Balancing Design Tensions: Iterative Display Design to Support *Ad Hoc* and Multidisciplinary Medical Teamwork

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ABSTRACT

In this paper, we describe how we developed an information display prototype for trauma resuscitation teams based on design ideas and feedback from clinicians. Our approach is grounded in participatory design, emphasizing the importance of gaining long-term commitment from clinicians in system development. Through a series of participatory design workshops, heuristic evaluation, and simulated resuscitation sessions, we identified the main information features to include on our display. Our results focus on how we balanced the design tensions that emerged when addressing the *ad hoc*, hierarchical, and multidisciplinary nature of trauma teamwork. We discuss the implications of balancing role-based differences for each information feature, as well as two major design tensions: process-based vs. state-based designs and role-based vs. team-based displays.

Author Keywords

Participatory design; information displays; design tensions; teamwork; healthcare; trauma resuscitation.

ACM Classification Keywords

H.5.0. Information interfaces and presentation (e.g., HCI): General

INTRODUCTION

This paper presents the select findings from an ongoing iterative design process, the goal of which is to develop ideas for technological innovation and to support *ad hoc*, multidisciplinary medical teamwork during trauma resuscitation. Awareness, cooperation, and information sharing are crucial for teamwork in the resuscitation setting; trauma teams work under extreme time pressure while stabilizing critically injured patients and addressing life-threatening injuries. Although we see opportunities for technological innovation, we recognize that designing for emergency scenarios is challenging for several reasons. First, trauma teams are *ad hoc*, 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 safety-critical events in which teams deal with incomplete information and unpredictable problems, adding even more design constraints.

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To address these challenges and, at the same time, create a design process that would support both researchers and practitioners in achieving common understanding across disciplines, we rooted our approach in participatory design (PD) [12,18]. In particular, we combined observations from our previous fieldwork with an iterative design process, rapid prototyping, and PD techniques to develop solutions that will meet the needs of these dynamic and multidisciplinary teams. Throughout the process, we created and evaluated a dozen prototypes using empirically accessible events and practitioner participation that ranged from design workshops, interviews, heuristic evaluation of paper prototypes, and simulated resuscitation events with entire teams using a high-fidelity prototype.

As an outcome of this process, we gained an understanding of role-based differences in information needs, and conceptualized several design tensions, two of which played a critical role in guiding our design decisions:

(1) The biggest design tension was between using *process-based*, checklist-driven designs that present information organized by the order of activity, and using *state-based*, snapshot-like designs that present information about patient and teamwork status. A state-based design was preferred because it allowed team members to observe treatment outcomes and trends in patient information.

(2) 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. A team-based design was preferred, but it required methods for reducing biases due to the multidisciplinary and hierarchical nature of trauma teams.

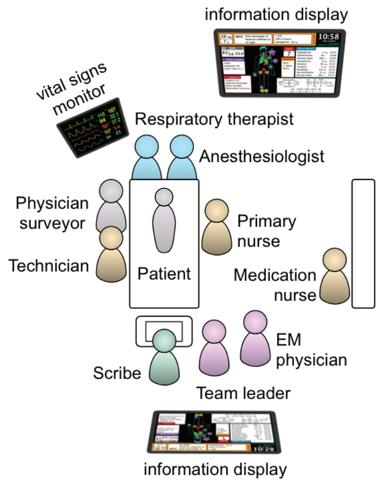

Figure 1. Team organization and layout of the trauma bay.

In addition to serving as mechanisms for analyzing the evolution of a design, these design tensions show the kinds of considerations HCI researchers must make when developing information technologies for *ad hoc*, hierarchical, and multidisciplinary teams.

BACKGROUND, RELATED WORK & CONTRIBUTIONS

Emergency Resuscitations: Overview

The process of trauma resuscitation is one of the most challenging in healthcare, requiring a team to focus on common tasks for a short time period (20-30 minutes, on average), while adapting to complex and changing circumstances driven by patient status. Unlike other clinical settings, patient management during resuscitation relies on emerging rather than existing information, demanding fast and effective cooperation among many disciplines [2]. Resuscitation teams are heterogeneous, consisting of clinicians with different roles, specializations, experience levels, ranks, and work responsibilities. Each role is strategically positioned (Figure 1): *respiratory therapist* and *anesthesiologist* at the head of the bed managing 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 *leader* and *emergency medicine (EM) physician* in the back overseeing team activities. Trauma teams follow the Advanced Trauma Life Support (ATLS) protocol for patient evaluation that focuses on the major physiological systems: **A**irway, **B**reathing, blood **C**irculation, and **D**isability or neurological status ("ABCD") [1]. While the protocol serves as a mechanism by which teams articulate their work, task coordination is still dynamic and changes with patient needs. Despite the extensive amounts of information teams must process, few information technologies are available to support their work. Information is shared verbally, with a high cognitive load of integrating data due to the lack of external memory aids [20]. Scribes record the information produced by the team on flowsheets and team leaders at our research site use a checklist to manage protocol tasks. These artifacts, however, are paper-based and rarely used for real-time decision making. Vital signs monitors are currently the only electronic displays in trauma bays at most hospitals.

Related Approaches to Designing Information Displays

An important challenge to implementing computerized support in emergency medicine is the need to efficiently synthesize and present information. One way to address this challenge is through shared information displays.

Information displays have been developed in medical and emergency response settings using a variety of approaches. The Ecological Interface Design (EID) approach [5], for example, highlights the importance of studying work domains at different levels of abstraction and hierarchy, and deriving display requirements based on this top-down work domain analysis (WDA). In contrast, Holzman [11] and Parush et al. [19] derived requirements for their information displays using bottom-up approaches, such as observations, interviews, and analysis of team communications. Our approach was also bottom-up, but relied on participatory design (PD) to understand the domain and elicit the information needs of individuals and teams. Other researchers have used PD techniques as well. For instance, Bardram et al. designed their AwareMedia system for an operating ward based on field studies and a series of design workshops with a group of clinicians [3]. Kyng et al. used participatory design to develop interactive systems for emergency response [14], while Kristensen et al. used design workshops in highly realistic settings ("future labs") to develop ideas for supporting emergency medical services during major incidents [13]. Where we differ, however, is in using PD as a vehicle to not only understand the domain and develop ideas, but also to manage design tensions that emerged from the design process. We see design tensions and associated challenges acknowledged in the HCI and CSCW literature [e.g., 6,7,9], but discussions on how to address and balance these tensions are lacking.

Our work makes the following contributions to HCI:

- Discussion of PD as a vehicle to manage design tensions that emerge from designing shared displays based on feedback from users with different information needs.
- Contextualized examples of why certain design directions work or do not work.
- Descriptions of role-based differences for targeted information presentation.
- Prioritized list of information types for display.

OUR APPROACH: FROM FIELD STUDIES TO AN ITERATIVE DESIGN PROCESS

The display design and evaluation process was preceded by several years of fieldwork, providing the basis for building shared knowledge with all participants. Our interdisciplinary team is composed of ten researchers and practitioners at four institutions, and involves HCI

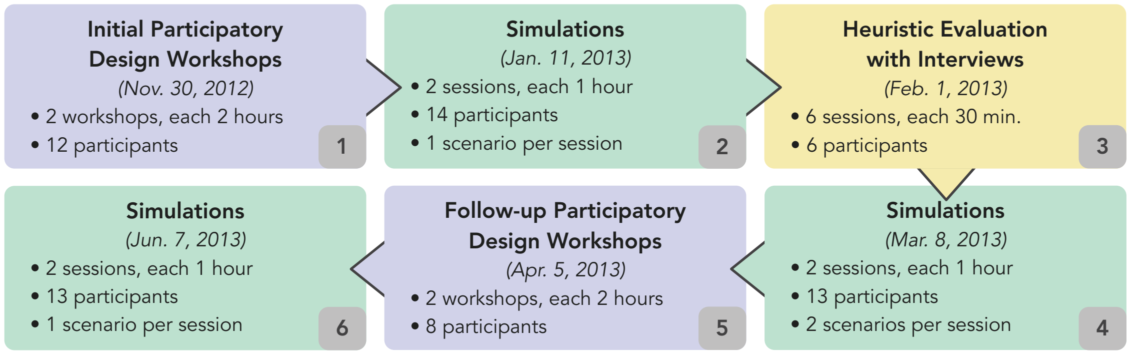

Figure 2. Display design and evaluation process: Phases and timeline of data collection sessions.

researchers and ethnographers, computer scientists, engineers, and clinical experts. Over the years, we have used different methods to engage with the domain: observations of live and simulated resuscitations, interviews with trauma team members, and micro-analyses of live video recordings [e.g., 20]. As an important part of the participatory design process, these field studies revealed the problems of coordination and 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. Our collaborators at the research site—a Level I trauma center at a pediatric teaching hospital in the U.S. Mid-Atlantic region—supported this idea, and installed two large wall monitors in the trauma bay. The results we report in this paper are from the first phase of the iterative design process, which focused on the design and development of the display prototype.

Display Design and Evaluation Process

Over the course of eight months (November 2012 – June 2013), we conducted six design and evaluation phases, with each phase including two or more data collection sessions for a total of 16 sessions: four participatory design workshops, six simulation sessions with entire resuscitation teams, and six heuristic evaluation sessions (Figure 2).

Participatory Design Workshops

We started with two participatory design workshops to create preliminary designs (Phase 1, Figure 2), and followed up with another set of workshops focused on display functionality (Phase 5, Figure 2). The main purpose of these workshops was to understand clinicians' perceptions of what information was critical to their work and how they needed this information displayed. We used the PD technique called PICTIVE [17] to provide an environment where users with diverse perspectives have equal opportunity to engage in the design process. Participants were asked to (a) discuss the most recent resuscitation in which they participated, (b) create display sketches based on their individual needs, (c) engage in a group design activity to create a shared display, (d) rank the priority of the information features based on their role, and (e) discuss any concerns with using the display. After several design iterations and evaluation sessions, we conducted two follow-up design workshops (Phase 5, Figure 2). The format was similar to the initial workshops, but focused on eliciting input on display functionality. We also used these workshops to validate prior findings.

Simulated Resuscitations in a Realistic Setting

We performed three sets of simulations (Phases 2, 4, and 6 in Figure 2) to both gather design requirements and evaluate display prototypes. Simulation sessions were conducted in an actual trauma bay with the equipment normally available to teams. In each of the hour-long sessions, we oriented teams to the display functionality. Following this brief overview, teams performed two to four resuscitations using a high-fidelity mannequin based on clinical scenarios ranging from moderate to demanding that were developed by medical experts. Participants were then asked to indicate up to five features they found useful (liked) and up to five features they did not find useful (disliked) on a paper copy of the display using stickers color-coded based on role. If an information feature did not receive a "like" or "dislike," we considered it neutral. Each session concluded with a discussion about team communication, information features and display design.

Prototypes were displayed using two 42" wall-mounted monitors showing the same information (Figure 1). Data capture varied between simulation sessions; the goal was to experiment with different data capture mechanisms for the entire system development. We first inputted information onto the display using a digital pen and paper flowsheet used by scribes. During the second set of simulations, the prototypes drew data via digital pens from both the flowsheet and the leader's paper checklist. A confederate scribe acted as the 'Wizard of Oz' in our third simulation session, inputting information using a computer interface.

Heuristic Evaluation with Interviews

The purpose of heuristic evaluation sessions (Phase 3, Figure 2) was to get feedback individually from each participant and their ideas for improving the display design. We asked participants to rate the display based on a set of criteria adapted from previous work on heuristic evaluation for ambient and peripheral displays [15,16]. Participants were instructed to explain their reasoning behind each

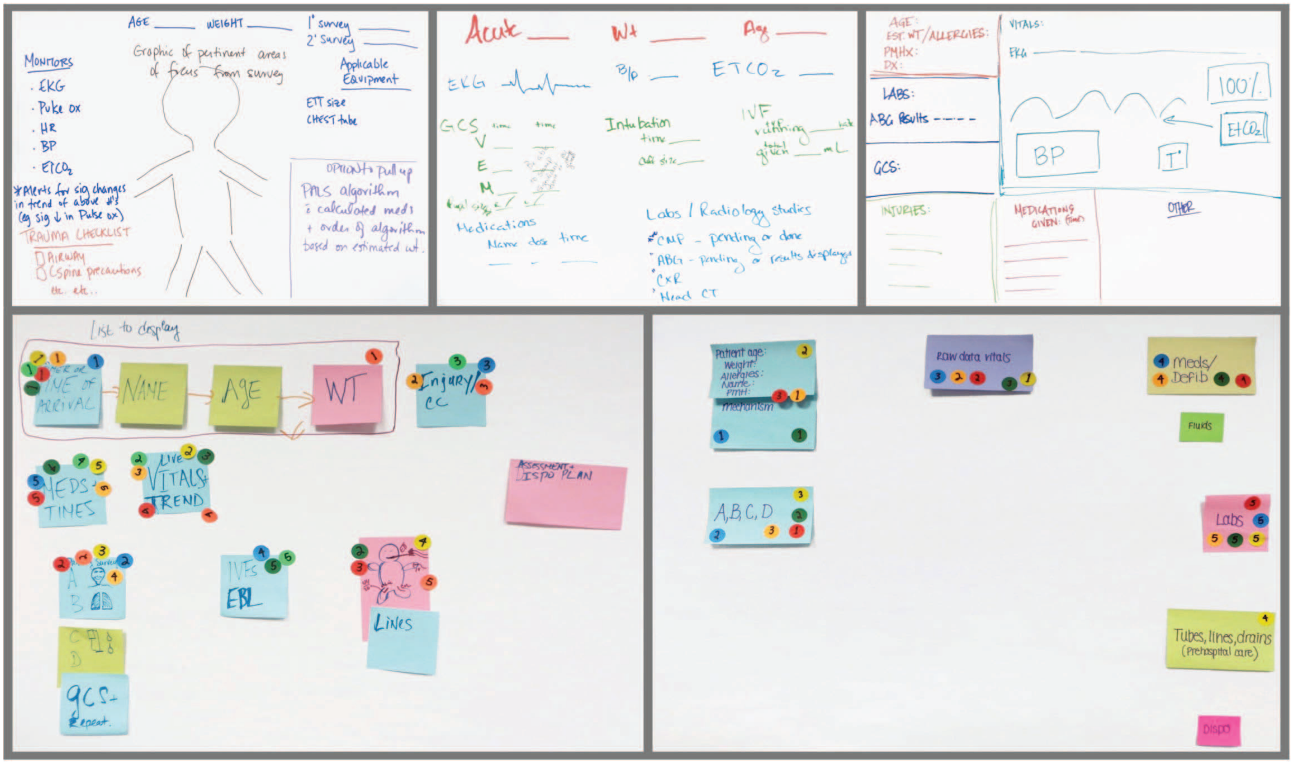

Figure 3. Participants' individual designs (three samples of sketches out of 12, top row) and group designs (bottom row).

rating and write notes on the paper prototype to show what they meant. Each session concluded with questions about concerns they had about using this display, and what they believed was the purpose of the display.

In summary, the types of participant feedback differed with each design and evaluation activity. We received feedback based on participants' own design ideas and perceptions of information needs through participatory design workshops. We also received feedback through heuristic evaluations using paper prototypes. Finally, we elicited feedback based on using the actual display prototype in the context of work through simulation sessions. This mix of feedback types ensured a holistic approach to design while minimizing methodological biases tied to each of the approaches.

Participants

Of the 39 unique participants involved in the design and evaluation process, 21 attended two or more sessions (Table 1). Repeated participation was allowed between but not within phases (Figure 2). Our participants were clinicians who regularly perform trauma resuscitations, with experience levels ranging from a few months to more than 30 years. We recruited participants to represent all core team roles for data collection activities to replicate the composition of actual teams. Participation was voluntary and participants were compensated for their time.

Roles	Partic. (N=39)	Avg. Exper. (yrs.)
Anesthesiologist	5	5
Bedside nurse	9	9
EM physician	4	5
Physician surveyor	6	4.5
Respiratory therapist	5	4
Scribe	4	14
Surgical team leader	6	3

Table 1. Participant demographics.

Data Analysis

Analyses were conducted to identify trends on all artifacts, design feedback, and other data collected throughout the process (i.e., design sketches, annotated paper displays, rankings, likes and dislikes, photographs, and audio and video recordings of discussions). Individual designs from workshops were transcribed into a matrix to analyze the information features each role included in their designs. The features were then grouped by type and sorted by number of times they were included in designs. Group designs were transcribed in a similar manner by grouping information features by type and recording the top five ranks that each role assigned to features. Likes and dislikes assigned to information features during simulations were also calculated to analyze the feedback trends over time. Information features were again grouped by type into main categories (e.g., header, ABCD, treatments, and orders); the percentages of people who liked and disliked each feature were then calculated as (the first term in the equation is because only one vote per category was allowed):

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

Discussions were transcribed and analyzed to supplement the findings from design artifacts, feedback, and prototypes.

Information features & team roles that included them in their individual designs	**Simulation 1, v2**		**Simulation 2, v4**		**Simulation 3, v5**	
	✓	**✗**	**✓**	**✗**	**✓**	**✗**
Header	**34.3%**	**12.9%**	**38.6%**	**1.4%**	**44%**	**0%**
Patient demographics	All team roles					
Pre-hospital information	Anesthesiologist, bedside nurse, physician surveyor, scribe, respiratory, leader					
Vital signs	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
Numeric values	Respiratory, anesthesiologist					
Live waveforms	Scribe, respiratory, anesthesiologist					
Trends	Scribe					
Patient evaluation findings (ABCD)	**21.4%**	**42.9%**	**21.4%**	**19.6%**	**25%**	**17.5%**
Checklist of steps	Physician surveyor, EM physician					
Findings and procedures under ABCD	Leader 1, leader 2, scribe, respiratory, EM physician					
Findings and procedures by type	Anesthesiologist 1, anesthesiologist 2, respiratory, bedside nurse, scribe					
Body with representations of findings	Physician surveyor, EM physician					
Treatments (medications and fluids)	**54.8%**	**2.4%**	**N/A**	**N/A**	**70%**	**0%**
Medications and fluids separated	Bedside nurse, scribe, respiratory					
Medications and fluids combined	Anesthesiologist, respiratory, leader					
Laboratory and radiology orders/results	**14.3%**	**14.3%**	**14.3%**	**30%**	**30%**	**30%**
Radiology tests ordered	Bedside nurse					
Labs and radiology tests ordered	Leader					
Labs ordered and results	Anesthesiologist, scribe, EM physician					
Lab results	Respiratory					
Lab results and radiology tests ordered	Scribe, respiratory					

Table 2: Role preferences for different information features and participants' attitudes toward major components of the display expressed through the percentage of likes (✓) and dislikes (✗) during 3 sets of simulations (N/A = not included in display).

FINDINGS: ROLE-BASED DIFFERENCES & TENSIONS

The hierarchical nature of trauma teams and the multiplicity of responsibilities, disciplines, and training levels naturally led to a diversity of information needs. As we found through fieldwork, patient data that was meaningful to one team member may go unnoticed by other team members. While each role has particular information needs, we also observed several roles with overlapping needs that allow them to coordinate tasks. This mix of information needs became evident as we were designing and evaluating display prototypes, revealing both role and design tensions. Due to space limitations, we show only six designs (out of 13 iterations), four of which were tested with users.

Role Tensions Around Information Features

Eight categories of information emerged from participants' group designs during the initial workshops (Figure 3). The categories included (ranked by perceived importance): (1) header with patient information; (2) vital sign values, waveforms, and trends; (3) findings from ABCD steps; (4) medication names, dosages, and administration times; (5) procedures, access types and their locations; (6) laboratory and radiology orders and results; (7) fluid types and amounts; and (8) disposition plan. Role-based differences in information needs emerged through analyzing the information features in individual designs, rankings in group designs, and likes and dislikes on prototypes tested in simulations (see Table 2 and Figure 5 for summary).

Header: 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 (Figure 3). For group designs, 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 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 (Figure 5).

The most debated portion of the header, however, was pre-hospital interventions. During the first set of simulations (v2, Figure 4), EM physicians, physician surveyors, scribes, and 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 (v4, Figure 4), and the header received only one dislike from a respiratory therapist. Pre-hospital information, however, emerged as important again during the second set of design workshops. After including pre-hospital information again with a more efficient layout (v5, Figure 4), users liked this version the best (Figure 5).

Vital Signs

Individual designs suggested three ways of monitoring the patient's vital signs: *numeric values*, *live waveforms*, and *trends* during resuscitations (Table 2). Only leaders and a physician surveyor did not include vital signs in their designs, noting 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

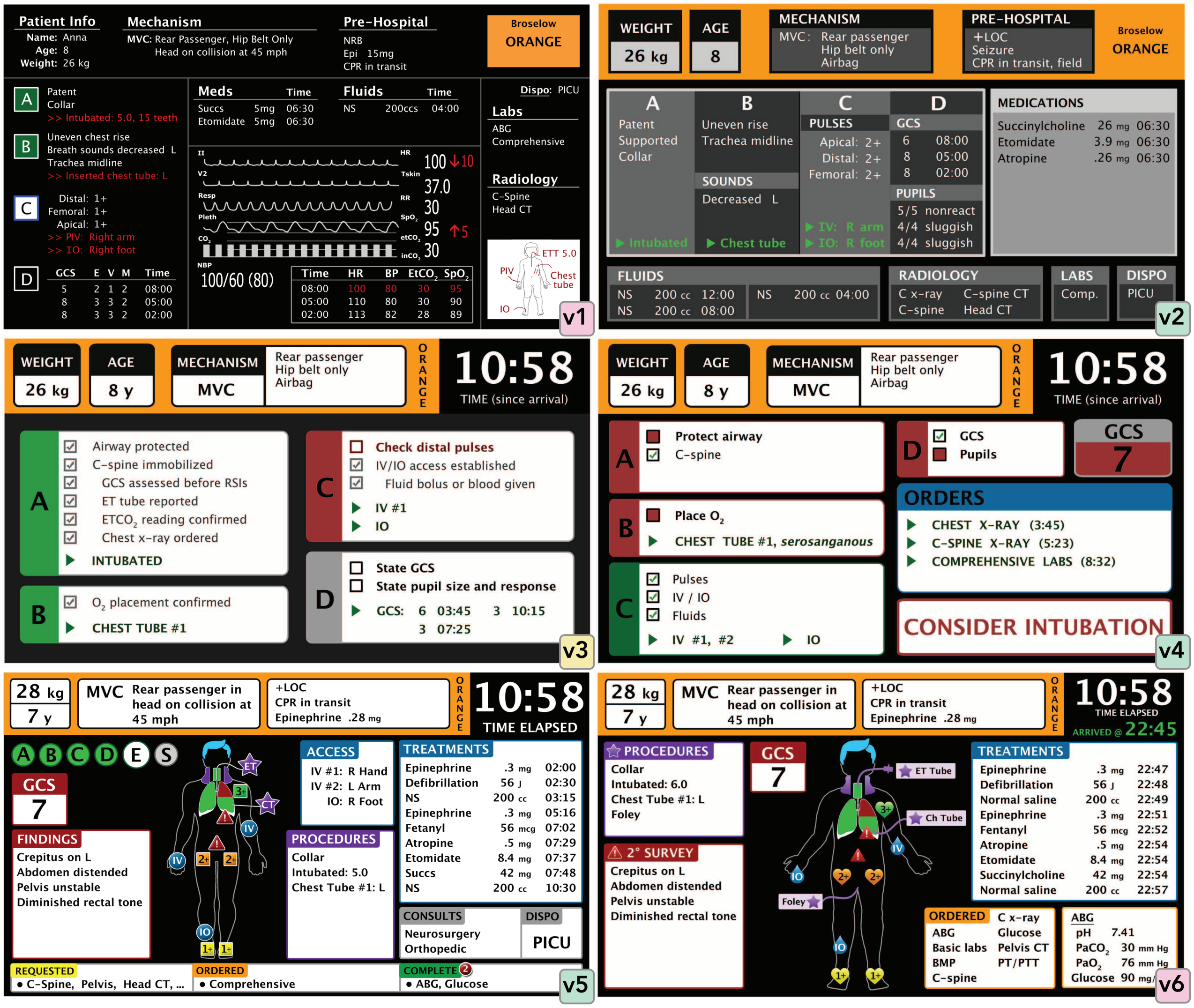

Figure 4. Evolution of display designs, moving from a process-based (v1-v4) to a state-based design (v5, v6).

most roles liked it. Scribes needed both waveforms and trends to record this data and alert the team about vital signs changes. 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 efficiently incorporate them 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 to develop a 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 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.

Patient Evaluation Findings from ABCD Protocol Steps

Information about ABCD ranked third overall. Individually, all participants from both initial workshops incorporated elements of ABCD in their designs using four methods (Table 2). The *first* method was a basic checklist of the steps; once the team completes a step, it turns green or is checked off. The *second* method was a list of abnormal findings and procedures under each ABCD step. The *third* method was extracting the elements of ABCD (e.g., a neurological exam score [Glasgow Coma Score], abnormal findings, and procedures) and then separating them into different display sections. The *fourth* method was 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 in conjunction

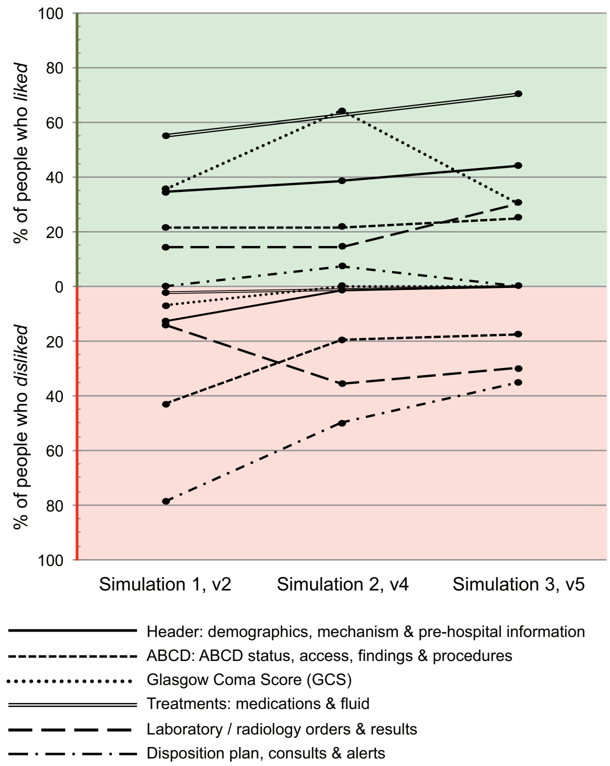

Figure 5. Evolution of participants' attitudes toward different components of the display evaluated in 3 sets of simulations.

with the more detailed second method of 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: (1) *process-based* (first and second method of presenting information organized by the order of activity) and (2) *state-based* (third and fourth method of presenting information about patient and teamwork status). After experimenting with these different methods, we found that the state-based combination of the third and fourth method (Figure 4, v5) was the most effective, as indicated by an increasing percentage of likes and decreasing percentage of dislikes (Table 2 and Figure 5).

Where we saw the most discussion surrounding ABCD from both participants and research team members was during the major shift from a list of abnormal findings and procedures under each step (second method, v2, Figure 4), to using the checklist-driven method in versions 3 and 4 (Figure 4). Emergency medicine physicians generally did not find the information about ABCD useful because it relates to the responsibilities of another role (surgical team leader). A bedside physician noted after a simulation that the checklist-driven information was not helpful because the primary survey assessment (ABCD steps) is his main focus with all of this information already in his mind, so 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 heuristic evaluations suggested that we could simplify each step and remove the less critical checklist items (v3, Figure 4). Scribe nurses in heuristic evaluations and simulations suggested providing numeric values and descriptive findings to make the checklist format more useful.

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 3 and 4 due to technical difficulties until we could capture and display this information accurately in version 5 (Figure 4).

Where participants differed, however, was in the ways they suggested treatments should be formatted (Table 2). Some roles 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 only needed the ordered amount of fluids or dosage of medications, while others preferred the amount that has actually been received by the patient or the time medications were administered (e.g., scribe nurses). 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' (v5, Figure 4). Participants in the last set of simulations responded positively to having this single, detailed list (Figure 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 only made it to one group's design. There were, however, different perceptions about the ways in which this information should be configured on the display (Table 2). The design evolved from separate lists of radiology and lab orders, to a combined list with timestamps when ordered, to a scrolling list divided by status of requested, ordered, and completed labs, to a final small list of orders with a separate section with lab results (Figure 4).

DISCUSSION: DESIGN TENSIONS

We next present the implications of two major design tensions we encountered throughout the process: process-based vs. status-based designs and role-based vs. team-based displays. As we describe each of these tensions, we discuss the findings that guided our decisions, as well as the approaches we used to resolve these tensions.

Process-Based vs. State-Based Designs

The biggest tension we encountered was between using process-based and state-based designs. The design evolution of the ABCD section demonstrates this tension well, as it moved from a process-based to a state-based design. *Process-based designs* followed a checklist-driven style and presented information organized by the order in which ABCD steps were performed. In design versions 1 to 4 (Figure 4), information was presented under each step, and the ABCD layout was used to represent the progression of the resuscitation process. *State-based designs* (v5 and v6 in Figure 4) presented a snapshot of the system's state, organizing information by the type of information produced by team activities (i.e., findings, procedures, pulse levels, and intravenous access) and their location on the patient's body. Both designs presented either *patient status* (findings and values of the patient's physiological condition) or *team status* (whether the team has performed a task).

While other researchers discussed design tensions in terms of assumptions about feasibility [9], we learned about trade-offs through trial and error. 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 and 2 had a process-based design with patient status information. Versions 3 and 4 also had a process-based design, but presented team status information. Finally, version 5 and 6 had a state-based design with patient status information. We next describe the nature of each combination and responses we received during evaluations.

Process-Based Design and Patient Status Information

The ABCD feature of the first two designs (v1, v2 in Figure 4) was process-based, showing patient status information. We tried this configuration first because it was the most prominent in individual and group designs. Each section of ABCD 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 liked the most in the first set of simulations. With this layout, however, participants felt the display was cluttered and unfamiliar because it was difficult to find information. Several participants noted that the display was not dynamic in that the information did not seem like it would update when the status of the patient changes or when the team reassesses the patient. More was needed to make the display useful than just duplicating the information that teams gather while performing each step.

Process-Based Design and Team Status Information

We thought the display might be more useful if we presented information at the teamwork level with a layer of the leader's interpretation about the team's progress. The next two designs (v3, v4 in Figure 4) were, therefore, organized by evaluation steps, but instead of showing normal and abnormal findings, they indicated whether or not the team had completed a task based on the leader's checklist. When all tasks from a step were 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. As such, the design avoided a major limitation of activity-driven designs, which is their focus on tasks anticipated at the design stage and inability to manage unanticipated events [5]. 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, with findings and steps checked off becoming irrelevant or inaccurate. Showing information linearly according to process also requires time to analyze trends. Users wanted task status represented through the information that the task produced. Furthermore, checklists are meant to catch errors in tasks that teams do routinely, which the leader at our site already does. After using this display in simulations, participants echoed that they needed abnormal findings, laboratory and radiology results, completed procedures, and treatments.

State-Based Design and Patient Status 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 (v5 and v6 in Figure 4). Although we included an image of the body in the first version, it was not feasible at that time because we just started to narrow down the information to display and the image was then too small to be useful. With the latest designs, normal and abnormal findings were included in the ABCD 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 ABCD in previous designs—Glasgow Coma Score, procedures, and intravenous access—then 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, thus we kept both.

Summary

As we experimented with different display configurations, we realized that both patient and teamwork information could be more accessible if we abandoned the checklist-like, process-based method. Our most recent design (v6, Figure 4) has patient information within state-based elements that in turn indicates team status without having to organize information using a process-based structure. Unlike EID-driven medical displays, which focus on patient data [5], 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 ABCD steps was ineffective. To make the ABCD feature valuable—after all, the entire resuscitation process centers around findings from ABCD 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 relevance to a system component (in our case, **A**irway, **B**reathing, **C**irculation) 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 information can 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. Finally, using a PD approach allowed us to design a display tailored specifically to the resuscitation setting, but also develop a template with key information features adaptable to other hospital contexts [6,7].

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. The tradeoffs of displaying individual versus group activities are also about the required amount of user attention [9]. Much of discussion with participants and within research team focused on this tension. Several considerations became apparent while developing and testing the display.

On one hand, designing different displays for each role has its advantages—it helps avoid the influence of the team's hierarchy and heterogeneity on the design to best meet each role's information needs. Mounting displays tailored for each role (at least eight displays in our case), however, is not as cost- or space-effective as two or three common displays mirroring the same information. Multiple displays in a small space may also introduce confusion about where to look and each display would need to be strategically placed. 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.

On the other hand, designing a team-based display that summarizes the key information also has its advantages—all team members share the same information to "get on the same page," and it is easier to know where to access information. The notion of "getting on the same page" was a recurring theme throughout the design process when participants described the main purpose of the display. This finding resonates with previous work that argued for common displays in group settings to support establishing common ground and conventions [7,8,21]. In addition, team-based displays have been proposed in other safety-critical settings characterized by multidisciplinary teams, precisely because they allowed for efficient common grounding [e.g., 3,4,10]. There are still disadvantages in that it is difficult to reconcile different needs, especially because team hierarchy and vocal participants could influence the information selected to display. Despite these challenges, we chose this second approach because it emphasizes efficiency and consistency.

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 their ideal display to suit their role, discuss the various information features, reach consensus, and then create a design as a group (Figure 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, because they would be able to individually rank the top five information features they needed the most. Information ranking provided participants with equal opportunity to voice their opinion, despite any differences in power and outspokenness; it also acknowledged these differences in the process of identifying individual priorities and those shared across roles. This approach helped us determine the overall rank order of group needs by analyzing the ranks assigned by participants. We used a similar strategy in simulation sessions. 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 further examine how roles were affected. Top-down methods such as work domain analysis (WDA) [5] 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 individual designs and compared them to the consensus-based group designs. We checked if 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 they were the least 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 less. 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 of their needs. Even so, we incorporated most features except name, pupils 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 (v5, Figure 4).

CONCLUSION

Through participatory design workshops, heuristic evaluation, and simulated resuscitations, we identified and prioritized the information features that trauma resuscitation teams require to coordinate their work. Taking an iterative participatory design 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* designs and *role-based* vs. *team-based* displays—and how we reached balance through different approaches. Our work has implications for HCI researchers interested in (1) using participatory design to develop shared information displays for hierarchical and multidisciplinary teams, and (2) designing information displays to support *ad hoc*, time-critical teamwork. The next phase of our research will focus on implementing and refining the display prototype for use during real trauma resuscitations.

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