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Envisioning a Shared Checklist Display to Support Teamwork During Emergency Medical Care

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Abstract. Information technology and systems in healthcare are becoming increasingly complex and dynamic, requiring design approaches that consider not only providers' information needs and work practices, but also their perceptions and expectations about technology. In this paper, we describe an exploratory study conducted to assess the feasibility and impact of a shared checklist display for supporting teamwork during trauma resuscitations. Using the concept of technological frames, we explore how members of multidisciplinary emergency medical teams perceive current technology and what they expect from a future shared checklist display. Our results showed discrepancies in team members' perceptions of technology and its roles. Some care providers envisioned a shared checklist display as a tool for achieving a global view of the process, improving communication and maintaining situation awareness. Others perceived it as a point of distraction, where team members may be checking each other's work to ensure accuracy

of documentation. These requirements and limitations extend beyond the capacity of a simple checklist, while also shifting the privacy of work from individuals to the entire team. We conclude by discussing design implications for a future shared display and how shifting to a multi-display environment within a safety-critical context may transform work practices.

Introduction

CSCW research has long focused on designing socio-technical systems for complex work, including computer-mediated communication tools, decision-support systems, shared displays, and cognitive aids. To design these systems, researchers have applied user-centered approaches to study social, informational, organizational, and technical aspects of work (Abraham and Reddy, 2008; Delaney et al., 2012; Faraj and Xiao, 2006; Houben et al., 2015; Kaplan and Fitzpatrick, 1997; Østerlund, 2008; Robbins, 2011; Whittaker and Schwarz, 1999). Fewer works, however, specifically studied user perceptions of technology, long before this new technology was conceptualized. For example, Bardram et al. (2006) ran field studies to identify collaboration and awareness issues in a surgical ward, and then conducted a series of design workshops with clinicians by using white boards as an inspiration for the wall-display system AwareMedia. Similarly, Söderholm and Sonnenwald (2010), explored user perceptions while brainstorming features of a prototype 3D telepresence technology for emergency care scenarios during envisioning workshops with stakeholders. This type of an early understanding of user preferences about technology is especially important in medical domains where user adoption and smooth continuation of work practices are critical.

In this paper, we describe our efforts during the conceptualization phase of a new technology in the emergency medical setting of trauma resuscitation, where we focused on exploring trauma team roles' assumptions, expectations, and knowledge of technology through a series of envisioning workshops. We used an existing, tablet-based checklist in a regional trauma center to first elicit user perceptions about sharing the checklist content on a wall display during patient care and then applied technological frames (Orlikowski and Gash, 1994) to interpret the findings. Although the resuscitation domain provides many opportunities for innovation, designing computerized support for multidisciplinary, high-risk collaboration is challenging. Prior research has shown that introducing new technology in safety-critical medical contexts can improve task performance and reduce errors (Gonzales et al., 2016; Hart and Owen, 2005; Kulp et al., 2017, 2019; Thongprayoon et al., 2016; Wu et al., 2014). Similarly, past efforts to project technology onto shared displays have shown positive effects on teamwork, leading to improved communication in settings like operating rooms (Ong et al., 2015; Parush et al., 2011), trauma units (Faraj and Xiao, 2006; Xiao et al., 2001), and

Figure 1: An example trauma bay equipped with medical tools and instruments, large wall displays, and other artifacts.

emergency departments (Bjørn and Østerlund, 2014; Østerlund, 2008; Wu et al., 2011). These studies, however, implemented design solutions based on user observations or analysis of interaction logs, without first exploring user perceptions and unintended consequences of the proposed systems.

The envisioning workshops helped us develop an understanding of team members' (a) perceptions of technology and its role in their work, (b) reactions to shifting information privacy from an individual artifact to a shared display, and (c) expectations of how the shared information would affect team performance. We therefore make two contributions to CSCW: 1) an understanding of role groups' visions of a new technology and its implications for their work in a complex, high-risk medical setting, and 2) design implications for a future technology to support time-critical teamwork.

Background and Related Work

Teamwork and Artifacts in Trauma Resuscitation

Trauma resuscitation is a team-based medical process that requires rapid decision making and lifesaving interventions in a time-critical setting (Figure 1). Trauma teams are hierarchical and interdisciplinary, consisting of seven to 15 members, each having a specific role and set of responsibilities (Sarcevic et al., 2012). An attending surgeon, fellow, or senior surgical resident assumes the role of team leader (TL) to guide the team, make decisions, and formulate a care plan. During patient evaluation, the team follows a standardized protocol called Advanced Trauma Life Support (ATLS). The protocol consists of two surveys: (1) the primary survey rapidly evaluates the patient's major physiological systems like Airway, Breathing, blood Circulation, Disability or neurological exam, and Exposure

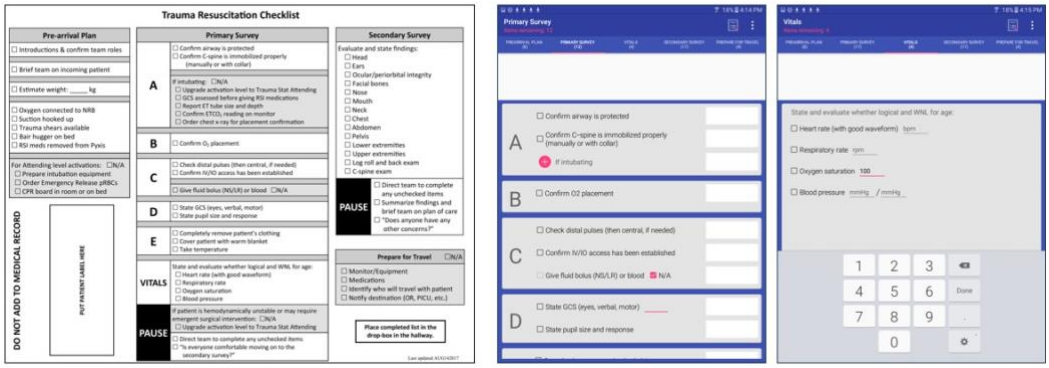

Figure 2: Paper checklist (left) and digital checklist interface for the primary survey (middle) and vital signs (right) screens.

assessment (ABCDEs), and (2) the secondary survey includes a head-to-toe patient evaluation to identify other injuries. To ensure protocol compliance and timely completion of all tasks, the leader administers a trauma resuscitation checklist that was designed for the leadership role only; no other role views or uses this checklist during resuscitations (Figure 2). This checklist is available in both paper and digital (tablet) formats, and team leaders can choose between the two based on their preferences. The checklist is not integrated with the official patient record and any information recorded on the checklist is not available to team leaders after they complete the resuscitation. The checklist has five sections: pre-arrival plan, primary survey, secondary survey, vital signs, and prepare for travel. Team leaders have been using this checklist during actual patient scenarios to check off items corresponding to resuscitation tasks, enter patient values (e.g., blood pressure), and take notes about exam findings (Kulp et al., 2019).

Other groups (team roles) include the Emergency Department physicians (ED), who assume the co-leadership role with surgical leaders. Bedside physicians (BP) perform the hands-on evaluation of the patient, reporting exam findings out loud for the team. Scribe nurses (REC) document the event, recording patient information, interventions and exam findings on a paper flowsheet. Medication nurses (MED) prepare medications, while the bedside nurses (BN) administer them. The nurses are drawn from the Emergency Department nursing pool and can rotate between roles depending on the nursing needs during resuscitations. Anesthesiologists (ANST) and respiratory therapists (RT) manage the patient's airway. Other specialists or staff may also be called, including neurosurgical, orthopedic, or pediatric intensive care unit (PICU) fellows, or radiology technician.

Trauma teams are ad hoc and team members may not know each other. To support coordination among roles, one of the first items on the checklist requires team members to introduce themselves and announce their role on the team. Teams also use several other tools and artifacts to facilitate teamwork, including the vital signs monitor (also projected on a large wall display), timers and clocks, the

i-STAT device for analyzing blood samples, a portable x-ray machine, the Pyxis system for dispensing medications, and a pager for notifications.

Approaches to Shared Display Design in High-Risk Work Settings

Shared displays have been introduced to improve collaboration and situation awareness in many team-based work settings, including healthcare. The approach to their design has varied from simple projection or input from an individual device (Hulfish et al., 2018; Wu et al., 2011), to ethnographic studies (Faraj and Xiao, 2006; Østerlund, 2008; Xiao et al., 2001), to design workshops with clinicians (Kusunoki et al., 2015), and to more advanced solutions that automatically capture information from sensors (Bardram et al., 2006; Parush et al., 2011). Hulfish et al. (2018), for example, simply projected a static paper checklist on the wall in a simulation setting to examine the effects of a shared trauma resuscitation checklist on task completion and provider mental workload. Although this shared checklist significantly decreased the number of omitted tasks, the display solution did not include any user studies to derive or design dynamic or interactive components. In contrast, our work explores how various team role groups perceive the value and importance of technology for their work and their expectations about the interactions with the technology. In an earlier study, we identified information needs of complex medical teams through interviews, video review, and design workshops, finding that a shared display could better support teamwork (Kusunoki et al., 2015). In this study, we envision this shared display by drawing on an existing technology (a digital checklist) that can provide dynamic information based on user input (e.g., patient status or team process) to support team situation awareness.

Others have also conducted field studies, observed work practices or interviewed clinicians to understand their information needs prior to designing systems (Bardram et al., 2006; Parush et al., 2011; Xiao et al., 2001). For instance, Parush et al. (2011) interviewed resuscitation team members to understand their roles, goals, and patterns of communication to create a conceptual design of a shared display for cardiac operating rooms. The concepts were evaluated through focus groups with healthcare professionals and iteratively designed based on feedback. An interdisciplinary team similarly conducted a field study to derive design directions for a shared visual representation of the neurosurgical symptoms to better support cooperative tasks of clinicians (Presnov et al., 2019). These previous studies have used a range of methods for designing shared displays to support teamwork, including understanding user needs and, in some cases, designing with users. In this work, we adapt the concept of technological frames to guide our envisioning workshops to both understand user assumptions and expectations while also prototyping initial system concepts with end users.

Technological Frames

Technological frames is a conceptual framework for studying the underlying assumptions, expectations, and knowledge that people have about technology (Orlikowski and Gash, 1994). Individual's technological frames have been shaped by past experiences or inclusion in social groups, forming their perception of the functionality and usefulness of technology for their work. These frames of reference may vary between key groups within organizations or roles within teams, posing challenges to technology design and development. When identified properly, however, technological frames provide a valuable lens for understanding how and why people interact with technology. In her classic study of the Notes groupware, Orlikowski (1992) applied technological frames to explore how technologists, managers, and consultants approached the introduction of new technology, finding incongruence between the groups' technological frames. For example, managers expected to see transformed business operations after technology was introduced, while users believed the technology was implemented solely to control their work processes. These insights resulted in three domains that characterize three different technological frames of the various groups: (1) the nature of technology, (2) technology strategy, and (3) technology in use. The results further suggested that recognizing differences in mental models about technology is important because cognitive habits that formed through initial exposure could be difficult to change later. Majchrzak et al. (2000) similarly studied the deployment and adoption practices around a virtual system for teamwork, identifying a shift in team hierarchy based on use behaviors, expectations, and adaptation over time. They found that collaborative technologies should include features that can adapt to the changing needs of users as their understanding of the technology evolves. We build on this work by understanding initial expectations of the technology and discussing potential adaptive features with various role groups to determine how the technology can best support collaborative work. We identify the information needs specific to each role group and derive design recommendations for a system that can support various user groups of a single collaborative technology.

Technological frames have also been used for evaluating deployed systems in medical settings, including Electronic Health Record (EHR) systems (Bardram and Houben, 2018; Jensen et al., 2009; Karsten and Laine, 2007), electronic medication prescribing (eRx) (Agarwal et al., 2010), and a 3D telepresence technology (Söderholm and Sonnenwald, 2010; Sonnenwald, 2013). Jensen et al. (2009), for example, studied how a group of physicians in two Danish surgery wards used a recently implemented Electronic Patient Record (EPR) system. Shortly after deploying the system, researchers conducted observations at each of the two wards, interviews, and a focus group with physicians to understand their sensemaking of the new technology. While physicians were open to the new system, they used it in ways that challenged its intended operation, which in turn created work-arounds that reinforced the old way of working. Although most prior studies applied

technological frames after system deployment, Orlikowski (1992) argued for understanding technological frames of different user groups prior to deploying a new technology to improve adoption rates. Early identification of where and why frames are incongruent or inconsistent can help preclude technology misuse, while also helping users understand the changes that may emerge with new technology. For example, Söderholm and Sonnenwald (2010) evaluated the benefits and feasibility of a prototype 3D telepresence technology for emergency care scenarios through a set of workshops. The authors defined three categories of technological frames in relation to the role groups who would be using the proposed technology; (1) physicians and nurses who would use the technology to provide services, (2) EMS managers who would manage people using the technology, and (3) IT professionals who would provide technical support for the technology. These workshops allowed the researchers to understand user perspectives on a new technology and its compatibility with current workflows, as well as to derive implications for system development and adoption.

Similar to prior studies, we chose to conduct the envisioning workshops before any prototyping or development of the shared checklist display had begun to understand the initial technological frames of different role groups within a multidisciplinary medical team. However, our approach differed because we had an existing, tablet-based checklist in regular use by a trauma team leader. We previously compared the impacts of this digital checklist and an earlier paper version on task performance, finding little difference between the digital and paper formats (Kulp et al., 2019). Now that we better understand the effects of this technology on task performance, we are further exploring how the checklist could support situation awareness for the entire team. We therefore used this artifact as a prompt and encouraged participants to consider what the future technology might look like, what information they expected to see, and how this new technology could fit into their workflow. Based on Orlikowski (1992), we also define the technological frames as different assumptions, expectations and knowledge of current and future technology. Using the workshop discussions, we extracted three frame domains that represent the individual technological frames of each user group and then identified areas of congruence and incongruence in each frame domain, which will now inform our design decisions.

Methods

To understand trauma team members' perceptions and expectations of a shared checklist display, we conducted four mixed-role envisioning workshops with participants representing different team roles (Table 1). The study took place at a level 1 trauma center in the U.S. mid-Atlantic region on four separate days between May 2017 and April 2018. The study protocol was reviewed for ethical issues and approved by the hospital's Internal Review Board.

Table 1: Summary of participant demographics per workshop, including team roles in each workshop and median years of their experience.

WSHOP #	**Team Roles**	**Experience** (median, years)
WSHOP#1	2 bedside physicians, 1 nurse	6
WSHOP#2	2 surgical team leaders, 2 ED physicians, 2 bedside physicians, 1 nurse, 1 anesthesiologist	2
WSHOP#3	2 surgical team leaders, 1 ED physician, 5 nurses	7
WSHOP#4	2 bedside physicians, 1 nurse	3

Participants

We recruited 22 unique participants (16 females and six males) representing six of the seven trauma team roles, including seven team leaders (three ED physicians and four surgical team leaders—three fellows and one senior resident), six bedside physicians, eight nurses, and one anesthesiologist. We intentionally planned for heterogenous (consisting of mixed role groups) workshops, ideally with all team roles represented in each to emulate the team makeup during an actual resuscitation. Because organizational power structures and team hierarchy play an important role in how people discuss and express perspectives in a group setting (M. J. Muller, 2002), we implemented several strategies to mitigate the effects of groupthink. For example, we started each discussion topic by first asking participants to independently perform a task (e.g., write responses on sticky notes, create an individual vision/sketch) and then share those responses as a group. Distribution of roles and participants varied between the workshops (Table 1), mostly due to the challenges in recruiting busy trauma team members. Team roles with significant representation included surgical and ED team leaders, bedside physicians, and nursing roles. We could not recruit a respiratory therapist and only one anesthesiologist participated in the study. Despite these challenges, we identified major technological frames and determined their levels of congruence between team leaders (surgical and ED), bedside physicians, and nurses—the three critical user groups for adopting new technology in this environment. All study participants are hospital employees and were compensated for their participation.

Data Collection and Analysis

We conducted the envisioning workshops in the hospital's emergency department, near the trauma bay, with some team members coming immediately after working the night shift and others beginning their work day. Each workshop was an hour long and consisted of individual activities, sharing individual work with the group, and group discussions. We started each workshop with an overview of the study, participants' rights, and introductions. Participants were then asked to recall the

most recent resuscitation they worked and write on a set of post-it notes how they obtained information about the patient when they arrived and throughout the event. Next, each participant shared their responses with the group. We followed with a series of open-ended questions focused on current use and perceptions of technology in the trauma bay, including the paper and digital checklists used by the team leader. All participants had an opportunity to explore both checklist formats during the workshops. Participants then envisioned how this individual checklist could transform into a shared display and discussed what information they expected to see on the display. This step included interactive components such as sketching and prototyping to visualize the layout and information distribution. Each participant presented their prototype to the group, explaining what information they expected to see and how the display would function. Reflecting on the prototypes of this shared checklist, participants discussed its potential effects on teamwork, privacy, and workflows. We concluded the workshops by asking each participant to think about the benefits or concerns of this future technology, write those on post-it notes and post them on the wall for group discussion.

Workshop discussions were audio recorded, and audio files were transcribed and then analyzed using a qualitative data analysis tool, Atlas.ti. We used a multi-step thematic analysis to understand different providers' interpretations of technology and identify frame domains. The data were first coded into six groups labeled by the trauma team role (e.g., team leader or bedside physician). For each team role, we then identified statements that reflected assumptions, expectations and knowledge of the current and future technology. We also examined statements across roles to determine common themes.

Results

We identified three frame domains that characterize trauma team members' perceptions and interpretations of current technology, as well as visions of a shared checklist display for supporting teamwork: (1) *importance of technology for work*—refers to the perceived importance of current technology for work and understanding of capabilities; (2) *private versus public work*—refers to the shift from managing individual information spaces to publicly sharing information on a wall display; and (3) *multiple roles of technology*—refers to understanding and expectations of the roles that a future technology may take and any consequences associated with use. The workshops provided an opportunity for identifying areas of congruence and incongruence between the roles' perceptions, expectations, and knowledge of information technology. For example, we observed divergence among team roles within the technology importance frame. Team role groups also differed in their expectations when discussing the shift from private to public information spaces, yet agreed that the introduction of a shared display would alter

information privacy. Although participants envisioned many functions for the display under the third frame, we observed overall congruence among roles.

Relative Importance of Technology for Work

In discussing participants' assumptions about current technology in the trauma bay, we found that technology plays an important role in performing medical work, but not all team members interpreted this importance in the same way. Rather, team members explained their technology use in distinctive ways, depending on their role on the team. Team leaders are responsible for guiding the team through the protocol in a timely manner, while ensuring that all tasks are completed. In doing so, they rely on a range of tools and artifacts, including the checklist (both paper and digital versions), vital signs monitor, timer, trauma flowsheet, real-time video transmission of a procedure, and wall charts. One surgical team leader (TL#1) explained the importance of the room timer to their work: *"I like the little clock that's timing things because it gives me a sense of how long I've actually been in the room so I can expedite things to get the kid out or finished."* Elapsed time since the patient's arrival is important information for leaders' work, as confirmed by prior research (Kusunoki et al., 2015). Because every minute matters, the leaders must ensure thorough yet efficient and timely performance of all tasks. The leader is positioned at the foot of the bed, overlooking the patient and team and facing the wall with the timer and large wall displays. No other team role mentioned the importance of the timer.

Another team leader highlighted the importance of a camera attached to the tube used to treat and manage the patient's airway. The team leader explained that the camera enables better training and confirms the outcome of the treatment:

> "Another piece of technology that not everybody interacts with is the camera attached to the endotracheal tube and we are able to watch other people intubate the patient, and I think that has provided huge levels of safety training as well as confirmation and has been instrumental in terms of ability to manage the airways." (TL#2)

In contrast to leaders who have an unobstructed view of the monitors due to their positioning, bedside physicians explained that they do not use the vital signs monitor or vitals projected on the wall display because they are standing next to the patient, turned away from the monitors:

> "I don't feel like I look at the monitors. I mean they [leaders] do, it's just our positioning in the trauma bay and we'd have to turn around and look behind to see the monitor, so I don't look at it…I look at the patient so personally in my role it's not as important." (BP#3)

> "For my specific role, I don't use a lot of technology and yes, there's a monitor but I don't even look at the monitor and other than the light [otoscope] to look at the eyes, my role is not heavily technology based." (BP#2)

A third bedside physician agreed that their role does not heavily rely on technology but also said that they would sometimes turn around to look at the monitor. One of the responsibilities of bedside physicians is to verbally report the

patient's vital signs during resuscitation, so looking at the monitor provides a quick reference before reporting the values.

The scribe nurses described that all charting work is still handwritten and paper-based, and that *"the only thing we would use electronically is the [vitals] monitor and the Pyxis machine to get the meds out."* The scribes use the vitals monitor to periodically record patient vitals on the multi-page paper flowsheet because patients may deteriorate at any time, requiring frequent reassessment and history of values. The medication nurse uses a paper-based reference guide to determine medication dosages and then retrieves those medications from the Pyxis machine. Although technology plays an important role in the workflows of many trauma team members, these results suggest that incongruences exist in how different roles perceive the importance of technology for their work.

Importance of the Checklist

Our workshop discussions also focused on the use of the leader's checklist because our overall goal was to assess the feasibility of designing a shared checklist display. Team leaders explained that the checklist mattered to their role but might not affect anyone else in the room because leaders are primary checklist users (e.g., *"I'm not sure it affects anyone other than us, that I know of," TL#2).* In contrast, other team roles thought of the checklist as a tool that supports the work of the entire team and not just the leader. A scribe, for example, offered this explanation:

> "My understanding from a nursing standpoint is that it's almost like the leader's version of the 3-page flowsheet and plethora of things that we fill out, to make sure that everything is getting done and we haven't forgotten a vital part of assessment or planning." (REC#1)

A bedside physician (BP#1) described the checklist as an assessment tool that helps reduce the cognitive load of the team:

> "It is a standardized way to approach [patient] assessment, but also a big component is taking the thinking out of it so everyone gets oxygen, everyone gets temperature control, and so on."

Participants also mentioned how the checklist facilitated information handoff from one team leader to the next, as explained by another bedside physician:

> "…if it's a trauma stat now or if someone is late, [the checklist] can help transition from team member to team member, someone else could pick up the checklist and take on that role until the actual team leader comes." (BP#2)

We have informally observed this handoff several times during our visits to the hospital. In one case, an ED physician filled out the pre-arrival section of the paper checklist and handed it off to the surgical team leader when they arrived. In a different case, the ED physician used a paper checklist for pre-arrival tasks and the surgical team leader continued with rest of the tasks using the digital checklist. One of the ED physicians explained how the checklist served as a tool to get updates about an ongoing resuscitation, especially when they arrive late:

> "I would say the simple checklist as technology is facilitating our processes. As the ED attending, when a fellow is running a trauma, I may just walk in and look over their shoulder, see where we are on the checklist, look at the patient, everyone seems like they got a handle on

things and I just kind of step back. I don't need to say what's going on, where are we at when I hear the surgical junior say something." (ED#1)

The checklist has become an indispensable component of the resuscitation workflow because it reduces the team's cognitive load and keeps the team organized. Now that the checklist has moved to a digital platform, we can take advantage of its potential and project the checklist information on a shared display.

Perceptions of Private versus Public Work

Discussions about projecting the leaders' previously private work on the checklist for the team in real time showed how team members may interpret the changes in information privacy as it moves from an individual checklist to a shared display. Team members also suggested additional data points for the display, which may affect the privacy of information for other roles as well.

Views on whether the digital checklist is a private or public document differed among team roles. Some participants agreed that the checklist is only for the team leader because it contains their notes about the resuscitation process, patient status, plan of care, and other information. Some thought that the checklist is private because it contains patient information. Others believed that the checklist is used to assist the team and is therefore a public document, as stated by one bedside physician (BP#2): *"I view it as a document to help the entire team, so, public."* One of the ED physicians (ED#1) posed a question to the group: *"Do you think it would be different if [the checklist] was displayed up there versus private to the team leader?"* This question led to a discussion about the effects of the shared information on teamwork. Participants expressed a concern that the display could be distracting because roles assessing the patient would be checking if their verbalized findings were added to the display, as shown in this exchange:

"Of course [it would be different] because then it's distracting to the whole team." (ED#2)

"Then people are like 'oh we said this but you didn't put it up there.'" (BP#4)

"Right, 'oh you didn't catch my abrasion I called out, I think it should be up there but it's not' […] some people are more focused on different things, have different concerns in your roles, and everyone should be concerned on the whole checklist." (ED#2)

Hearing this discussion, two bedside physicians commented that regardless of who can see the checklist, any information marked or written on the form is public because it was previously verbally called out or shared through reports. In other words, these participants thought that physically displaying the checklist information for the entire team would not change its already public status. What could change, however, is access to information by people outside the trauma team, which might lead to breaches of privacy. The resuscitation rooms are often frequented by other personnel and people, like social workers, patient family members, or police, who would now see the displayed information: "*It's all shared within the room, I mean it's shared verbally now, but I guess there's another*

question, now that we're displaying traumas in the social work area, you know, is that like a privacy issue?" (BP#4) This comment revealed a new concern related to shifts between public and private work that now involves not only leaders versus team, but also trauma team versus everyone else.

Displaying the checklist data on a shared display would allow the team to view the leader's interactions with the checklist in real time, including items being checked off, values entered, or notes taken. The participants' expectations of the display, however, exceed that of a single person entering information. One bedside physician proposed distributing the responsibility of data entry by allowing other team members to enter information. For example, the leader would be checking off the checklist items, the scribe would be entering vitals or patient values, and the medication nurse could enter administered medications using her interface:

> "In a way, I think it would be ideal if the checklist could be manned by several people, so the team leader does exactly what they've been doing on their checklist, which is just focusing on the surveys and then the med nurse would document medications and the nursing administrative liaison would document labs and consults, so people can still use it as a reference, but it's not one person in charge of everything." (BP#2)

A bedside physician from a different workshop explained the importance of the checklist to organize the room and all team members, and to distribute the preparatory tasks across the team prior to patient arrival:

> "My thought was to display a checklist of everything that needs to be done before the kid arrives so that everybody participates in making sure the oxygen is there, the suction is there […] I think that would help so we can see what's there and what's not because it's always sort of a shouting match and 'oh we forgot this' because not everybody can see that [check]list now." (BP#5)

One of the scribe nurses suggested that their data entry from the flowsheet, especially when it becomes electronic, could be coupled with that of the leader's entry from the checklist to contribute to the information on the shared display. As a counterargument, a bedside physician (BP#1) suggested an entirely new role for administering the checklist: "*I was even thinking as to who would do it, ED attending or I don't know, or should it just be a separate role in itself?*"

Implementing these ideas, whether feasible or not, may impact the team workflow. The leaders echoed this concern, explaining how they must focus on the patient and checklist, and any extraneous inputting of information would only distract them. Furthermore, with several roles inputting information for the shared display, more individual work would become public. Any errors or inaccurate information could change the team dynamic and affect patient care.

Multiple Roles of a Shared Checklist Display

Three distinct themes emerged during the workshops as we discussed user expectations of a checklist display: (a) display as an information source, (b) display as a tool to support communication, and (c) display as an awareness tool.

Display as an Information Source

While sketching and discussing the types of information expected on a shared checklist display, participants frequently came back to the idea of having checklist items automatically update on the display as they are checked off on the tablet. This portion of the display would show checked items and upcoming unchecked items, as well as highlight any items where the leader took a note because of an abnormal exam finding. Bedside physician #1 explained their sketch (Figure 3(a)) as follows: "*I'm envisioning ABCDE [steps] similar to what's on the tablet right now, that's scrolling going down to the secondary survey with highlighted any pertinent positives.*" The leaders suggested an activity summary with exam findings at the completion of the checklist, explaining how this information could help them remember the findings and formulate a care plan:

> "I think what would be useful at the end as a recap, if we had a final screen that popped up, here's the things we wrote down that were pertinent, cause the only things I write down, if pupils are normal I just check it, check the box, we did that, and then if there's seatbelt sign or significant abdominal tenderness, I'll write that over in the little box, and if those little things popped up at the end [on the display] when we recap, that would be helpful." (TL#2)

While many of the information items that were discussed already appear on the checklist, participants also expressed the need for several new types of information that are beyond the scope of the checklist. Prior studies of shared displays for supporting awareness in high-risk medical domains identified a need for information related to patient and process status (Bardram et al., 2006; Wu et al., 2011; Xiao et al., 2001). Our participants similarly mentioned the need for medication orders and administration times, consultations, and a process summary. Multiple roles also suggested a pre-hospital information summary at the top of the display. Although the current checklist does not contain a section about pre-hospital information, prior work has shown that leaders often write this information in the checklist margins (Sarcevic et al., 2016). An ED physician drew a sketch with constant information that is static, patient values that are dynamic and scrolling, and then a section for the existing checklist items that update in real time as the leader checks them off (Figure 3(b)). Bedside physician #1 had similar ideas for their sketch (Figure 3(a)) as well:

> "I'm envisioning the constants – whoever the patient is, medical record, age, weight, mechanism of injury, so it's a quick description that's not going to change, along with pre-hospital interventions or any meds, you know, CPR times 2, 20 minutes in the field, and then scrolling current vitals [points to top right], interventions and meds, again scrolling, and then possibly after secondary survey is done you get a patient summary, next steps, orders, chest x-ray, basic labs, again so everyone is on the same page as to what we're waiting for, and then possibly patient disposition at the bottom." (BP#1)

Participants also suggested showing trends in vital signs that would allow for quick assessment of the patient condition and rapid decisions. A team leader envisioned the role of this shared display as a visual aid for determining the care plan based on changes in patient vital signs:

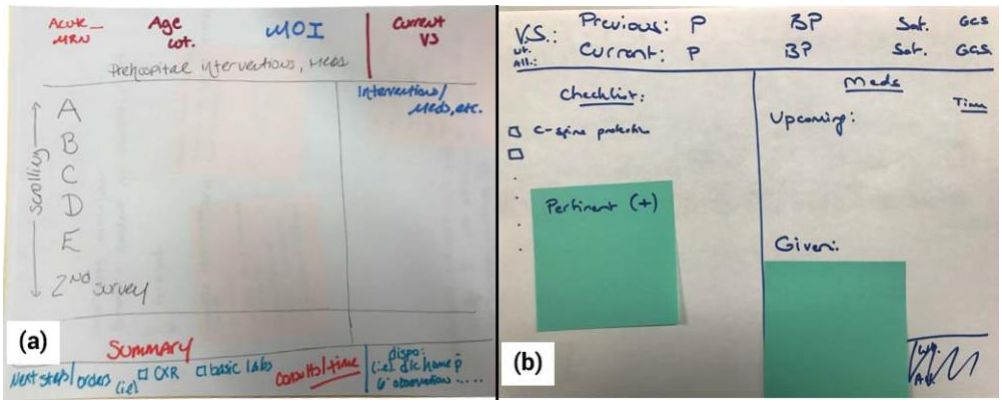

Figure 3: Sketches of the envisioned displays by bedside physician (a) and ED physician (b).

> "I think that the vitals trend is actually a really good idea because sometimes that alone is a really good visual indication of a patient that is very stable or very unstable. If you see a low blood pressure, you are like heart rate is slowly going up, you might not necessarily notice the end point value, but if you see a trend it's like a visual reminder." (TL #1)

Some participants voiced concerns about the fine line between the display providing necessary information and becoming a distraction point. The fear was that team members would fixate on the display instead of focusing on the patient, as explained by an ED physician:

> "I think there's an important downside of too much information up there, like vitals, are they stable, so I think it's like we're all looking up while we're supposed to be focusing on the patient, nurse is supposed to be focused on getting the blood pressure instead saying this is not pertinent, just needs to be focused on the patient." (ED#2)

Display as a Communication Tool

One salient theme throughout the workshop discussions was the impact of a shared checklist display on team communication. Trauma resuscitations are hectic and verbal reports are often missed or incomplete because of ambient noise and overlapping speech. Participants agreed that a shared checklist display could help improve teamwork and communication. A bedside physician commented: *"It could keep everyone on the same page. People tend to focus on their own roles, but it also pulls in a global view of where we are, what we need to do, and priorities."* (BP#2).

Another bedside physician (BP#1) and a scribe nurse (REC#3) saw the display's positive effects on team communication when team members arrive after the primary survey had started and ask redundant questions ("*A display would keep everybody on the same page and eliminate some of the redundancies of people asking if something has been done.*"). For scribes, the display could provide a reference for missed or incomplete information in the record:

> "When you're documenting all of this stuff is very easy to miss, what has been missed in all of the three pages […] it's almost like a second check to make sure we're getting all of our documentation done as well." (REC#1)

As with any technology deployment, there is an anticipation of the system malfunction and a need to revert back to the workflow prior to the use of a new technology. Our participants expressed concern that if the digital checklist or shared checklist display stopped working, they needed a quick way to revert back to the paper checklist, which could alter the team's communication or task coordination:

> "The situations when it [technology] goes down, we have to be able to get back to paper really quickly in a nimble way." (ED#1)
>
> "That's always an issue." (BP#4)
>
> "Yeah, always have the backup that's easy, and this is just one sheet of paper. […] Paper checklists are always in the room so it's easy to just pick it up and use." (TL#2)
>
> "As long as those [paper forms] don't go away." (BP#4)

Display as an Awareness Tool

The dynamic nature of trauma resuscitation requires team members to simultaneously work on several tasks. Because bedside physicians often need to verbally repeat the findings, they commented that a shared display would provide a quick reference for the progress in relation to the checklist: *"A one liner at the top so if people come in late they know at least the summary statement."* (BP#2) Another bedside physician suggested a simple display with only checklist sections and the status progress:

> "It would be helpful to have the display primarily for people who are coming into the trauma at different time periods, so if it was a chaotic situation where they weren't able to get a clear picture of what was going on, they could see 'oh they're on secondary, this is what has been done'…and in terms of the display I think because traumas are so fast-paced and there is a lot going on, it would be helpful to display the least amount of pertinent information as possible, so primary survey, 'check', has been done and if there was any intervention that would be helpful to make note of like, 'airway: intubated'." (BP#5)

One of the scribe nurses proposed a split-screen display that allows for detailed checklist items and pertinent findings, as well as a high-level summary of where the team is in the protocol:

> "Maybe it should be a split screen where one screen is an actual checklist and the other screen is a summary of what's been done so it can be like primary has already been done and if someone walks in they can be like 'ok we're at the secondary right now'." (REC#3)

Discussion

The results from our envisioning workshops with trauma team members showed that technology serves an important role in emergency medical teamwork and that a shared checklist could bring an added value to the team. We also observed role-based congruences and incongruences across all three frame domains. As such, our results fulfill Orlikowski and Gash's expectation (1994) that further empirical work

will expand the frame domains reflecting specific technologies in unique contexts. Below we discuss the challenges that the observed alignments and misalignments in perceptions of new technology pose for designing a shared checklist display for emergency medical care processes.

Designing for Misaligned Perceptions of Technology

Although technology serves a critical role in the work of many trauma team members, we observed differences in how team role groups perceived the importance of technology. One of the main incongruences between team roles that emerged early in the workshops was that bedside physicians do not use current displays for a visual reference because their focus is on the patient and hands-on evaluation. This initial assumption about technology suggested that bedside physicians would most likely develop resistance toward a future shared checklist display or simply not use it, even though fellow team members perceived the new technology as useful for the team. Later in the sessions, however, we observed a shift in bedside physicians' assumptions, when they envisioned new information types for the checklist display in their prototypes. These observations suggested that the initial frames about current technology evolved throughout the discussion, making the bedside physician role more open to the idea of a shared checklist display. Schubert and Röhl (2017) argued that in work environments, sensemaking consists of making, acquiring, maintaining and appropriating technology artifacts. These artifacts may initially become invisible as they become embedded into workflows, but as the purpose or materiality (e.g., wall display) of the technology shift, the technology may become more visible to the entire organization (or team). Forcing users to adopt a technology they do not perceive useful may lead to resistance or misuse of the system (Agarwal et al., 2010), making it important to not only understand the initial technological frames but also how they evolve over time. Orlikowski and Gash (1994) argued for tracking frames of role groups over time to better understand the underlying reasons for incongruence and identify appropriate points of intervention. Our findings confirm that recognizing user apprehension about technology and how the frames can change over time represent an important factor in conceptualizing the design of a new technology. This nuanced recognition of changes in user attitudes toward technology also has implications for the process of designing a new technology. For example, it is important to include all role groups in the design process in an attempt to understand the frames of different groups and meet their needs.

Although the leader's digital checklist is now fully incorporated into the trauma team workflow, the workshop participants disagreed on the purpose of the checklist. Team leaders saw it as a tool for keeping their own work organized, while other roles viewed the checklist as a tool that supports the entire team. For team members that acknowledged the importance of the checklist, this frame will likely

carry over to the new technology. To maintain this frame, the new design should preserve the information currently on the checklist since team members already perceived it as important for their work. For the roles whose frames of reference differed, we should first understand those differences and design to support them rather than to align them. As we prepare to proceed with the design of a shared checklist display, we must address the needs of each role rather than using a one-size-fits-all design. Our prior research has identified the information needs of trauma team members and can provide insight about the types of information important for each role (Kusunoki et al., 2014). Results from this study extend this prior work by providing an in-depth understanding of user expectations related to information on the checklist as identified in this study.

Previous work has described a "sensitizing concept" as a starting point for deriving design guidelines in a specific work setting (Blumer, 1954; Bowen, 2006). The workshop discussions reflected on how technology was being used for work and how additional technology could further support information needs and team situation awareness. In turn, the discussions sparked ideation and design thinking about the possibilities of technology in a complex work environment. By involving stakeholders, we now have a clearer understanding of how they perceive technology for their work and can build on this knowledge when proceeding with technology design and implementation.

Designing for Shifting Privacy of Information Spaces

Sharing the content of an individual checklist with the team will necessarily lead to changes in information privacy and access rights, as the information moves from a private device to a shared display. Team leaders view the checklist as their private work and decisions about what to record and when to check off items are solely theirs. Making the checklist information available to the entire team, and even to those outside the team, may disrupt this view because information will no longer be private to the team leader. Our results suggested that publicly displaying the checklist information may affect how leaders use the checklist. On one hand, leaders may become more compliant with the checklist because more people will be able to see their work in real time. Based on prior research, this change in use practices as a result of shared work is common. Wilson et al. (Wilson et al., 2006), for example, found that the availability of a large display for supporting information sharing during shift handovers encouraged physicians to write their summaries more neatly, thereby improving their work for the benefit of the team. On the other hand, sharing the checklist content may create tension between roles if people start checking the work of the leader. Similarly, the leader may start documenting less information in an effort to avoid their work checked. Team roles involved in patient evaluation and treatment were especially concerned about this effect; they thought the display would be distracting because they would keep checking if their reports

were documented. Other roles suggested multiple entry points for the display to allow team members to enter information specific to their work processes.

Several design implications emerged from these results. First, given the high-risk and dynamic nature of the resuscitation domain, the shared checklist display should be designed to keep the leader in control of what information gets shared and when. The leader would remain responsible for discerning the pertinent positives that might affect the plan of care and whether or not to share them. Even so, there are benefits in allowing others on the team to input information, as shown in prior work. Greenberg et al. (Greenberg et al., 1999), for example, evaluated a SharedNotes system that supports both private and public note taking, but once a private note is made public, its creator no longer owns it. This study suggested that a rigid distinction between private and public work was not realistic and recommended a system that would let people fluidly shift notes and other artifacts between personal to public spheres. Similarly, allowing other trauma team roles to own the information and input data for the checklist display could potentially lead to increased alertness to any incorrect or missing information.

The second design implication pertains to the effects of the display on team communication. Wilson et al. (Wilson et al., 2006) describe a shift between active and passive information seeking after a shared display was introduced in a hospital ward, noticing how medical staff went from actively seeking information to passively receiving it, as the information was now automatically presented to everyone. A similar shift can be expected in behaviors of trauma team members with the introduction of a shared checklist display, especially in latecomers' inquiries about the team status that were described as redundant and disruptive. A previous study on information needs of trauma team members suggested that providing pre-hospital information and history throughout the resuscitation could reduce redundant information and communication (Sarcevic and Burd, 2008). The shared display is an ideal mechanism for removing this negative redundancy, while still allowing for positive redundancy by continually displaying critical patient or process information. The shared-checklist display could therefore include a "one-liner" related to pre-hospital information or progress indicator for where the team is in the protocol, providing shared awareness for both team members in the room and those who arrive late.

Finally, we need to consider another shift in information privacy that may occur when the checklist information becomes public. Currently, the team is communicating verbally, reporting and discussing patient data and exam findings. This information, however, is only temporary until it is recorded on the scribe's flowsheet or the leader's checklist. With a shared display, the recorded information will move to a public sphere and will become visually available to anyone in the room, further eroding patient privacy. This shift then brings up an issue of how to effectively filter information on the checklist, while also providing an automatic and timely reflection of the leader's work. Rather than automatically sharing all of

the information, the design could allow the leader to filter out sensitive information. As Wilson et al. (Wilson et al., 2006) found, simply sharing information on a display encouraged more thorough review of the information. In contrast, other studies have found that setting a privacy filter ahead of time alleviates the cognitive load of the decision maker in a complex work environment (Won and Pipek, 2003). Adopting a similar solution in our context would allow the leader to project the status of their work without being concerned with revealing the sensitive and private information.

Designing for Dynamic Teamwork in a Multi-Display Environment

Participants mentioned other technology and artifacts that support their work in the trauma bay, including the vital signs monitor, wall charts, and other cognitive aids. Introducing yet another information display (a shared checklist display) will require determining what information remains helpful when redundant (e.g., vital signs) and what information becomes distracting if redundant (e.g., wall timer). These considerations may lead to a multi-display environment. Furthermore, our participants expected to see more information than what is currently available on the checklist. Items like pre-hospital information, medication orders and administration times are all related but extraneous to the idea of a checklist. A recent study of a hospital-wide implementation of an electronic patient record system showed that information needs of team members are often based on team and patient status rather than that of the process (Karsten and Laine, 2007). Given these and our own insights, we must consider whether the checklist is the right tool to fulfill these expectations. As the results from our study have shown, simply projecting the content of the current checklist will not suffice.

One solution is to use existing displays in the environment and add the checklist information to their contents. Research on multi-display environments (MDEs) has shown that participants use the shared display differently than their individual devices by taking a step back to see an overview of the group's progress, which offers communication grounding and synchronization of tasks (Wallace et al., 2011). Bardram and Houben (2018) suggested using portable, context-aware devices for accessing patient health records because this ecosystem of devices would better support the collaborative affordances of an EHR system. A multi-display environment in the context of trauma resuscitation could help improve team communication and situation awareness, but multiple displays could be distracting. An MDE for a complex-medical setting means not only several displays to view but also to manage in terms of what data to enter and when. Our results showed that participants welcomed the idea of multiple inputs for the shared display, and even multiple formats or screens for representing the information (e.g., one detailed view and one summary view). Another suggestion was to introduce a new role dedicated to inputting the information for the shared checklist display. A previous

study has made similar arrangements to evaluate the impact of a displayed checklist on trauma team performance in a simulation setting—an entirely new trauma team member was added as the checklist documenter to check off items on a handheld checklist when activities were verbalized by the team (Hulfish et al., 2018). As their findings showed, this addition of the checklist documenter decreased the workload of the team leader, who was now free to refer to the checklist display without the need to administer the checklist. However, it is unclear how the addition of the checklist documenter affected the work of the leader and team dynamics in general. Shifting the ownership of the checklist administration removes the leader's ability to make notes about the patient status and use the checklist as a memory aid. In our study, the scribe nurses compared the digital checklist to their multi-page flowsheets, explaining that the digital checklist could serve as an extension of the flowsheet. The flowsheet also has all of the additional information that participants envisioned for the shared checklist display. Even so, the same concerns and challenges we observed for the idea of projecting the leader's work would also apply to projecting the forms filled by the scribe nurses, including how people in the room might be checking the accuracy of data entry as it gets projected on the display. Despite all the risks, recent work on developing an MDE in the commercial flight deck that captures contextual interactions and collaboration during layered tasks shows promise that MDEs could improve complex, team-oriented task performance when designed and implemented in a manner that considers workers' assumptions, expectations, and knowledge of technology (Roesler et al., 2017).

Conclusion

We conducted envisioning workshops with team members working in a high-risk medical setting to understand their perceptions of technology and assess the feasibility and impact of a shared checklist display during medical emergencies. We applied the concept of technological frames to understand perceptions of technology for each team role group. We found that team members value technology differently based on their role and the nature of tasks they are performing. While our participants expected a shared checklist display to have positive effects on teamwork and communication, they envisioned a tool that exceeded the capacity of a simple medical checklist. These findings suggest different approaches to designing for high-risk medical collaboration, such as supporting differences in technological frames rather than aligning them, allowing users to shift their information between personal and public spheres, and providing an environment where information is effectively shared through multiple displays yet unobtrusive to teamwork. Although we conducted a single site study, our results generalize to emergency medical work in other U.S. trauma centers because of the similarities in team roles and standardized patient evaluation protocols. As we

continue this work, it will be important to track the frames of team roles over time to understand technology adoption and use behaviors for improved system design.

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