus of data using thematic analysis revealed the nature of awareness, particularly temporal awareness in this context.

In the next chapter, we discuss the overall outcomes of this research and its contributions to the understanding of the awareness of teams in *ad hoc*, collocated, interdisciplinary, emergency contexts.

CHAPTER 7: DISCUSSION

7.1 Overview

This research makes three main contributions to understanding and designing for awareness support in CSCW, HCI, and healthcare. First, we provide insights into several facets of awareness from the CSCW literature that trauma resuscitation teams must manage. We extend these facets of awareness by providing contextualized examples of what awareness means to *ad hoc*, collocated, and interdisciplinary teams in emergency settings. Second, based on clinicians' designs and role-based needs, we discuss the design considerations researchers must make when designing displays to support awareness in similar domains with *ad hoc*, collocated, interdisciplinary, and urgent characteristics. We particularly focus on how we designed the display to support temporal awareness, which naturally emerged as the most salient facet of awareness due to the nature of time-critical teamwork. Third is the description of two design tensions emerging from the design process in this setting that we managed using techniques from PD and user-centered design: process-based versus state-based design structures and role-based versus team-based displays.

7.2 Insights into Awareness from the Perspective of *Ad Hoc*, Collocated, Interdisciplinary Teams in Emergency Settings

Our findings suggest that clinicians manage four facets of awareness at the team level in order to coordinate their work during trauma resuscitations. These four facets can be mapped to the existing facets found in the CSCW literature as follows: (1) *overall progress awareness* (i.e., process awareness); (2) *team member awareness* (i.e., social and spatial awareness); (3) *teamwork-oriented* and *patient-driven task awareness* (i.e., activity and articulation awareness); and (4) *elapsed* and *estimated time awareness* (i.e., temporal awareness). We extend the existing facets of awareness by offering a micro-level perspective on what these facets mean in the context of *ad hoc*, collocated, interdisciplinary and emergency medical teamwork.

7.2.1 Process Awareness—Overall Progress Awareness

CSCW literature has used 'process awareness' to describe knowing the general sequence of main tasks, tasks due next, and current status of the process (Cabitza et al. 2009a). Process awareness may take place synchronously or asynchronously over varying amounts of time depending on the context. In emergency resuscitations, teams work synchronously; but the process timeline is condensed, requiring clinicians to refresh their overall awareness of the resuscitation's progress frequently. Clinicians must aggregate their awareness of tasks, elapsed time, and other team members to gain a holistic understanding of the resuscitation at any given point in time. The team leader's main responsibility is to orchestrate the team by continually reassessing overall progress. ***Overall progress awareness*** *can thus be described as knowing what procedures and interventions have been performed, the protocol step on which the team is currently working, and what still needs to be completed to stabilize and transfer the patient* (see Table 19 for a summary of awareness facets).

Similar to Cabitza et al. (2009b), we found through the analysis of display sketches that there is a need for periodic checklists of ATLS protocol steps (ABCDE) so that the 'big picture' of the resuscitation progress is maintained at all times to support planning and dynamically managing individual tasks. Our participants also believed that

Table 19. Facets of awareness clinicians manage during trauma resuscitation.

FACET OF AWARENESS	*RELATED FACET(S)*	INFORMATION NEEDED TO MAINTAIN AWARENESS
Overall progress awareness	*Process awareness*	- Procedures and interventions that have been performed - The protocol step on which the team is currently working - What needs to be done to stabilize and transfer patient
Team member awareness	*Social awareness, Spatial awareness*	- Which roles are present, absent, or en route - Who is leading the event - Who is responsible for certain tasks - Who is available to assist with additional tasks
Teamwork-oriented and patient-driven task awareness	*Activity awareness, Articulation awareness*	- Contextual information about the patient (object of work) - Feedback information for task completion - Status and progress of individual tasks - How each task affects the progress of other tasks
Elapsed and estimated time awareness	*Temporal awareness*	- Time elapsed since the patient arrived - Time elapsed since interventions or certain tasks - Time elapsed after changes in patient status - Estimated time of the patient's arrival - Estimated time until task completion

the display could reduce unnecessary redundancies in communication increased by latecomers (Chapters 6.2.1, 6.5.4, 7.2.3). Participants discussed losing track of time and procedures completed by other team members while they were engaged in their own tasks (Chapters 6.2.4, 6.4.1.1).

Patient status can also change at any time, and teams need to be aware of when they must collectively return to a step. For example, the team might be working on Circulation (step C), but the patient's airway suddenly deteriorates. Then, all the clinicians must revise the focus of their tasks and give priority to readdressing the Airway (step A). While resuscitation protocols guide teams in delivering optimal patient care, they also make *ad hoc* work possible, despite some inefficiencies. Regardless of team members' experience working together, varied experience levels, or changing leadership, the protocols provide general guidelines of which everyone on a team has the same knowledge.

7.2.2 Social and Spatial Awareness—Team Member Awareness

"Social" and "spatial awareness" are popular concepts in CSCW studies of distributed teamwork. These concepts have been defined in previous work as knowing the availability of a person with whom a person is coordinating work (or will coordinate work in the case of asynchronous collaboration); knowing where the person is located; and knowing how the person is interacting with the space (Bardram et al. 2006; Carroll et al. 2006). In contrast to distributed teams, resuscitation teams are collocated and coordinate their work synchronously. Each person's general availability is displayed to the others and is determined by presence in the room; however, immediate availability may not be apparent due to the spatial constraints of the room and low visibility around the patient bed (Chapter 6.5.4). Social and spatial awareness in the context of *ad hoc*, emergency medical teamwork can then be conceptualized as ***team member awareness****—that is, knowing which roles are present, absent, or en route; who is leading the event; who is responsible for certain tasks; and who is available to assist with additional tasks*.

When discussing social and spatial awareness, participants in this research tended to draw a distinction between being inside and outside the resuscitation room (Chapter 6.2.5). As our findings show, most of the information that emergency medical teams need is inside the room. Teams are concerned mainly with the people in the room at the moment and which roles are missing so they can determine how to compensate. Because team membership depends on providers' availability and scheduling, there is no set group of people on a team so it is not possible, or even necessary, to know who is coming from where. The information needed for achieving social and spatial awareness outside the room is mainly about who is bringing in the patient, who is coming in to consult, and whether the next hospital unit is ready for the patient. These needs, however, emerge either initially or at the end of the resuscitation rather than during it.

For resuscitations to run smoothly, there has to be an implicit trust that everyone knows what he or she is doing, even though each team member might not know the others and their backgrounds, training, and experience. Teams do their best to introduce themselves before resuscitations; but as our participants mentioned, time to prepare is often limited and latecomers are common (Chapters 6.2.1, 6.2.2). Clinicians from the same specialization may work together on a daily basis, but only one or two people from each specialization are present during resuscitations. Unlike surgical (Bardram et al. 2006) or ICU teams (Cabitza et al. 2007; Reddy et al. 2006) that have the opportunity to develop a shared, implicit understanding of each other's work habits while working together on a regular basis or on long-term projects, trauma teams cannot rely on previously established rapport, trust, and understanding. Each time team members enter the room, they need to build common ground; each time latecomers arrive, extra effort is required to bring them up to speed. This *ad hoc* and collocated nature of the team introduces a potential risk to establishing social awareness, making it challenging to support such awareness beyond knowing the team members' roles and levels of experience.

7.2.3 Activity and Articulation Awareness—Teamwork-Oriented and Patient-Driven Task Awareness

Studies on “activity,” “articulation,” and “task” awareness in CSCW describe individuals as “displaying” their own actions and “monitoring” the actions of others so that team members can articulate their work accordingly (Cabitza et al. 2007; Prinz 1999; Schmidt 2002; Schmidt & Bannon 1992). As pointed out by our participants, resuscitation teams work in a crowded space, with team members gathering around the patient bed and having limited visibility of both the patient and other team members (Chapter 6.5.4). It may also be the case that *ad hoc* team members have difficulty monitoring each other for non-verbal cues because interpreting them accurately can be problematic without having first established rapport and common ground. Rather than continually checking for visual cues that will help them align their actions, team members rely on verbal communication (Bergs et al. 2005). Verbal communication thus acts as a mechanism for displaying actions for others as well as for monitoring others’ actions (Chapter 6.5.4). For example, a bedside nurse will display his or her actions by verbally reporting when IV access is established; the medication nurse and other bedside nurse will monitor for this verbal cue and will administer medications and fluid immediately after hearing it. When team members arrive late or leave early, especially during critical resuscitations, this verbal-coordination mechanism becomes heavily strained, potentially resulting in redundant and lost communications.

In contrast to trauma resuscitation teams, teams in contexts such as air traffic control rely more on visual cues and non-verbal communication (Schmidt 1994). While both contexts are time-critical, different kinds of teams tend to use one “mechanism of interaction” (ibid) more than another. Like air traffic controllers, trauma teams use forms of non-verbal cues and "embed cues in objects"—for example when the medication nurse places a syringe on the bed to let the bedside nurse know that a medication is ready. Trauma teams usually verbalize important information emerging from the resuscitation process such as findings from the physical examination because it is the fastest mechanism to communicate complex information (e.g., patient's breath sounds are decreased on the left lung). Verbal communication is also essential due to the limited visibility around the patient and the constant changes in visual attention and physical movement. Leadership roles and the scribe nurse standing at the foot of the bed may not always have a clear visual of the patient and must thus rely on these verbal updates. Clinicians have noted that they try to limit verbal communication to critical updates so that the team can hear the physician surveyor announce his or her findings. Bedside nurses frequently move around the room and typically have their eyes and hands busy with various tasks. The physician surveyor and anesthesiologist are relatively stationary but are usually completing tasks that require their full visual attention.

To articulate their work, trauma teams require the knowledge and awareness of many interdependent activities to complete tasks that meet the requirements of each trauma resuscitation. Furthermore, teams must actively seek, evaluate, confirm, and manage patient data and evidence to make diagnoses and decisions. Activity or articulation awareness in this context can therefore be defined as ***teamwork-oriented and patient-driven task awareness****—that is, knowing contextual information about the patient, feedback information for task completion, the status and progress of individual tasks, and how each task affects the progress of other tasks*.

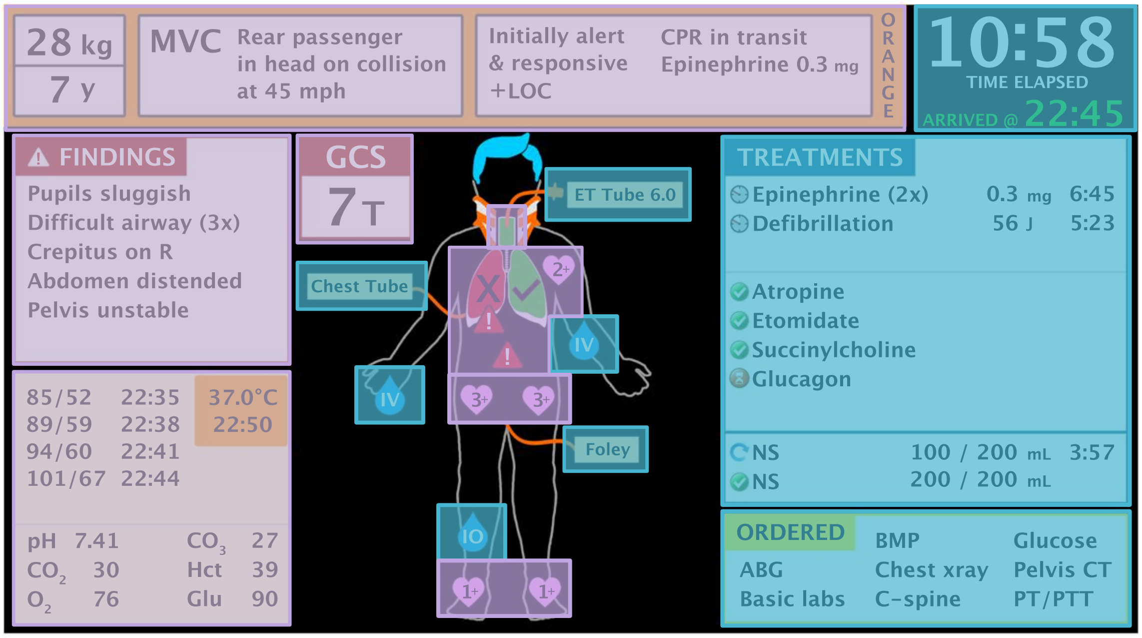


Figure 27. Teamwork-oriented (highlighted in blue) and patient-driven (highlighted in purple) elements of the final display design.

7.2.3.1 Teamwork-oriented information

Teamwork-oriented information provides awareness of task status, progress, and interdependency (Figure 27). Teamwork during the intubation procedure is again a useful vehicle for illustrating the complexities of coordination and the types of awareness information needed to support the activities. To proceed with intubation, the anesthesiologist needs to know when intubation medications are administered by the bedside nurses; the bedside nurses need to have IV access ready and know when the medication nurse has medications; the medication nurse needs to know which medications to prepare from the anesthesiologist; the anesthesiologist needs to decide together with the team leader and emergency medicine physician whether to intubate; and the team leader and emergency medicine physician need to know the status of the patient's airway and breathing, a finding reported by the physician surveyor.

The status and progress of each of these tasks are currently conveyed through verbal reports; if the reports are missing, team members inquire until hearing them. Although some non-verbal "displays" of these actions occur (e.g., if near the patient, a person can see an IV line on the patient's body) the actual status of an action may not be clear until confirmed by a team member (e.g., the IV line might be visible but malfunctioning). Verbal communication helps clinicians articulate their work by providing updates to team members' awareness about task progress—allowing them to determine the necessity, priority, speed, or timing of their actions.

7.2.3.2 Patient-driven information

The patient is a critical source of information and feedback in medical work. Patient-driven information provides awareness of the context and requirements of tasks. Our previous research on how trauma teams use vital signs monitors has shown that maintaining awareness of feedback about the patient's status is critical to making decisions and evaluating the effectiveness of treatments (Kusunoki et al. 2013; Chapter 4). Contextual information provides background about the patient, including patient demographics, mechanism of injury, pre-hospital interventions, and pertinent medical history (Figure 27); it also serves as the base on which subsequent, emerging information builds. Feedback information includes real-time vital signs and trends and results from patient evaluation, labs, and imaging studies (Figure 27).

It is important for clinicians to see not only what the team is doing in response to the patient's needs but also how the patient is responding to the treatments and procedures performed by the team (Chapter 6.2.3). For example, feedback such as dropping blood pressure can allow a team to identify that an IV line is malfunctioning and resolve the issue. Patients' statuses change throughout the resuscitation, requiring clinicians to adapt their care dynamically. Even factual information such as patient age or weight can vary, as EMS reports en route to the hospital or during handover sometimes contradict those of the patient or a family member.

Changes in both contextual and feedback information highlight the fact that awareness in trauma resuscitation is ongoing and dynamic (Chapter 6.5.2). Most participants sketched patient-driven information as a persistent section on their displays with contextual information on the top for at-a-glance viewing and feedback information at the center or right side for dynamic, real-time monitoring (Figure 20 and Figure 21). Contextual information and feedback help clinicians (1) to refine their diagnoses of illnesses and injuries, (2) to make decisions about which tasks to perform and how, (3) to monitor the patient's response to treatments and procedures, (4) to evaluate the effectiveness of their actions as they occur, and (5) to decide to continue their actions when receiving positive feedback or to revise their actions when observing negative outcomes.

7.2.4 Temporal Awareness—Elapsed and Estimated Time Awareness

'Temporal awareness' of past, present, and future actions during synchronous and asynchronous collaborations is particularly crucial in medical work (Bardram 2000; Reddy et al. 2006), as our findings have also confirmed (Chapter 7.3). Time and temporal awareness in the CSCW literature are discussed mainly in relation to schedules, rhythms, patterns, and cycles that span hours, days, or months (Bardram 2000; Carroll et al. 2006;

Reddy & Dourish 2002; Reddy et al. 2006). Although clinicians in the emergency resuscitation setting are also concerned with synchronous communication and coordination, the aspects of temporal awareness previously discussed in the CSCW literature may not become relevant until the end of or after the resuscitation. Team members nevertheless face the challenge of coordinating work under significant time pressure because their objective is to stabilize patients as quickly and safely as possible.

The need for awareness of past, present, and future actions is thus situated within the condensed timeframe of minutes and even seconds. ***Elapsed and estimated time awareness*** *in emergency medical settings can therefore be considered as knowing the time elapsed since the patient arrived, time elapsed since interventions or certain tasks, and time elapsed after changes in patient status, estimated time of the patient's arrival, and estimated time to complete tasks*. The *ad hoc* aspect of resuscitation teams makes awareness of elapsed time especially important because latecomers must synchronize their awareness of the tasks and overall progress of the resuscitation with the rest of the team (Chapters 6.2.1, 6.2.2). Time is also a universal metric by which team members can gauge their activity and overall progress, even though they might not have previously worked together. Information technologies to support elapsed and estimated time awareness are currently limited to the stopclock, requiring clinicians to estimate or calculate elapsed time for a particular task based on the difference in the absolute time and the time the task was performed as recorded by the scribe.

Elapsed and estimated time awareness is used for synchronizing tasks, especially those that are sequentially dependent (Chapters 6.2.4, 6.4). For example, certain medications need to be administered before intubating the patient; but the anesthesiologist must complete the intubation within three minutes or the medication will lose its efficacy, requiring a new round of medications. This task interdependency in turn requires close coordination between the anesthesiologist and the nurses who are preparing and administering medications. Each part of the task needs to be completed not only in the correct order but also in a timely and efficient manner. Elapsed time awareness is also important because certain procedures and orders require extra time to prepare and perform that must be taken into account. Finally, awareness of elapsed time combined with vital signs feedback such as dropping oxygen saturation over time can allow clinicians to recognize subtle changes in patient status that could result in clinical errors and to react accordingly (Chapter 6.2.3).

Estimated time awareness is important for coordinating tasks as well. Clinicians are usually notified of approximately how much time they have before a patient arrives with an initial report of the mechanism of injury, allowing them to prepare any instruments or medications that might be necessary (Chapter 6.2.2). Estimating the amount of time to complete tasks also helps clinicians with multitasking and coordinating their activities (Chapter 6.2.4). For example, after the leadership roles decide to intubate, the anesthesiologist will prepare the necessary instruments with the knowledge that it will take a few minutes for the bedside nurse to finish preparing IV access (if it is not already completed), the medication nurse to prepare medications, the other bedside nurse to administer medications, and a few seconds for the medications to take effect. Team members usually bear in mind the estimated timespans of these kinds of task dependencies when planning and completing their work.

7.2.5 Summary of the Four Facets of Awareness Requiring Support

Four facets of awareness emerged as important for trauma teamwork and extend our knowledge about the existing high-level facets found in the CSCW health-related literature. *Overall progress awareness* focuses on the general status of the whole process on the rapid and condensed timeline of a single resuscitation. This facet of awareness can be viewed as encompassing the other three overlapping facets of awareness (Figure 28). *Team member awareness* focuses on how the collocated members of *ad hoc* teams coordinate tasks over a short time span. *Teamwork-oriented* and *patient-driven task awareness* focus on the feedback, interdependencies, and individual progress of tasks of the team—all driven by the patient's status. Finally, *elapsed and estimated time awareness* focuses on estimating the amount of time that has passed since or until major events, including the patient's arrival, interventions, critical tasks, or changes in patient status.

7.3 Designing for Awareness

Tailoring awareness support is important for creating useful information systems. One major contribution of this research is that we demonstrate how we adapted the current facets of awareness characterized in the literature to address the micro-level awareness needs of teams working in a particular context (Kolfschoten et al. 2013)—one characterized by intense *ad hoc*, collocated, interdisciplinary, and emergency teamwork. By designing and consulting with clinicians through PD workshops, we were able to (1) compare each role's perceptions on awareness and how clinicians would like to receive

Figure 28. Relationships between the facets of awareness in trauma resuscitation.

awareness support and (2) to identify concrete design strategies to manage the differences in trauma team members' awareness needs.

Because many tasks and treatments are repeated throughout the resuscitation process, it is important to provide a sense not only of what tasks have been completed (Chapter 6.2.4) but also of the current status of the patient (Chapter 6.2.3), all within a limited amount of display space. Participants' sketches and group designs showed different prioritizations of information types based on role, suggesting different preferences for the kinds of awareness each role needs to maintain (Chapter 6.3). For example, anesthesiologists and respiratory therapists cared the most about information about patient and physiological status so they could quickly assess the effectiveness of their treatments, while those in leadership roles prioritized information about the overall progress of the event. Thus, the display was designed so that both ***teamwork-oriented*** (Chapter 7.2.3.1) and ***patient-driven*** (Chapter 7.2.3.2) information was presented.

Teamwork-oriented sections of the display indicate team activities (Chapters 6.3.4, 6.3.5). A list of completed treatments, laboratory and radiology orders, and visual indicators on the image of the patient body for completed procedures support teamwork-oriented task awareness (Figure 27). The temporal features support elapsed and estimated time awareness—including patient arrival, the main stopclock for the resuscitation, and stopclock features for time-sensitive treatments. The ***patient-driven*** sections incorporate emerging, patient-driven information from multiple sources (Chapter 6.3.1, 6.3.3). The header section shows patient demographics, mechanism of injury, pre-hospital interventions, and pertinent medical history to support *patient-driven task awareness* (Figure 27). Another section with the image of the patient body with findings from the physical examination and lab results also supports patient-driven task awareness. Together, the combination of these sections supports *overall progress awareness* (Chapter 7.2.1).

7.3.1 Designing for Temporal Awareness

Presenting temporal information is particularly challenging when supporting teamwork during highly dynamic and time-critical events. In these environments, perception of time is skewed (Chapter 6.4.1); priorities change rapidly (Chapters 2.5, 6.4.1.3; Hertz & Ezer, 1997); information is easily lost in the shuffle (Chapter 7.2.3; Bardram et al., 2006); and it is difficult to identify trends as time passes (Chapters 6.2.3, 6.4.1.2). The information on the supplemental displays, especially for updating temporal awareness, therefore needs to be accessible and absorbable at a glance (Chapter 4.6.1). It is thus important to identify all the time-based features that should be used to support temporal awareness (Chapter 6.4.2) and to avoid including any unnecessary info: too much detail about tasks requires clinicians to spend time looking and analyzing the display to gain situation awareness, which can be hazardous to patient safety (Bardram & Hansen, 2010). In this section, we discuss how we identified *"time elapsed since task was performed"* as the time-based feature most suitable for supporting temporal awareness in our problem domain.

7.3.1.1 Presenting Temporal Design Features to Support Time-Critical Work

We found that using and explaining specific terminology is important for facilitating accurate and focused discussions about temporal features during display design (Chapter 6.4.2.3). Confusion and lack of awareness about time-related terminology, such as the use of "timer" and "stopclock" interchangeably, delayed our progress on developing these features. We concluded that four types of time representations can help designers facilitate both the design and discussions of time-based features: (1) timestamps relative to the start of the process (in our case, resuscitation start time, Chapter 6.4.2.1); (2) timestamps based on the absolute time a task was performed (Chapter 6.4.2.1); (3) time elapsed since a task was performed (in our case, completed treatment or evaluation step; Chapter 6.4.2.2); and (4) time until a task should be performed again (Figure 29, Figure 30, Figure 31). These techniques can be separated into *static* and *dynamic* categories of temporal representations.

7.3.1.2 Timeline-based (Static) Time-Representation Techniques

The first two techniques, *timestamps relative to the resuscitation process start time* and *timestamps based on absolute time (wall clock),* can be considered as static techniques in which temporal representations are based on unchanging timestamps to indicate fixed points on the timeline of a process (Figure 29; Chapter 6.4.2.1). These techniques require users to calculate the amount of time that has passed by mentally subtracting the time when a task was performed from the present time. Devoting cognitive resources to this task calculation makes it difficult to use the information on the display to decide what future tasks are necessary and the speed at which they should be performed (Hutchins 1995). *Timestamps based on the time the task was performed relative to the start of the resuscitation process* were confusing because they require calculating the time elapsed after a particular task by subtracting the overall elapsed time when a task was performed from the current overall elapsed time of the resuscitation process (#1, Figure 30). *Timestamps based on the absolute time the task was performed* take more screen real estate because they must include the hour even when the whole process is completed within an hour (#2, Figure 30). Screen real estate is even more limited for presenting information about tasks on peripheral displays in contexts spanning longer periods. It is important to note that clinicians in our domain still found it helpful to see the absolute time of the patient's arrival to situate their temporal awareness within the larger temporal context and rhythms of their workday (Chapter 6.3.1; Matthews et al. 2007; Reddy et al. 2002).

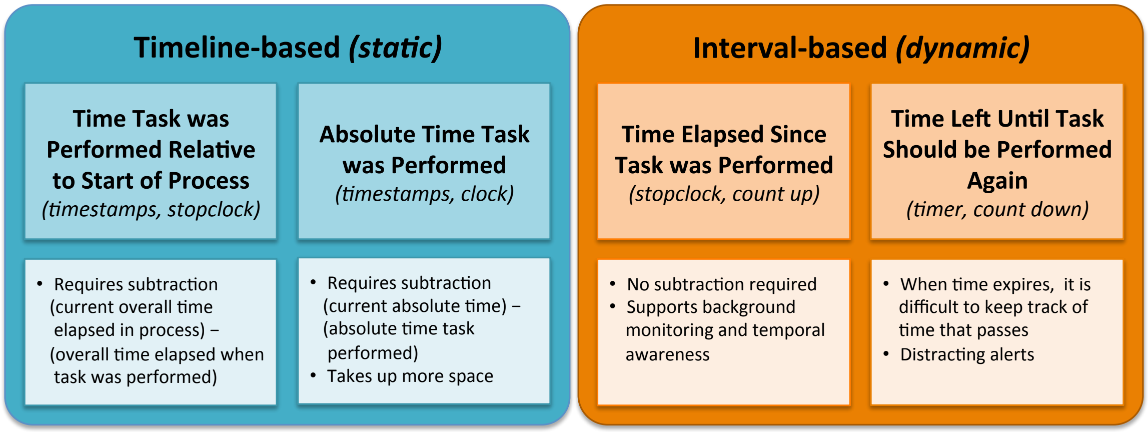


Figure 29. Four different types of time representation techniques for time-critical, collocated teamwork.

7.3.1.3 Interval-based (Dynamic) Time-Representation Techniques

The second two techniques, *time elapsed since task was performed (stopclock)* and *time left until the task should be performed again (timer)*, can be considered as dynamic time-representation techniques in which time is shown as ticking and temporal information is based on intervals between tasks or steps (Figure 29; Chapter 6.4.2.2). These techniques remove the requirement for users to calculate how much time has passed since the last task. When designing for information displays that can be used quickly, we found that using *time elapsed since task was performed* to be the most effective time-representation technique for supporting temporal awareness because it does not require any calculation and because it supports both background monitoring and temporal awareness (#3, Figure 31; Chapters 6.4.2.2, 4.6.1.1). Contexts spanning time periods longer than an hour may also benefit from this time-representation technique because it can help condense information. *Time until the next required task* is less

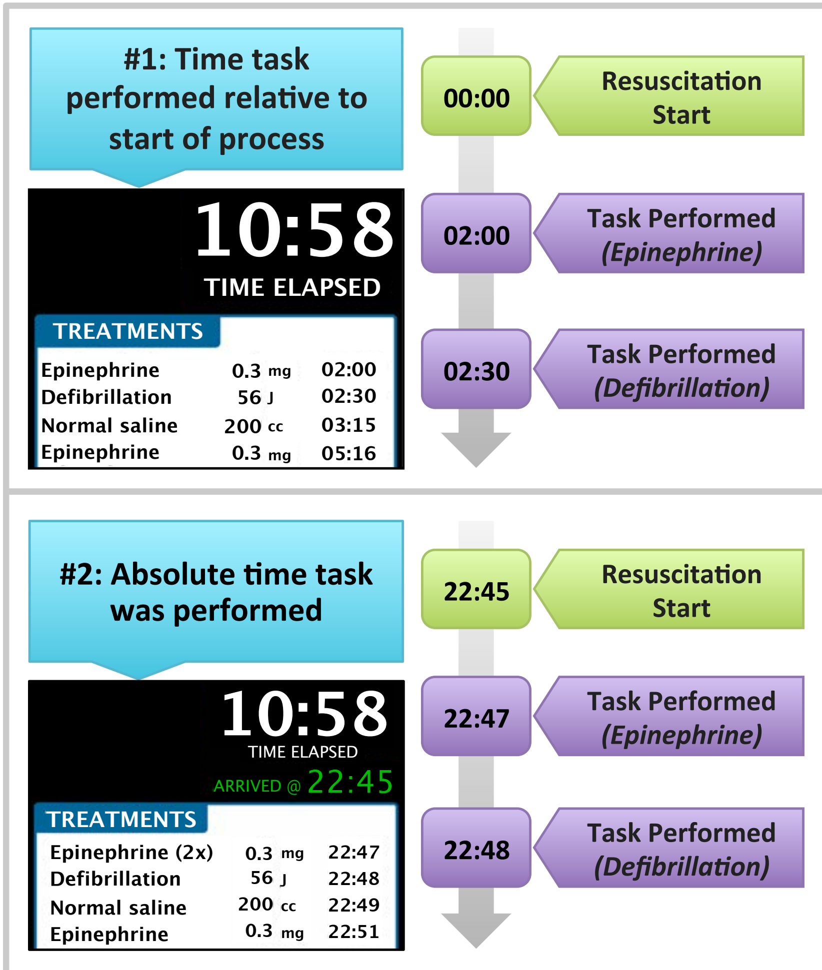


Figure 30. Calculations for timeline-based (static) temporal representations.

preferable than time elapsed because the clock stops counting when it reaches zero, making it difficult to keep track of how much time passes after it stops (#4, Figure 31). This situation could mask the difference between a few seconds or several minutes past the expiration time. A common remedy is to use periodic alerts indicating that the timer has expired, but even these alerts do not allow for time tracking. Active alerts can also become distracting or overlooked in an environment that is already noisy, hectic, and intense (Xiao et al. 2004).

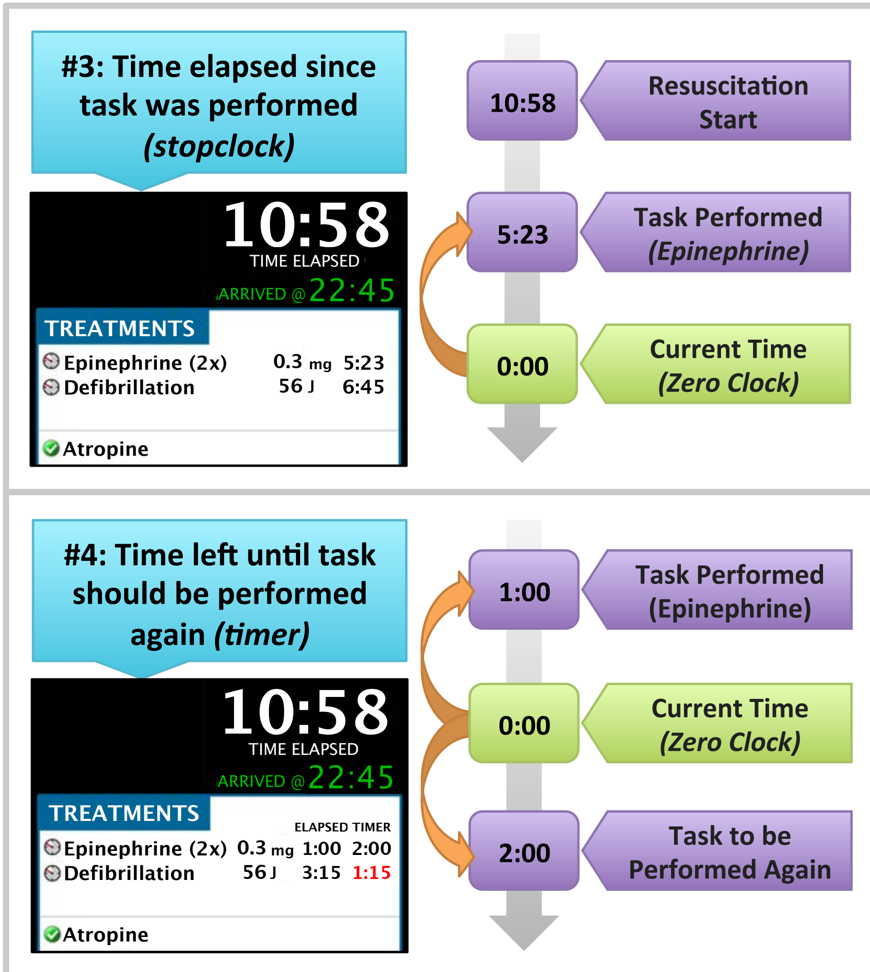


Figure 31. Calculations for interval-based (dynamic) temporal representations.

The accuracy and reliability of all four time-representation techniques depend on the mechanism (Chapter 6.4.2.1) for setting the reference points (i.e., patient arrival and task completion) by which times are calculated. Although automatic methods such as recording time upon the start of documentation by the scribe seem advantageous, there is a high possibility that they will be inaccurate in trauma teamwork. While the exact time of patient arrival is not difficult to determine, a few minutes passing between the start and end of a task can make a significant difference in temporal awareness (Chapter 6.5.2), especially for time-critical tasks. Clinical expertise is still required due to variability and subjectivity in determining when a task is actually completed. A manually selected mechanism (e.g., checkbox, button) for indicating task completion appears most feasible.

7.3.2 Summary of Designing for Awareness

The information display we designed was meant to be a tool for quick reference. An overview of critical tasks to remind clinicians of what was recently completed turned out to be more useful than a detailed log of events, as Bardram and Hansen (2010) also concluded. In our case, however, we found that time elapsed after a completed task is still helpful, but only for select tasks—time-sensitive treatments. Through multiple trials, we were able to identify "*time elapsed since task was performed*" as the most suitable time-based feature for our problem domain. We also found it was more useful to present temporal information for iterative tasks by showing the most recent task iteration and indicating the number of times the task has been performed. This presentation method saves space on the display and reduces the time needed to search through a task list. Overall, experimenting with time-based features in trauma resuscitation has allowed us to understand the fundamental differences between *static* and *dynamic* time-representation techniques. These insights may have implications for the design of information systems in other domains in which time plays a critical role in coordination.

7.4 Balancing Tensions Emerging from the Design Process

We next present the implications of two major design tensions we encountered throughout the process: ***process-based vs. state-based design structures*** (Chapters 6.2, 7.2.1) and ***role-based vs. team-based displays*** (Chapters 6.3, 4.5.3.2, 4.6.3). As we describe each of these tensions, we discuss the findings that guided our design decisions as well as the approaches we used to resolve these tensions.

The biggest design tension we observed was between using *process-based*, checklist-driven design structures that present information organized by the order of activity and using *state-based*, snapshot-like design structures that present information about patient and teamwork status (Figure 32; Chapters 6.2.4, 7.2.3). A state-based design structure was preferred because it allowed team members to observe treatment outcomes and trends in patient information.

Another design tension was between creating individual, *role-based* displays that suit the needs of each role and creating a *team-based* display that meets the needs of all roles as a team (Chapter 6.3). A team-based display design was preferred, but required methods for reducing biases toward any role due to the interdisciplinary and hierarchical nature of trauma teams.

7.4.1 Process-Based vs. State-Based Design Structures

The biggest tension we encountered was between using process-based and state-based design structures. The design evolution of the ABCDE section demonstrates this tension well, as it moved from a process-based to a state-based design structure (Chapter 6.3). Our ***process-based design structures*** follow a checklist-driven style and present information organized by the order in which ABCDE process steps are performed. In design versions 1 through 9 (Figure 32 and Figure 33), information was presented under each step, and the ABCDE layout was used to represent the progression of the resuscitation process. Our ***state-based design structures*** (Figure 32 and v10-16 in Figure 33) present a snapshot of the system's state, organized by the type of information

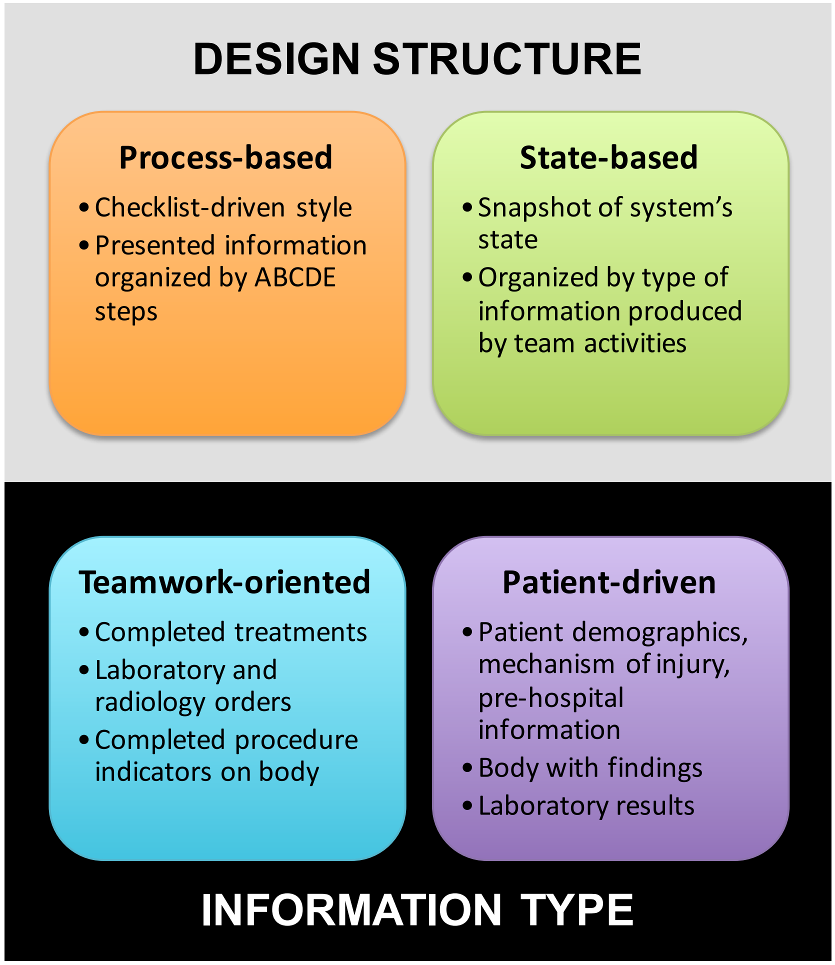


Figure 32. Design structures and information types tested. Most successful combination was a state-based design structure with patient-driven information.

produced by team activities (i.e., findings, procedures, pulse levels, and intravenous access) and their location on the patient's body.

Both process-based and state-based design structures present information that is ***patient-driven*** (findings and values of the patient's physiological condition) and ***teamwork-oriented*** (indications of whether the team has performed specific tasks) (Figure 32 and Figure 34). Process-based design structures have more teamwork-oriented information and state-based designs have more patient-driven information. Our final display design evolved into a state-based design structure with patient-driven information.

While other researchers discussed design tensions in terms of assumptions about feasibility (Gutwin & Greenberg 1998), we learned about design trade-offs through experimentation. In doing so, we found an effective combination of design approaches that suited the nature of teamwork in the resuscitation context and provided concrete, contextualized examples of why certain design directions did or did not work. Versions 1-5 in Figure 33 had process-based and state-based design structures with a mixture of patient-driven and teamwork-oriented information in our research context. Versions 6-9 have more of a process-based design structure and presented teamwork-oriented information. Finally, version 10-16 had more of a state-based design structure with a mixture of patient-driven and teamwork-oriented information. We next describe the nature of each combination and the responses we received during evaluations.

7.4.1.1 Process-Based Design Structure and Patient-Driven Information

The ABCDE feature of the first two main designs (v1-v5) was process-based (Figure 33), showing patient-driven information (Figure 34). We tried this configuration first because it was the most prominent in individual and group designs. Each section of ABCDE had a list of both normal and abnormal findings in the order reported by the team. At the bottom of each section, we included a list of completed procedures, which participants preferred in the first set of simulations (Chapter 6.3.3). With this layout, however, participants concluded that the display was cluttered and unfamiliar because it was difficult to find information (Chapter 6.5.3). Several participants noted that the display was not dynamic in that the information did not appear like it would immediately

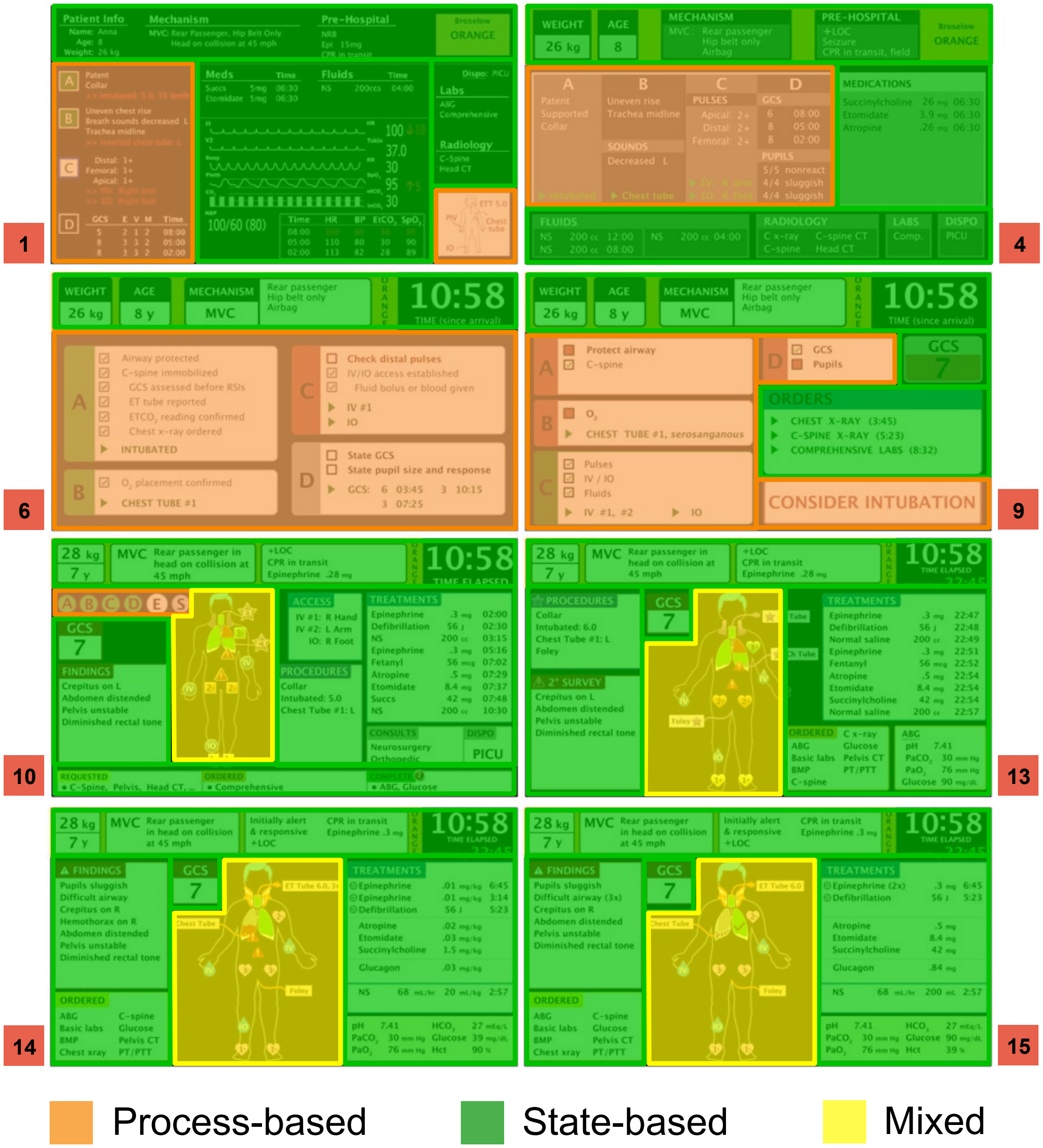


Figure 33. Evolution from a process-based (v1-9) to state-based (v 10-16) design structure. Process-based elements shown in purple and state-based in blue.

update when the status of the patient changed or when the team reassessed the patient (Chapter 6.5.2). More was needed to make the display useful than just duplicating the information that teams gather while performing each step.

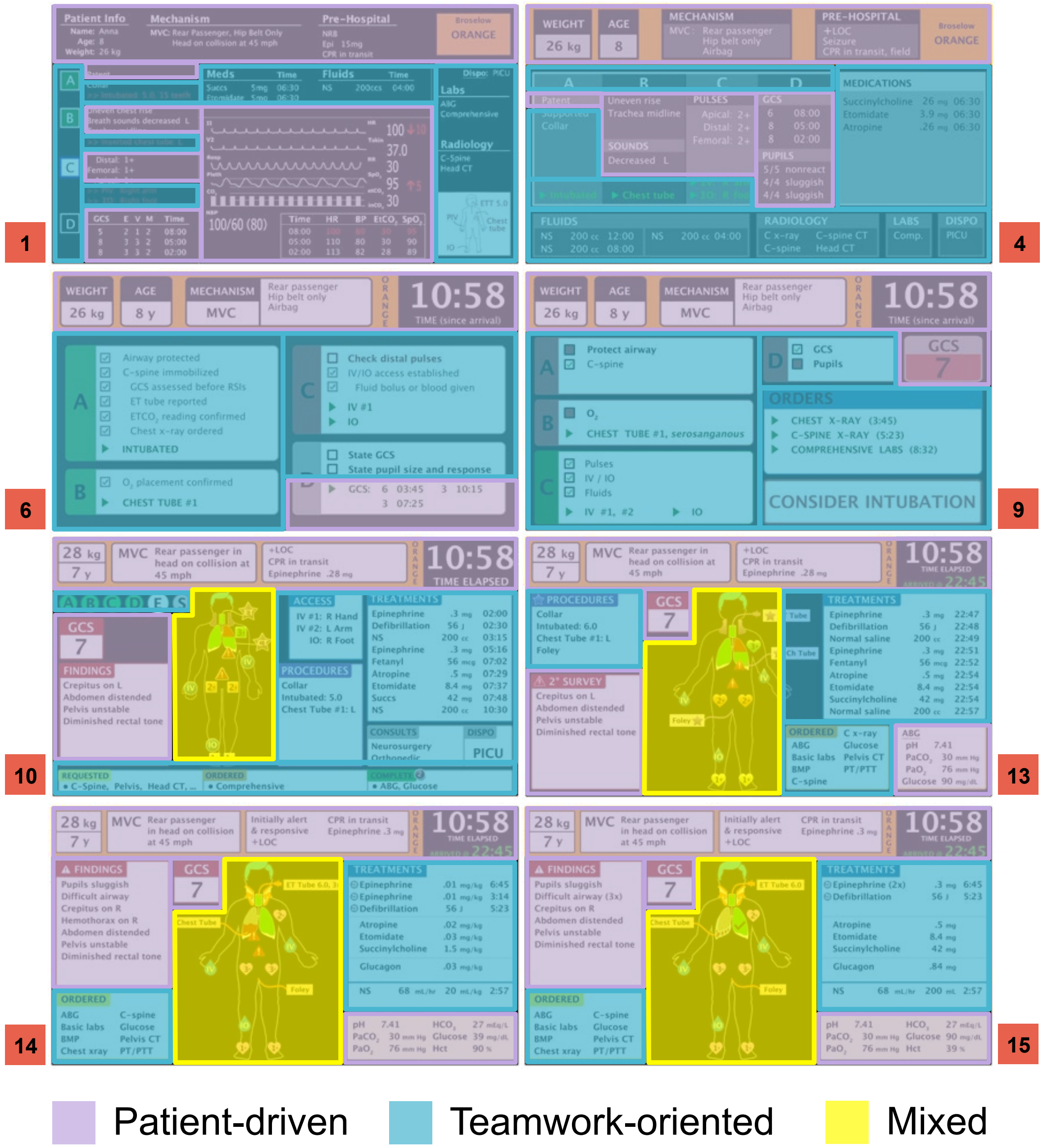


Figure 34. Evolution from more teamwork-oriented information to a mixture of both patient-driven and teamwork-oriented information.

7.4.1.2 Process-Based Design Structure and Teamwork-Oriented Information

We thought the display might be more useful if it presented information at the teamwork level with a layer of the leader's interpretation about the team's progress. We therefore organized the next designs (v6-v9) by evaluation steps in a process-based design structure (Figure 33). Instead of showing only normal and abnormal findings however, these designs indicated whether the team had completed a task based on the leader's checklist as teamwork-oriented information (Figure 34; Chapter 6.3.3). When all tasks from a step had been completed, the overall step letter (A, B, C, or D) turned green and the checkbox was checked. If a task was skipped, the overall step letter and checkbox turned red.

This design was much like a checklist, but it did not require a strict order of task completion. Thus, the design avoided a major limitation of activity-driven designs, which is their focus on tasks anticipated at the design stage and their inability to manage unanticipated events (Burns & Hajdukiewicz 2004). Even so, information about completed tasks was found ineffective. The problem with using this checklist-like presentation is that the human body and the resuscitation process are much more complex than a list of tasks that can be checked off just once. Patient status can rapidly change, and findings and steps checked off become irrelevant or inaccurate (Chapter 6.5.2).

Showing information linearly according to process also requires time to analyze trends (Chapter 6.4.1.2). Users wanted task status represented through the information that the task produced (Chapter 6.2.4). Furthermore, checklists are meant to catch errors in tasks that teams do routinely, which the leader at our site already does (Chapters 5.4.1, 6.2.4.4). After using this display in simulations, participants echoed that they need to see abnormal findings, laboratory and radiology results, completed procedures, and treatments on a display.

7.4.1.3 State-Based Design Structure and Patient-Driven Information

Once we gained a better understanding of how to present the most important information features, we experimented with a large image of the patient's body in the last set of designs (v10-16 in Figure 23; Chapter 6.3.3). Although we included an image of the body in the first version, it was not useful at that time because we had just started to narrow down the information to display and the image itself was too small to contain all the candidate information. With the latest designs, normal and abnormal findings were included in the ABCDE feature again, but in visual form—using images and icons to indicate the current status of the patient's airway, breath sounds, pulses, intravenous access locations, and procedures. We extracted the most liked features from ABCDE in previous designs—Glasgow Coma Score, procedures, and intravenous access—and separated them into their own sections on the display. Abnormal findings from the secondary survey were also added in a separate section marked "findings" with icons on the body showing these findings. Some participants liked the idea of using an image of the body to superimpose information graphically, while others preferred the textual lists; therefore, we kept both.

As we experimented with different display configurations, we realized that both patient-driven and teamwork-oriented information could be more accessible if we abandoned the checklist-like, process-based structure. Our most recent design (v16, Figure 24) has patient-driven information (Figure 33) within a state-based structure (Figure 34). Unlike EID-driven medical displays, which focus on patient data (Burns &

Hajdukiewicz 2004), our display also incorporates information about teamwork (i.e., status of phases, tasks, activities).

User feedback throughout the process showed that listing information according to ABCDE steps was ineffective (Chapter 6.3.3). To make the ABCDE feature valuable—after all, the entire resuscitation process centers on the findings generated from completing the ABCDE steps—information had to be grouped to allow quick access to and analysis of treatment outcomes and trends in patient information. Instead of presenting information based on the relevance to a system component (in our case, **A**irway, **B**reathing, **C**irculation, etc.) or the team's progress using checklist data, we believe that information organized into chunks showing a snapshot of the process is more effective because it allows information to be compared within a category. Our final design is independent of the current workflow practices, making the display more flexible and amenable to modifications with future workflow and protocol changes (Chapter 6.5.2). Finally, using a PD approach allowed us to design a display tailored specifically to the resuscitation setting and also to develop a template with key information features adaptable to other hospital contexts (Fitzpatrick & Ellingsen 2013; Gross 2013).

7.4.2 Role-Based vs. Team-Based Displays

The second major tension we observed was between creating *role-based displays* that individually suit the needs of each role and creating a *team-based display* that meets the main information needs of all roles as a team (Chapters 6.3, 4.5.3.2, 4.6.3). Related work discussed balancing the needs of individuals with those of the group (Czeskis et al. 2010). The tradeoffs of displaying individual rather than group activities also involve considerations of the required amount of user attention by each team member at each stage of the resuscitation process (Gutwin & Greenberg 1998). Much of discussion with participants and within the research team focused on this tension. Several considerations became apparent while developing and testing the display.

On the one hand, designing different displays for each role has its advantages and disadvantages. Role-based displays would help avoid the influence of the team's hierarchy and heterogeneity on the design to best meet each role's information needs. As we discussed previously (Chapter 6.3), different roles expressed different preferences for information types, so there is no need for a 'visible-by-all' kind of display. Given the relatively consistent positioning of roles during resuscitations, it may be possible to tailor displays to particular roles and their information and awareness needs. These displays could appear in different forms (e.g., wall displays, tablets, or wearable displays) and locations, depending on the work and space constraints around each role (Chapters 6.5.3, 6.5.4). Mounting displays tailored for each role (at least eight displays in our case), however, is not as cost- or space-effective as mounting two or three common displays mirroring the same information. Multiple displays in a small space might also introduce confusion about where to look. Further, each display would need to be strategically placed in order to maximize their utility for various team members who stand in a circular formation around the patient bed. It is difficult to design a display or set of displays that will be visible by everybody at all times. Distributing displays with different information would require clinicians to look in different directions to gather information, albeit from less disparate sources.

On the other hand, designing a team-based display that summarizes the key information also has its advantages and disadvantages. With this kind of display, team members share the same information (Chapter 6.3) to "get on the same page," and it is easier to know where to access information. This finding resonates with previous work that argued for common displays in group settings to support establishing common ground and conventions (Gross 2013; Grudin 2001; Wallace et al. 2011).

Trauma teams are collocated, but also *ad hoc*. The act of collocating from different areas of the hospital and emergency department to the trauma bay itself poses a design challenge (Chapters 6.2.1, 6.2.2). While core team members are in the same room when engaging in teamwork during the resuscitation, team members inevitably arrive late. If a role arrives late (which happens often), other roles may have difficulty managing information on multiple displays while covering the duties of the missing role. Even though team members would need displays primarily while they are in the room, team members on their way might also benefit from other forms of information display (e.g., wearable displays or displays in other departments) that would allow them to focus their attention and update their awareness before arriving (Chapter 6.2.1). The other aspect of *ad hoc* team formation is that, even though clinicians must work closely with one another in the same room, team member composition is continually changing, making it difficult to allow individuals to customize shared displays in the room to suit their needs and preferences (Chapter 6.2.2).

Team-based displays have been proposed in other safety-critical settings characterized by interdisciplinary teams, precisely because they allowed for efficient common grounding (e.g., Bardram et al. 2006; Bowers & Martin 1999; Heath & Luff 1991). While it is difficult to reconcile different needs in team displays—especially because team hierarchy and vocal participants could influence the information selected to display—we chose to design a team display because it emphasizes efficiency and consistency.

7.4.2.1 Reconciling Information Needs

Although it is difficult to reconcile various information needs and address role hierarchy when developing a shared display, we used several strategies to minimize the effects of these factors. First, we had each participant create an ideal display to suit his or her role; next, we had the team discuss the various information features, reach consensus, and then create a design as a group (Chapters 5.6.1, 5.7.3.1, 5.7.3.3). This strategy allowed us to understand the detailed role-based information needs that may be lost through group design activities. Second, we encouraged participants to include as many information features as possible when creating their group designs so they would be able to rank the five information features they needed the most. Information ranking provided participants with an equal opportunity to voice their opinions, despite any differences in power and outspokenness within the group. This approach also tacitly acknowledged these differences in the process of identifying individual priorities and those shared across roles, helping us determine the overall rank order of group needs by analyzing the ranks assigned by participants and possibly increase the likelihood that users will appropriate the system to support their work (Miller et al. 2007). We used a similar strategy in simulation sessions (Chapters 5.6.2, 5.7.3.3). Instead of ranking their top information items, participants rated information features on the display using “like” and “dislike” stickers. Rating and follow-up discussions provided feedback about their experiences using our display designs, which allowed us to examine in greater detail how roles were affected. Top-down methods such as work domain analysis (WDA) (Burns &

Hajdukiewicz 2004) can also be used to understand role differences and shared information needs, but the level of granularity to describe those needs is much coarser than that of our approaches.

To quantify the potential effect of our approaches, we analyzed the individual designs and compared them to the consensus-based group designs (Chapters 5.6.1, 5.7.3.1, 6.3). We checked to see whether some roles compromised more than others, in that fewer information items suggested in their individual designs propagated to the group design. Similarly, we analyzed rankings from simulations to see if any roles compromised in the group design and whether clinicians representing these roles were less satisfied with the display design. Results from these analyses showed that we included most of the information features proposed in individual and group designs, with each role compromising on only three features or fewer. Although our display did not include vital signs, we made sure to have a separate vital signs monitor during simulations. Until we included labs and radiology results in our final design, anesthesiologists, scribes, and respiratory therapists compromised the most without this feature. While scribes had three unaddressed features, they included the most features in their designs (total of 32 between two scribes), which made it difficult to meet all their needs. Even so, we incorporated most features except name; pupil size; and Glasgow Coma Score details (score for eye opening, verbal response, and motor response). No particular role appeared dissatisfied more than others with the final design we tested (v14, Figure 23).

7.4.3 Summary of the Tensions Emerging from the Design Process

In addition to serving as mechanisms for analyzing the evolution of a design, these design tensions allowed us to explore the kinds of considerations HCI researchers must make when developing information technologies for *ad hoc*, collocated, interdisciplinary, and emergency teamwork. After experimenting with process-based and state-based design structures that feature either teamwork-oriented or patient-driven information, we found a balanced design for a shared information display that has a state-based structure with patient-driven information. Engaging with clinicians throughout the design process allowed us to identify and reconcile the individual role-based differences in display content, functionality, and organization to develop a shared display.

CHAPTER 8: CONTRIBUTIONS AND FUTURE WORK

This research has several contributions to HCI and CSCW, which may be particularly useful to researchers interested in the formative design and evaluation of information displays to support awareness during (1) *ad hoc*, (2) collocated, (3) interdisciplinary, and (4) emergency teamwork. Through a variety of methods, we addressed our research questions and offer several contributions (Table 20).

Table 20. Contributions in relation to research questions.
See **Table 1** *for full list of research questions*

CONTRIBUTION	RQ(s) ADDRESSED
The identification of information needs and features of trauma teamwork that require support	1, 2
New insights into awareness in *ad hoc*, collocated, interdisciplinary, and emergency teamwork based on our understanding of the trauma domain	2, 3
A description of the role of temporality in trauma teamwork and considerations for supporting temporal awareness in time-critical teamwork	2, 3
An understanding of the role-based differences in needs for teamwork and an example of how participatory and user-centered design approaches were used to reconcile these differences	2, 4
A conceptualization of two major tensions researchers might face when designing information displays for teamwork in related settings	3, 4
An example of participatory and user-centered research that engaged users throughout the formative design process in a highly structured and hierarchically controlled domain	4

We conducted qualitative comparisons of clinicians' perspectives across two institutions about information requirements for supporting awareness. PD workshops elicited clinician-generated sketches and detailed discussion that allowed us to characterize five features of *ad hoc*, collocated, interdisciplinary, and time-critical teamwork that require support through information displays. We then used this understanding to address the need for tailored awareness support based on concrete, contextualized tasks by providing rich descriptions of four facets of awareness from clinicians' perspectives. These descriptions of awareness helped us to develop design guidelines for display content and functionality. Our findings built on and validated the findings of previous work from observations and video analyses to provide new insights into supporting the awareness of emergency medical teams.

We identified and prioritized the information features that trauma resuscitation teams require to coordinate their work. Taking an iterative, PD approach was critical to balancing role tensions as well as two major design tensions that emerged during the design process. We first described in detail the role-based tensions surrounding each information feature and how our designs evolved to meet the needs of different roles. We then discussed two major design tensions that emerged—*process-based* vs. *state-based* design structures and *role-based* vs. *team-based* displays—and how we reached balance through different approaches. Thus, we contribute an understanding of the various design tensions that researchers must manage and strategies for reducing their impact on the design process.

Analysis of the data revealed the aspects of maintaining temporal awareness that clinicians perceived as important in trauma resuscitation. These findings then contributed to the design of time-based features that evolved during the iterative design of an information display to support the temporal awareness of clinicians. Using the insights from the design process, we identified four types of time-representation techniques and offered guidelines for which time-based features should be used when designing information systems to support temporal awareness in time-critical, collocated teamwork.

8.1 Avenues for Future Research

Future research in this area can move in several possible directions. *The first is to continue work on display design to support the awareness of emergency medical teams*. This work would involve summative evaluation of the information display prototype in simulated and real resuscitation environments. Insights gained through this study could be used to pursue a more focused analysis of the formative evaluation process and develop a set of guidelines for designing methods for both formative and summative evaluation methods. Discussions about clinicians' issues and concerns have already suggested several metrics that can be used for assessing the success of the display (e.g., is the display accurate, reliable, easy to interpret, and responsive to changing scenarios).

Second, changes in awareness of teams before and after real-world implementation of the display could be examined. Placing the display in the real environment would allow for an assessment of whether what we observed and what participants sketched in the workshops is what they actually need in action. Using the Situation Awareness Global Assessment Technique (SAGAT, Endsley 1995a) that we experimented with in simulations four and five would be a useful approach to measuring changes in awareness levels post-implementation. Further investigation of how teams' visual attention is impacted with the addition of the information display could be compared with the data from our previous study on vital signs monitor use.

Third, finding efficient and meaningful ways to integrate vital sign trends into the display or on a separate display would be worth exploring. Interventions and treatments completed by trauma teams could be contextualized by the trends in patient status. Trends could be presented in graphical form, with unique icons and labels to indicate interventions and treatments similar to the image of the body on the display design proposed in this dissertation. This type of visualization would help teams determine the effectiveness of their interventions and treatments to plan future actions. If this visualization were to be placed on a separate display, it could potentially feature the immediate vital signs (e.g., span of 30 seconds to one minute) on one half and vital sign trends with integrated interventions and treatments on the other.

Fourth, we are also interested in finding useful ways to support team member awareness. Our display design did not address team member awareness because clinicians (and therefore design) were more focused on awareness of the patient's status and the resuscitation process than on using the display to coordinate teamwork. We believe that, because the design has stabilized even further, we could focus on improving the design to support team member awareness with information about team members inside and outside the room. This information would likely be placed on a separate display and could incorporate features such as a list of team members with roles, names, experience levels, photos, and missing roles to support team member awareness. Clinicians at CHOP discussed using their badges equipped with RFID tags as a mechanism for obtaining information to display for team member awareness. At CNMC, clinicians are required to wear role tags that help support team member awareness; but they could perhaps be modified to be reusable and equipped with RFID tags that include role information. Examining clinicians' values and perspectives on awareness, security, privacy, and responsibility would then be necessary.

Fifth, future work might also explore the development of role-based displays. These displays could accommodate multiple user profiles, showing role-specific or individualized information to supplement information included on shared displays. It might not be necessary to create separate displays for each role but instead for the different role groups (i.e., leaders, performers, supporters, and documenters). Along similar lines, we could apply the knowledge we gained from designing this information display to develop other integrated devices that might be located in other rooms, departments, hospitals, or emergency vehicles.

8.2 Toward a Conceptual Model of Awareness

Examining the trauma resuscitation domain has led me to begin formulating a conceptual model of awareness—one that draws on several concepts from Activity Theory (AT) as a framework to understand work in this domain: object-orientedness, subject, community, division of labor, tools as mediating artifacts, and rules (Kuutti 1995). I propose an initial model that describes the levels of situation awareness in relation to the level of externalization among actors using the trauma resuscitation domain as an example. In this section, I explore the ideas that I have developed thus far.

8.2.1 Using Activity Theory as a Theoretical Framework to Understand Teamwork and Awareness in Trauma Resuscitation

Previous work by Jakob Bardram has used Activity Theory to describe the complex work and coordination of activities in the surgical department (Bardram 1997; Bardram & Doryab 2011). Similar to Bardram's approach, I propose AT as a possible theoretical framework for understanding trauma resuscitation as a socio-technical system. AT defines an ***activity*** situated within a context as the basic unit of analysis. The goal of an activity completed by a ***subject*** is to transform an ***object*** into a particular outcome (Table 21). The ***patient*** can be considered the object of work, and stabilizing and resuscitating the patient is the goal (object). ***Tools*** mediate between a ***subject*** and the object, resulting in the subject transforming the object or managing his or her actions to transform the object. Examples of tools include the team leader's checklist, the weight board, vital signs monitor, scribe nurse's flowsheet, and the information display designed in this research. A ***community*** is a group of subjects who share a common object. There is a ***division of labor*** among subjects of a community that structures the coordination of activity mediated through ***rules***. ***Clinicians*** are the subjects working together on a ***trauma team*** as a community with the shared objective of resuscitating a patient; their labor is distributed by ***role***. The main set of rules by which the trauma team coordinates their activity is defined by the ***ATLS protocol (ABCDE)***. Each role is responsible for a general set of ***activities*** that may or may not be shared with other roles. Activities are also shaped dynamically based on how a patient's status changes. Using this framework based on AT, we can further conceptualize awareness in this information space.

Table 21. Using Activity Theory to understand trauma resuscitation as a socio-technical system. Based on Kuutti's (1995) description of the structure of an activity.
**Information display can be considered a tool when implemented.*

ELEMENTS	DESCRIPTION	TRAUMA RESUSCITATION
Object	The goal of actions that the object of work that necessitates	Patient resuscitation and stabilization; patient is the object of work
⮝Tools⮟	Mediating artifacts created by subjects to manage their actions to transform an object	Vital signs monitor, flowsheet, checklist, weight board, information display*
Subject	A person shaping an object through activity	A clinician
⮝Rules⮟	Mediates the relationship between subject and community	ATLS protocol (ABCDE)
Community	A group of subjects sharing the same object	A trauma team
⮝Division of labor⮟	Mediates relationship between object and community	Trauma team roles and hierarchy

8.2.2 Levels & Externalization of Awareness Information

Examining the role-based similarities and differences in information needs (Chapter 6.3) indicated a spectrum of awareness levels and an externalization of awareness from the subject to the community level (Figure 35). Similar to the "levels of activity" described by Kuutti (1995), there appear to be three ***levels of awareness***: (1) the

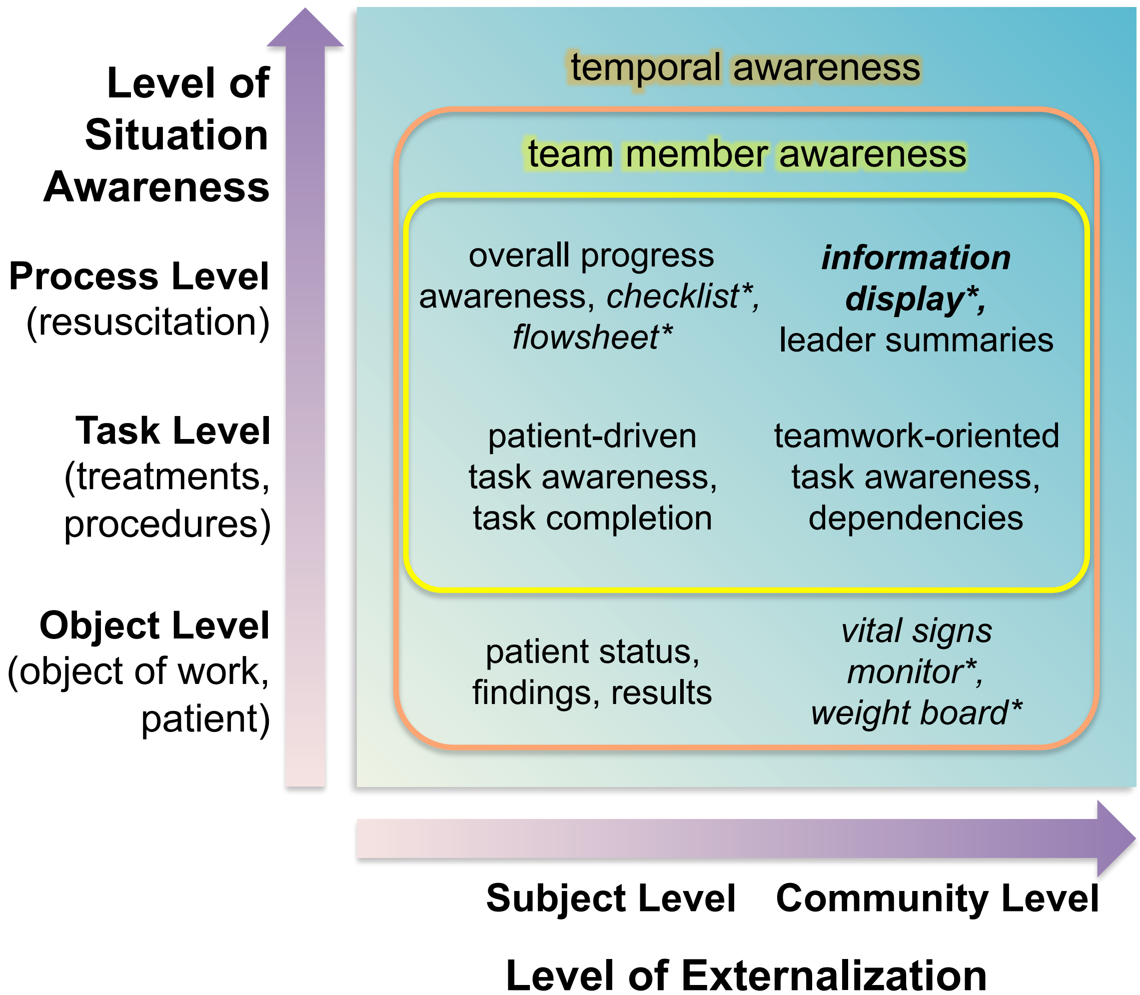


Figure 35. Spectrums of awareness from the subject (individual) to community (group) level.
**Information tools that support awareness.*

object level, at which the object of work is the patient and the objective is patient stabilization; (2) ***task level***, involving awareness for completing individual and shared tasks (including task dependencies); and (3) ***process level***, looking at the overall state of the resuscitation process. Along the horizontal axis is another aspect of awareness ranging from the ***subject level*** (individual) to the ***community level*** (group).

8.2.3 Awareness Information Consumed at the Subject Level or Produced for the Community Level

Awareness information could be viewed as being ***consumed*** at the subject level and ***produced*** and externalized for the community level of awareness. An example of information being *produced* for the community level of awareness would be the physician surveyor producing a large portion of the *object level* information needed during the resuscitation (e.g., reporting the results of the primary and secondary survey) while consuming less information than other roles to maintain awareness. In contrast, the scribe nurse typically collects and consumes the most information from all roles and occasionally notifies the team of important events. Leadership roles (team leader, emergency medicine physician) also tend to consume information sought through the other roles in order to produce *process level* information for overall awareness (e.g., giving summaries to the team). In the middle, supporting roles (bedside nurses, medication nurse, respiratory therapist, and anesthesiologist) tend both to produce and to consume *task level* information.

8.2.4 Visibility and Ephemerality of Awareness Information

Visibility and ***ephemerality*** of information are also potential dimensions of awareness. Externalization of awareness information can be affected by its *visibility* to other team members. For example, sheets of paper with patient-driven and teamwork-oriented information like the checklist and flowsheet might be useful for supporting process level awareness but are visible only to the person holding the artifact or to people within close proximity; as a large monitor, by contrast, allows most or all team members to view the same information at the same time. Externalization can also be affected by the *ephemerality* of the information that has been sensed, verbalized, or recorded. Information that has been recorded on paper, a whiteboard, an electronic medical record, or an information display is more stable than information that has been sensed and displayed (e.g., vital signs) or reported verbally, as with team leader summaries or physician surveyor findings. I hypothesize that temporality plays an important role in ephemerality as well. Some interesting questions would be whether information can "expire"—that is, whether immediate information has more weight and importance than past information for decision makers. The ways in which the visibility and ephemerality of information affect the levels of externalization and of situation awareness is an interesting direction for future research.

8.2.5 Facets of Awareness

The facets of awareness discussed in this dissertation can also be conceptualized within the information space I described above (Figure 35). Awareness of information at the *object level* includes patient status, findings, and results—some of which is externalized through tools visible to the whole team, including the vital signs monitor and weight board. Awareness of object level information is usually necessary to support awareness at the task level. At the *task level*, clinicians need *patient-driven task awareness* of information to complete tasks individually (e.g., exams, treatments, procedures) and *teamwork-oriented task awareness* of information such as task dependencies to complete shared tasks. When moving to the *process level*, task level and object level awareness are necessary to support *overall progress awareness* of the resuscitation, which can be at the subject or community level. *Team member awareness* spans across task level and process level awareness because it is concerned with coordinating tasks and how the team is performing overall. Temporal awareness can be applied to the whole spectrum, making it an interesting focus for future research to understand how it takes shape across these different dimensions of awareness and externalization.

8.2.6 Awareness Tools

The tools trauma teams use also range in the awareness and externalization levels they support. While there are tangible tools for supporting awareness at the *object* and *community* levels (i.e., vital signs monitor and weight board for the team) and at the *subject* and *process levels* (i.e., checklist for team leader and flowsheet for scribe nurse and occasionally the team leader), only ephemeral verbal team leader summaries currently support awareness at the *community* and *process levels*. The information display, once implemented, can serve as a tool to support awareness at the group process level. How the information display functions as this type of awareness tool in comparison to team leader summaries would be interesting to explore in future research. There are also no apparent tools for supporting awareness the *task level*, which would also be important to address in forthcoming designs.

8.2.7 Extending this Conceptual Model of Awareness

I would like to expand on my initial ideas for this conceptual model of awareness through future research. First, I hope to gain a deeper understanding of the dynamics of awareness as it moves between the subject and community levels. How does the intentionality of producing information for collective awareness differ (or not) from the intentionality of consuming awareness information (i.e., selecting or seeking awareness information) for individual use? Studying this phenomenon would involve examining similarities and differences in information consumption and production both *between* and *within* roles to achieve the different levels of awareness. Looking to the air traffic control literature for guidance could help us to describe aspects of individual and collective awareness.

Second, in addition to the aspects of awareness discussed above (i.e., visibility, ephemerality, consumption, and production), I would also like to investigate the ways in which behaviors change when clinicians manage information that is relatively ***static*** (e.g., age, weight) rather than information that is ***dynamically changing*** through activities (e.g., vital signs, findings, treatments). What aspects of static versus dynamic information influence awareness? How do subjects externalize static information? Dynamic information? In what ways do actors modify their tools (or want their tools modified) to accommodate static and dynamic information? Answering these types of questions could help me to understand how to design for both static and dynamic information displays to support awareness at the subject and community levels.

Finally, I would like to take a closer look at information tools to understand how they not only mediate *activity* between the object and the subject but also how they mediate *awareness* between the subject and the community. One way to understand this process would be to trace information chunks and examine how they transform through activities among roles as mediated through tools and rules. Using AT to describe the ***distribution of labor*** in trauma resuscitation in further detail could provide a structure on which to base these analyses of awareness. Chapter 7.4.2 presents some initial implications for designing role-based displays that can be developed to extend this conceptual model of awareness.

CHAPTER 9: REFLECTIONS ON RESEARCH AND DESIGN

I have learned many things about research and design through the journey of earning my PhD. My strongest conviction relates to the tension between the generalizability and customization of research and design methodology. This idea does not refer just to the notion of "one size does not fit all." Much of my passion for qualitative research comes from the richness in detail it emphasizes—allowing us to see the subtle differences in user needs and behaviors yet also allowing us to craft broader themes that describe phenomena at a higher level. While it is impossible to satisfy all users and all of their needs, there are still common themes and priorities that can inform the way a system is designed. My design philosophy has been shaped significantly by a commitment to exploring new ways to elicit knowledge that leads to the creation of useful designs for users as individuals and as groups.

Another aspect of my design philosophy was formed by the idea of iterative design with users—iteration of both system design and research methodology. In thinking of PD more as a design philosophy and structure for methodology than as a method to be followed according to previous work, I felt free to experiment with different techniques. Research is messy and imperfect; but through iteration with users throughout the process, we can get closer to an optimal design. One must be agile in adapting methods "on the fly" when situations are less than ideal or as planned as well as in drawing on new information *in situ* then incorporating questions to take advantage of moment and users' knowledge.

I also discovered the importance of scope to PhD training. It is easy to want to add as many details and connections to a thesis as possible, but the greater challenge is scoping a thesis in a way that makes it manageable and focused to demonstrate one's ability to conduct research. Data collection can take a lifetime. Liberation can be found when viewing the data collected as a pathway for new research after the dissertation rather than as a corpus that must be exhausted within the dissertation.

When reflecting on the difficulties of scope, I am also reminded of the difficulty of describing both the many details of the research conducted and thinking broadly about the works' contributions to the field. Moving from low- to high-level analysis requires reflection on the lower-level analyses that have been completed over time in relation to the experience gained from conducting research in the field of study. With guidance from mentors in the field, this skill can be improved in time.

Exploring temporal awareness in a time-critical setting was especially interesting because, although time is a universal language, the ways in which each person experiences time can vary greatly. What moves to the foreground and what fades to the background of our *focus*, what becomes more *important* or *less important*, depends on individual experiences and the surrounding context. *Priority* can also be described in a similar manner: everyone has priorities, but the order and weight of the priorities differ for each person. The ways in which we, as designers, study users and create designs to mediate these three dimensions of time in user experience can greatly influence how users perceive and utilize the information we present to them.

As I continue my path in user experience design, I think of my dissertation and my PhD as a means to having gained valuable skills that can be transferred to other contexts. I also consider myself lucky to have received domain knowledge training in emergency medicine because it provided me with a foundation for understanding other healthcare contexts. The most useful skills I acquired through this research are in: (1) creating and implementing formative design and evaluation methods (especially PD workshops, interviews, and user testing); (2) translating research findings into functional designs, including the visual interface wireframes, content, and functional requirements; and (3) developing an understanding of awareness based on user behaviors and perspectives. I look forward to applying my skills as a user experience developer to create systems that address the concept of awareness in other healthcare contexts.

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Appendices

Appendix 1: Participatory Design Workshop Survey

Think about the most recent trauma resuscitation in which you participated.
Please provide a few key words about your experience.

What was your role?
How did it go?
Why did it go the way it went?
What could be changed?
What should be kept the same?
Is there anything else you would like to share?

Appendix 2: Simulation 1 Discussion Questions

Follow-up Discussion

- Communication and performance as a team:
  - Were there any communications that could have been better?
  - Were there any redundant communications that could have been minimized?

- Display information:
  - Were there any important pieces of information you needed, but could not get easily?
  - Were there any important pieces of information that you were able to get that are normally harder for you to get?
  - How easy or difficult was it to find information on the display?

- Display design and functionality:
  - How effective was the display in helping you complete your tasks?
  - How did the monitor change your workflow or focus if at all?

- Questions for Charge nurse:
  - How was your experience documenting the resuscitation?
  - Do you have any issues or concerns about using this display?

Wrap-up Discussion

- Is there anything we could have done differently today with the simulations and our discussion?
- Anything we should have asked you that we didn't?
- Anything on the survey that was unclear, irrelevant, or missing?

Appendix 3: Simulation 2 Discussion Questions

Follow-up Discussion

- **Display design, layout, functionality, and usefulness:**
  - How easy or difficult was it to use the display?
  - How accurate and reliable was the display?
  - How appropriate was the display placement?
  - How useful was the display in helping you complete your tasks?

- **Teamwork and communication:**
  - How did the display affect your workflow, focus, or patient management if at all?
  - How did the display affect your communication as a team?
  - How well did you feel your teammates were using the display?

- **Issues and values:**
  - Do you have any issues or concerns about using this display?
  - What is the added value of this display?

- **Questions for charge nurse and team leader:**
  - How easy or difficult was it to use the digital pen?
  - Did your documentation match what was on the display?

Wrap-up Questions

- Is there anything we could have done differently today?
- Anything we should have asked you that we didn't?

Appendix 4: Simulation 3 Demonstration Scenario and Discussion Questions

Display Demo

Go over display

- We re-designed the display based on your comments and experimented with some graphics.
- Zhan and I will do a little demo to give you an idea of what the display looks like and how it functions.

- <u>EMS calls ahead and lets you know that:</u>
- You have an **[18 mo]** old Female
- Approximately **[12 kg]**
- She was in an **[MVC]**
- Restrained by a **[car seat in back]** seat
- **[+ LOC]**
- EMS did **[CPR in transit]**

- <u>Child rolls in and you start the primary survey:</u>
- **Airway is clear**
- But [**breath sounds]** are **[decreased on Left]**, so the image of the left lung is half red and half green.
- She has weak **femoral** and **distal** pulses **[1+]**, an icon with 1+ appears on the hips and feet and is listed under access.
- You insert a **[22 ga] IV** in the **Left arm**, then an IV icon appears on the left arm.
- GCS is **[8]**
- You decide to intubate so the med nurse draws up:
    - **[.2 mg]** of **[Atropine]**; **[3.6 mg]** of **[Etomidate]**; and **[18 mg]** of **[Succs]**, and that shows up under treatments.
- Then anesthesia **intubates** with a **[4.5]**, then that shows up as a tube with an ET icon and is listed under procedures.
- Physician doer goes through the secondary survey and finds **[Crepitus on L]** chest, which shows up under findings.
- You order a **[chest x-ray]**, **[head CT]**, and **[comprehensive labs]**, and that comes up on the bottom under requested in the ticker.
- You decide to send the child to **[PICU]** and you call **neurosurgery** in for consultation as you finish up the secondary survey.

- Are there any questions?

Discussion

- **Display design, layout, functionality, and usefulness:**
    - How useful was the display in helping you complete your work?
    - How dynamic and responsive was the display to the changing circumstances of the scenario?
    - How accurate and reliable was the display?
    - What would you say about the organization and layout of the information?
    - Were you able to see and interpret what was on the display?
    - Were you able to see and interpret the image of the body with icons? Was it useful?
        - [ask about ABCs and orders]

- How appropriate was the display placement?

- **Teamwork and communication:**
  - How did the display affect your workflow, focus, or patient management if at all?
  - How did the display affect your communication as a team?
  - How did the display affect your awareness of what your teammates were doing?

- **Issues and values:**
  - Do you have any issues or concerns about using this display?
  - What do you think is the purpose of the display?

Wrap-up Questions

- Is there anything we could have done differently today?
- Anything we should have asked you that we didn't?

Appendix 5: Simulation 4 Demonstration Scenario and Discussion Questions

Display Demo

Go over display

- We re-designed the display based on your comments from the last simulation in June.
- Nadir and I will do a little demo to give you an idea of what the display looks like now and how it functions.

- <u>EMS calls ahead and lets you know that:</u>
- You have an **[18 mo]** old Female
- Approximately **[12 kg]**
- She was in an **[MVC]**
- Restrained by a **[car seat in back]** seat
- **[+ LOC]**
- EMS did **[CPR in transit]**

- <u>Child rolls in and you start the primary survey:</u>
- **Airway is clear**
- But **[breath sounds]** are **[decreased on Left]**, so the image of the left lung is half red and half green.
- She has weak **femoral** and **distal** pulses **[1+]**, an icon with 1+ appears on the hips and feet and is listed under access.
- You insert an **IV** in the **Left arm**, then an IV icon appears on the left arm.
- GCS is **[8]**
- You decide to intubate so the med nurse draws up:
    - **[.2 mg]** of **[Atropine]**; **[3.6 mg]** of **[Etomidate]**; and **[18 mg]** of **[Succs]**, and that shows up under treatments.
- Then anesthesia **intubates** with a **[4.5]**, then that shows up as a tube with an ET icon and is listed under procedures.
- Physician doer goes through the secondary survey and finds **[Crepitus on L]** chest, which shows up under findings.
- You order a **[chest x-ray]**, **[head CT]**, and **[comprehensive labs]**, and that comes up on the bottom under requested in the ticker.

- Are there any questions?

Discussion

- **Display design, layout, functionality, and usefulness:**
    - How useful was the display in helping you complete your work?
    - How easy was it to see and interpret what was on the display?
    - How dynamic and responsive was the display to the changing circumstances of the scenario?
        - How accurate and reliable was the display?
        - How appropriate is the display placement?

- **Teamwork and communication:**
    - How did the display affect your workflow, focus, or patient management?

  - How did the display affect your communication as a team?
  - How did the display affect your awareness of what your teammates were doing?

- **Issues and values:**
  - Do you have any issues or concerns about using this display?

Wrap-up

- Is there anything you would like to discuss?
- Anything we could have done differently today?

Appendix 6: Simulation 5 Demonstration Scenario and Discussion Questions

Display Demo, 5min (Diana & Wizard)

Go over display

- We re-designed the display based on your comments from previous simulations and heuristic evaluations.
- We'll do a little demo to give you an idea of what the display looks like now and how it functions.

- <u>EMS calls ahead and lets you know that:</u>
- You have an **[18 mo]** old Female
- Approximately **[12 kg]**
- She was in an **[MVC]**
- Restrained by a **[car seat in back]** seat
- **[+ LOC]**
- EMS did **[CPR in transit]**

- <u>Child rolls in and you start the primary survey:</u>
- **Airway is clear** and turns green
- But **[breath sounds]** are **[decreased on Left]**, so the image of the left lung is half green and half grey.
- She has weak **femoral** and **distal** pulses **[1+]**, an icon with 1+ appears on the hips and.
- You insert an **IV** in the **Left arm**, then an IV icon appears on the left arm.
- GCS is **[7]** and because it's below 8, the box turns red
- You decide to intubate so the med nurse draws up:
    - **[.02 mg/kg]** of **[Atropine]**; **[.03 mg/kg]** of **[Etomidate]**; and **[1.5 mg/kg]** of **[Succs]**, and that shows up under treatments.
- Then anesthesia **intubates**, making two attempts, then that shows up as a tube with a label showing the size of **[4.5]** and **[2x]**.
- Physician doer goes through the secondary survey and finds **[Crepitus on L]** chest, which shows up under findings.
- You order a **[chest x-ray]**, **[head CT]**, and **[comprehensive labs]**, and that comes up on the bottom under ordered.
- The results from the iSTAT come back and you can see the values for **pH [7.41], CO2 [30], O2 [76], bicarb [27], glucose [39], and hematocrit [90]**.

- Are there any questions?

Discussion, 10min (Diana & Aleks)

- **Display design, layout, functionality, and usefulness:**
    - How useful was the display in helping you complete your work?
    - How easy was it to see and interpret what was on the display?
    - How dynamic and responsive was the display to the changing circumstances?
    - How accurate and reliable was the display?

- **Teamwork and communication:**
    - How did the display affect your workflow, focus, or patient management?
    - How did the display affect your communication as a team?

- **Lung representations:**
  - Feedback on the different ways the lungs can be represented. Here are 6 different lung statuses. Write on the sheet what you think each one represents.
  - **[Reveal labels]** Are these icons what you had expected them to be? Why or why not?

- **Treatments:**
  - What do you think about having fluids and blood separated from medications?
  - Does knowing the rate at which fluids are administered helpful to you?
  - What did you think about the way treatments were shown and organized?
  - What do you think about having the medications separated into these categories of time-sensitive, intubation, and other medications?
  - Is it enough to have only time-sensitive treatments with a timer? Or should all treatments have timers?
  - Would you rather see the actual dose or the weight-based dosing?

- **Results:**
  - What did you think about the way iSTAT results are shown?

Wrap-up, 2min (Diana & Aleks)

- **Issues and values:**
  - Do you have any issues or concerns about using this display?
  - Is there anything you would like to discuss?
  - Or anything we could have done differently today?

Appendix 7: Heuristic Evaluation Discussion Questions and Instrument

Opening Discussion

Trauma Experience

- Could you tell me a little about your typical team member role?
- How many years of experience do you have in this role, including years at Children's?

Workflow & Information Needs

- From your typical role perspective, let's think in terms of situations when you get low volume/high risk patients that are seriously ill. Which pieces of information are critical to your work in these situations?
- How do you go about getting these pieces of information?

Pre-hospital Communication

- What about pre-hospital information? Which pieces of information do you care about?
- How do you get this information? How is it delivered? Does is this process working for you?
- If you could have pre-hospital information delivered in some form, what would you want and how?

Go over display

- Here is the latest version of the display that we are considering.
  Basically the display consists of checklist information merged with trauma flowsheet information.
  On the top we have the patient demographics and timer.
  On the bottom we have information about the process.
    - What has been done will be checked off and greyed out. When all of the tasks for ABCDE are finished, the box turns green.
    - Any interventions will be noted in green at the bottom.
    - Tasks that have been missed will be highlighted in red and the box will also turn red.
    - Tasks that still need to be completed will be black and bold. That's how this bottom half will look like when the resuscitation starts.

- Do you have any questions?

Explain Reason Behind Heuristics

- Now that you have seen what the display looks like, I would like to go over some evaluation criteria with you and get your feedback on the display.
- The purpose of this part is to:
    - Understand how you would rate the display according to a set of criteria and why.
    - Understand which parts of the display you are referring to.
    - See if there are any criteria we missed.

[Move on to Heuristics & Annotation sheet]

Follow-up Questions After Heuristics & Annotation

- Do you have any issues or concerns about using this display?
- Now that you have an idea about what the display might look like and generally how it works. What do you believe is the purpose of this display?

Briefly Discuss Display v7

[Show display v7]

- We have been experimenting with how to include vital signs on the display. What do you think about this layout?
- Any suggestions for how we can better integrate vitals, if at all?

Wrap-Up Discussion

- Is there anything I could have done differently today?
- Was there anything about the survey that was confusing or should be changed?
- Is there anything that I should have asked you or is there anything else you would like to discuss?

Heuristic Evaluation Instrument

Please indicate your regular trauma team role:

☐ Anesthesiologist	☐ Emergency Medicine Attending	☐ Respiratory Therapist
☐ Bedside Nurse	☐ Medication Nurse	☐ Surgical Attending
☐ Bedside Physician	☐ Recording/Charge Nurse	☐ Surgical Fellow/4th yr

Number of years experience in this team role (including years at Children's): __________

Please think aloud while doing the following:

1. Rate the display based on each of the criteria described,
2. Explain your reasoning behind the rating, and
3. Annotate the paper version of the display to demonstrate what you mean

1. Useful Information
The display presents information that is useful during resuscitations.

1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

2. Sufficient Information
The display provides just the right amount of information.

1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

3. Understandable Information
The information presented on the display is easy to understand & interpret.

1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

4. Visible & Readable Information
The information on the display is clear and readable.

1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

5. Domain Appropriate Language
The display uses language normally used during trauma resuscitations.

1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

6. Improvement over Current System(s)
The display improves or supplements the information sources currently in the trauma bay.

1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

7. Intuitive & Appealing Layout
The layout of the information on the display is intuitive & appealing.

1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

Are there any criteria you feel are missing that are important to evaluating this display?

1. Describe the criteria that are missing,
2. Rate the display based on each criterion you describe,
3. Explain the reasoning behind your rating, and
4. Annotate the paper version of the monitor to demonstrate what you mean.

Criterion:
Description:

1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

Criterion: **Description:**							
1 Not at all	2	3	4 Somewhat	5	6	7 Extremely	NA
Criterion: **Description:**							
1 Not at all	2	3	4 Somewhat	5	6	7 Extremely	NA

Evaluation Metrics Review

- Today I could only ask for feedback on the content and visual aspects of this static display. I wasn't able to show you how the display works dynamically or have you test the display in a simulation.

- We are still building a set of metrics that you and trauma teams care about that will focus on the actual functionality of the display.

- Now I would like to ask for your feedback on evaluation metrics we might use when asking participants after having used the live display during a simulation.

- This way I know that questions I am asking are on point in later sessions.

Please think aloud while rating your perceived *importance* of each criterion to evaluate the display in our next simulation.

1. Timely Feedback & Dynamic Changes The display provides timely feedback about changing information.							
1 Not at all	2	3	4 Somewhat	5	6	7 Extremely	NA
2. Unobtrusive & Peripheral The display is unobtrusive and easy to monitor while working.							
1 Not at all	2	3	4 Somewhat	5	6	7 Extremely	NA

3. Easy to Document
It is easy for the ***charge nurse*** to document or for the ***emergency medicine attending*** to fill out the checklist using the digital pen.

1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

4. Recover Easily from Errors
It is easy for the ***charge nurse*** or ***emergency medicine attending*** to change information on the display.

1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

5. Supports Communication
The display does not interfere with team communication.

1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

6. Accurate & Reliable
The information presented is accurate and reliable.

1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

7. Minimal Training Required
The display is easy to use with minimal training.

1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

Are there any other criteria you feel are missing that are important to evaluating this display?

1. Describe the criteria that are missing,
2. Rate your perceived importance of each criterion, and
3. Explain the reasoning behind your importance rating.

Criterion:							
Description:							
1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	
Criterion:							
Description:							
1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	
Criterion:							
Description:							
1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

[Move on to follow-up questions and briefly discuss display v7]

Appendix 8: Video Review Session Discussion Questions and Instrument

Video Narration

- Can you just state your typical role?
- For the next 25 minutes, I'm going to have you narrate a video of a simulated resuscitation from the perspective of your role. I may ask you questions as we go.
- Pause the video as necessary and please note:
  - Things you find important, unusual, or interesting that you would like to discuss
  - What you think the team is doing well or not as well
  - Instances where you feel like the team or the person playing your role has good or not as good awareness of what is occurring, the tasks being performed, the information that emerged, and what other team members are doing.

Questions About Awareness

- [Beginning] I noticed that when there is a little more time for people to trickle in before the patient arrives, more repetition of the story occurs because people arrive at different times and want to be updated. Is that true?
- [Beginning] When you arrive late to a resuscitation, how do you update your awareness of the patient or where the team is in the process?
- [Middle] When roles are missing, how do you adjust your awareness to cover the duties of another role?
- [Middle] I've seen people change out roles during resuscitations or leave early. How does that affect your work and awareness?
- [End] I observed that a patient's vitals started to drop after most of the team left after completing the secondary survey and before x-rays. Some team members were called back in. How does your awareness change or priorities for awareness change after the secondary survey?
- [End] How would you say the team performed during this resuscitation?

Demo

[Video Start: 14:00; Stop: 26:00]

- Patient arrived at 7:48am
- EMS reported 5 year old male pedestrian struck by an SUV at 40mph. At scene was aware and oriented and stopped responding in transit.
- Pulses 1+ for distal and femoral.
- GCS 6.
- Physician doer reported bilateral breath sounds and the airway is patent.
- IV access in both forearms.
- Administered Etomidate & Succinycholine.
- Intubated the patient with a 5.0 tube.
- Secondary survey found that the abdomen was distended.
- They administered 400 ccs of Normal Saline through both IVs and ordered a chest x-ray.
- Although it was not ordered in the simulation, we could also show some results from the iSTAT.

Heuristic Evaluation Instrument

Please indicate your regular trauma team role:

☐ Anesthesiologist	☐ Emergency Medicine Attending	☐ Respiratory Therapist
☐ Bedside Nurse	☐ Medication Nurse	☐ Surgical Attending
☐ Bedside Physician	☐ Recording/Charge Nurse	☐ Surgical Fellow/4th yr

Number of years experience in this team role (including years at Children's): _________

Please think aloud while doing the following:

4. Rate the display based on each of the criteria described,
5. Explain your reasoning behind the rating, and
6. Annotate the paper version of the display to demonstrate what you mean

Display Content and Appearance

1. Useful Information
The display presents information that is useful to completing your work during resuscitations.

1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

2. Sufficient Information
The display provides just the right amount of information you need to complete your work.

1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

3. Understandable Information
The information presented on the display is easy to understand & interpret.

1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

4. Visible & Readable Information
The information on the display is clear, visible, and readable.

1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

5. Domain Appropriate Language
The display uses terminology and language normally used during trauma resuscitations.

1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

6. Improvement over Current System(s)
The display improves or supplements the information sources currently in the trauma bay.

1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

7. Intuitive & Appealing Layout
The layout of the information on the display is intuitive, appealing, and organized.

1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

8. Timely Feedback & Dynamic Changes
The display provides timely feedback about changing information at different stages in the process.

1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

9. Coordination & Communication
The information presented is useful for coordinating tasks and teamwork.

1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

10. Decision-making The information presented is useful for making decisions.							
1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	
11. Minimize Memory Load The display serves as an external memory aid and allows users to recognize rather than recall information.							
1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	
12. Display Positioning The current positioning of the two displays at the head and foot of the bed is appropriate.							
1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

Are there any other criteria you feel are missing that are important to evaluating this display?

4. Describe the criteria that are missing,
5. Rate your perceived importance of each criterion, and
6. Explain the reasoning behind your importance rating.

Criterion: **Description:**							
1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	
Criterion: **Description:**							
1	2	3	4	5	6	7	NA
Not at all			Somewhat			Extremely	

Guiding Questions

- **Useful information**
  - *The display presents information that is useful to completing your work during resuscitations*
    - Are there any other types of information or features that would be useful to you that are not included?
    - Is there any information that is not useful?

- **Sufficient Information**
  - *The display provides just the right amount of information you need to complete your work*
    - Is there enough detailed information to make it useful?
    - Is there too much information included on the display?

- **Understandable Information**
  - *The information presented on the display is easy to understand and interpret*
    - Are the icons and labels on the body easy to interpret?
    - What about the way breath sounds are represented with the lungs?
    - Does the color scheme make sense?

- **Visible and readable information**
  - *The information on the display is clear, visible, and readable*
    - Is the text large enough?
    - Is the font easy to read?
    - Is there enough white space to see which information is important?

- **Domain appropriate language**
  - *The display uses terminology and language normally used during trauma resuscitations*
    - Are the medical terms correct?
    - Are the headers for each type of information appropriate?

- **Improvement over current system(s)**
  - *The display improves or supplements the information sources currently in the trauma bay*
    - Is this display an improvement over the weight board?
    - (For EM/Surgical) Is this display an improvement over looking at the flowsheet?

- **Intuitive and appealing layout**
  - *The layout in the information on the display is intuitive, appealing, and organized*
    - Does the way the information is organized make sense?
    - Does the layout help you identify information quickly and with ease?

- **Timely feedback and dynamic changes**
  - *The display provides timely feedback about changing information at different stages in the process*
    - Does the information update in the way you would expect it to?
    - Is it easy to see when and how the information is updated?

- **Coordination and communication**
  - *The information presented is useful for coordinating tasks and teamwork*
    - Does the information help you coordinate your tasks with other team members or other departments?
    - Does the information help you plan your tasks?

- Does the information help minimize redundancies in communication for teamwork and common grounding?
- What do you think is the purpose of the display?

- **Decision-making**
  - *The information presented is useful for making decisions*
    - Does the information help you decide which tasks to do and how?
    - Does the information help you make clinical decisions or diagnoses?

- **Minimize memory load**
  - *The display serves as an external memory aid and allows uses to recognize rather than recall information*
    - Does having the information on the display help offload your cognitive work?
    - Does the display help you review the information that has resulted from the resuscitation?

- **Display positioning**
  - *The current positioning of the two displays at the head and foot of the bed is appropriate.*
    - Would any other position be better suited to your role positioning around the bed?

Discussion

- **Issues and concerns**
  - Do you have any issues or concerns about using this display?

Wrap-Up Discussion

- Is there anything I could have done differently today?
- Was there anything about the survey or the protocol that was confusing or should be changed?
- Is there anything that I should have asked you or is there anything else you would like to discuss?

Appendix 9: Focus Group Demonstration and Discussion Questions

Display Demo

Go over display

- We re-designed the display based on your comments from previous sessions.
- We'll do a little demo to give you an idea of what the display looks like now and how it functions.

- <u>EMS calls ahead and lets you know that:</u>
- You have an **[7 year]** old Female
- Approximately **[28 kg]**
- You can see the Broselow color turn orange
- She was in an **[MVC]**
- Restrained by a **[car seat in back]** seat
- **[+ LOC]**
- EMS did **[CPR in transit]**

- Child rolls in and you start the primary survey:
- **Airway is clear** and turns green
- There is **[decreased breath sounds]** on the **[Left Lung]**.
- **[Right Lung]** is **[clear]**.
- GCS is **[7]** and because it's below 8, the box turns red
- You insert an **IV** in the **Left arm**, then an IV icon appears on the left arm.
- You decide to intubate so the med nurse draws up:
    - **[.5 mg]** of **[Atropine]**; **[8.4 mg]** of **[Etomidate]**; and **[42]** of **[Succs]**, and that shows up under the **airway** section of treatments.
- Then anesthesia **intubates**, making two attempts, then that shows up as a tube with a label showing the size of **[4.5]** and **[2x]**.
- She has weak **femoral** and **distal** pulses **[1+]**, an icon with 1+ appears on the hips and arms.
- You start administering **[200mL]** of **[Normal Saline]** at **[68 mL/hr]**.
    - The stopclock starts, indicating the time elapsed since fluids were administered.

- Physician doer goes through the secondary survey and finds **[Crepitus on L]** chest, which shows up under findings.
- You order a **[chest x-ray]**, **[head CT]**, and **[comprehensive labs]**, and that comes up on the bottom under ordered.
- The results from the iSTAT come back and you can see the values for **pH [7.41], CO2 [30], O2 [76], bicarb [27], glucose [90], and hematocrit [39%]**.

- Are there any questions?

Integrated Discussion Questions

- **Display design, layout, functionality, and usefulness:**
    - How **useful** was the display in helping you complete your work?
    - How **easy** was it to see and **interpret** what was on the display?

- How **dynamic** and **responsive** was the display to the changing circumstances?
- How **accurate** and **reliable** was the display?
- How **often** did you **look** at the display?

- **Lung representations:**
  - We would like to get your feedback on the different ways lung status can be represented. Here are **5** different **lung status icons**. Write on the sheet what you think each one represents.
  - **[Reveal labels]** Are these icons what you had **expected** them to be? Why or why not?
- **Treatments:**
  - What do you think about having the **medications** separated into these **categories** of **time-sensitive**, **intubation**, and **other** medications?
  - What do you think about having **fluids** and **blood separated** from medications?
  - Does knowing the **rate** at which **fluids** are administered helpful to you?
  - We have **stopclocks** for time-sensitive treatments and fluids. This indicates the **time** elapsed **since** the treatment has been administered. Is this useful?
  - Is it enough to have **only time-sensitive** treatments with a stopclock? Or should **all** treatments have stopclocks?
  - How about the **number of times administered** for repeated doses?
  - Would you rather see the **actual dose** or the **weight-based** dosing?
- **Findings**
  - We have number of **intubation attempts** for difficult airways in findings. Is this helpful?
- **Results:**
  - What did you think about the way **iSTAT** results are shown?

Wrap-up Questions

- **Issues and values:**
  - Do you have any issues or concerns about using this display?
  - Is there anything you would like to discuss?
  - Or anything we could have done differently today?