MEDIATING ICU PATIENT SITUATION-AWARENESS WITH VISUAL AND TACTILE NOTIFICATIONS

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DEDICATION

To my family, friends, and mentors

Even when I doubted myself, they never did

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Preethi Srinivas

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Healthcare providers in hospital intensive care units (ICUs) maintain patient-situation awareness by following task management and communication practices. They create and manipulate several paper-based and digital information sources, with the overall aim to constantly inform themselves and their colleagues of dynamically evolving patient conditions. However, when increased communication means that healthcare providers potentially interrupt each other, enhanced patient-situation awareness comes at a price. Prior research discusses both the use of technology to support increased communication and its unintended consequence of (wanted and unwanted) notification interruptions.

Using qualitative research techniques, I investigated work practices that enhance the patient-situation awareness of physicians, fellows, residents, nurses, students, and pharmacists in a medical ICU. I used the Locales Framework to understand the observed task management and communication work practices. In this study, paper notes were observed to act as transitional artifacts that are later digitized to organize and coordinate tasks, goals, and patient-centric information at a team and organizational level. Non-digital information is often not immediately digitized, and only select information is communicated between certain ICU team members through synchronous mechanisms such as face-to-face or telephone conversations. Thus, although ICU providers are exceptionally skilled at working together to improve a critically ill patient's condition, the use of paper-based artifacts and synchronous communication mechanisms induces several interruptions while contextually situating a clinical team for patient care.

In this dissertation, I also designed and evaluated a mobile health technology tool, known as PANI (Patient-centered Notes and Information Manager), guided by the Locales framework and the participatory involvement of ICU healthcare providers as co-designers. PANI-supported task management induces minimal interruptions by: (1) rapidly generating, managing, and sharing clinical notes and action-items among clinicians and (2) supporting the collaboration and communication needs of clinicians through a novel visual and tactile notification system. The long-term contribution of this research suggests guidelines for designing mobile health technology interventions that enhance ICU patient situation-awareness and reduce unwanted interruptions to clinical workflow.

Davide Bolchini, Ph.D., Chair

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Chapter 1. Introduction

Collaboration and coordination are integral to medical work (Dourish & Belloetti, 1992; Reddy et al., 2003). This is particularly true in a hospital intensive care unit (ICU), where healthcare providers often work in multidisciplinary teams to accomplish the common goal of providing safe, effective, and efficient patient care. Awareness of individual and group activities is critical to successful collaboration in medical work, and Computer Supported Co–operative Work (CSCW) systems commonly support such awareness (Dourish & Belloti, 1992; Talaei–Khoei et al., 2012). Existing research categorizes awareness in terms of workspace, context, the group involved, and social aspects (Bardram & Hansen, 2004; Cabitza et al., 2012; Dourish and Bellotti, 1992; Fitzpatrick & Ellingsen, 2013; Randell et al., 2010). Yet, there is a gap in up–to–date knowledge or awareness of patients' conditions in a medical setting such as the ICU. For instance, prior research includes a focus on context, but neglects to consider providers' knowledge about the patients' condition in relation to context. With increased and continuous visibility to information, healthcare providers' knowledge about context can be further established by understanding their patient's situation, referred to as "patient–situation awareness" (Parush et al., 2011). Provider patient–situation awareness includes understanding patients' current conditions (in relation to past and future predicted outcomes) and understanding his/her role in patient care in relation to the other team members (Green et al., 2016; Nemeth, 2008; Endsley et al., 2003; Reader et al., 2011; Reddy et al., 2001). Another significant factor deeply intertwined with collaboration and coordination is communication, which plays a vital role in increasing patient–situation awareness and other team members' activities. Healthcare providers engage in several task management and communication practices, using both electronic and non–electronic information sources, as they continually inform themselves and fellow team members of evolving patient–centric knowledge, tasks, and goals. For instance, healthcare providers make paper–based notes to organize and accomplish individual tasks and goals (paper–based notes are “handed off” between healthcare providers during shift change). These paper–based notes serve as transitional artifacts that are later digitized to organize and coordinate team information, tasks, and goals. However, these paper notes are often not immediately digitized and shared, and only select information is synchronously communicated between select team members through mechanisms such as face–to–face or telephone conversations. In the remainder of this chapter, we refer to the practices involved with delayed digital transcription of information as “passive digital practices.”

Figure 1.1 depicts an example of communication between healthcare providers. During the discussion, R receives a phone call. Since he cannot determine who is calling, he responds to the phone call by stepping away from his existing conversation. The phone call is from the nurse (N) of another patient. Hence, R stops his current thought process about Mr. Smith and immediately starts recollecting information for phone call. His pre–rounding paper notes aid him in this process. The conversation between R and rest of the team members is interrupted – R is unable to participate with the other team members in seeking and interpreting information on the new lactate result and discussing on next steps. At the end of his phone call, he moves to a computer workstation to sign an urgent order resulting from phone conversation. By the time R comes back to the rounding conversation, the rest of the team members have already made a decision on how to handle Mr. Smith’s case and have moved on to discuss about the next patient.

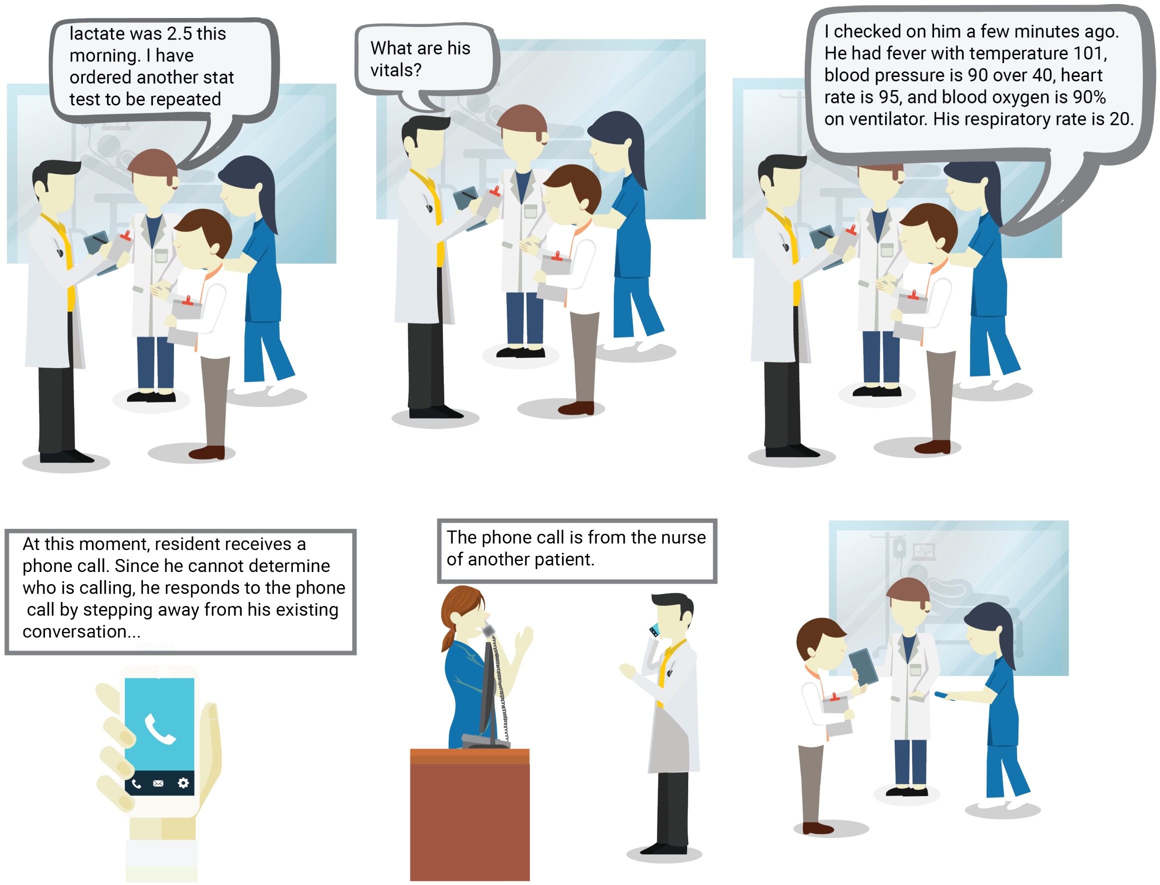

Figure 1.1: Figure depicting observations from conversation between physician (AP), fellow (F), post–call resident (R_{PC}), day–shift resident (R) on a patient, Mr. Smith.

ICU healthcare providers are exceptionally skilled at working together to improve a critically ill patient's condition. However, passive digital practices do not always inform the healthcare providers of the patients' current condition. Healthcare providers must therefore make additional efforts to become aware of the (i) patient's current condition and (ii) contributing factors to that condition. Lack of updated patient–situation awareness has been found to result in incorrect decisions that can lead to medical mishaps; these negative effects are further amplified by existing cognitive overload that healthcare providers experience (Kohn, 2000). Given the mobile nature of ICU teamwork, passive digital and communication practices inhibit teams from effectively becoming aware of, and sharing perspective on, a patient's dynamically changing condition and ongoing care. Therefore, to support the improved teamwork afforded by increased goal–, task–, and patient–centric awareness, we must examine and understand how paper note–making and communication practices aid task management in the collaborative ICU environment.

The synchronous nature of communication in the ICU often results in notification interruptions to the healthcare providers' ongoing activity (such as a phone ringing while a healthcare provider is busy rounding on a patient). Despite a dominant negative view of interruptions in the ICU, some studies acknowledge the important, time–critical information an interruption may carry, which in turn can form an integral part of safe decision–making. Not all interruptions can be avoided or immediately responded to. Still, several studies have attempted to overcome interruptions through the introduction of mobile, ubiquitous communication tools that allow healthcare providers to communicate with one another through asynchronous mechanisms such as text messages, voicemails, and more. (Gill et al., 2012; Hall et al., 2010; Ho & Intille, 2005; Jett & George, 2003; Klemets & Evjemo, 2014; Kohn, 2000; Sitterding et al., 2012) However, these tools do not simultaneously enhance healthcare providers' shared perspective on patients' conditions. Further, these tools do not help healthcare providers determine if the notifications require immediate attention, i.e., whether they should interrupt their ongoing activity to respond. Hence, there is a need to design novel communication systems that both inform healthcare providers of dynamically–changing patient conditions and optimally manage notification interruptions.

1.1 Research Motivation

Healthcare providers, especially nurses, deploy "working records" or "scraps" to facilitate team collaboration in both paper and electronic environments (Fitzpatrick, 2004; Hardey et al., 2000; Hardstone et al., 2004). Various studies report on how paper is used as a passive information repository to tailor, represent, externalize, and augment information in support of an individual's work practice. For example, ICU healthcare providers often use various pieces of paper as "working records" that evolve over time based on reflection and patient care (Fitzpatrick, 2004).

According to Hardey and colleagues (2000), nurses generate "scraps" as a strategy to define and organize nursing–specific knowledge; this study uncovers the significant role played by nursing scraps in the communication of information (especially during handoff sessions) and delivery of care. Paper–based artifacts are essentially coordination strategies or tools that help healthcare providers summarize and become aware of patients' situations relative to their own role in patient care. These summaries are used to manage personal tasks or goals, as well as facilitate patient–situation awareness generation and key information and knowledge–sharing among team members during face–face or phone conversations.

Several hospitals report increasing continuity of patient care and awareness in the ICU with the introduction of communication practices involving (i) face–face handoff sessions and (ii) the usage of synchronous and asynchronous technologies (such as telephones, mobile phones, email, and pagers). These practices, however, do not involve rapid and simultaneous communication of dynamic patient information between all the team members. Hence, there is limited patient–situation awareness within and between teams. Further, existing technology tools mediating communication and awareness among healthcare providers carry the potential to synchronously disrupt a healthcare provider's ongoing activity or asynchronously provide information that may be outdated by the time it is seen. For instance, a telephone call from an unknown caller may force a healthcare provider to stop their ongoing activity. Thus, although the call may result in increased awareness between the people involved in the conversation, it interrupts the receiving healthcare provider's ongoing activity. Hence, there is a need to design a novel communication system that assists healthcare providers in optimally managing interruptions while maintaining patient–situation awareness. Two key gaps in the current research motivate this dissertation:

1.1.1 Research gap 1: Understanding ICU clinical work in the context of paper note–making, patient goals, clinical task dissemination, and other communication practices that enhance healthcare providers' patient–situation awareness.

Chen (2010) describes paper–based notes as transitional artifacts that act as a bridge between EMR–based documentation and actual clinical workflow. According to her description, notes are made on information printed from the EMR system, and are later computerized. These transitional notes result in dual documentation activities, whereby the same information is documented at two different points in time, thus consuming more of a healthcare provider's work time. Not all healthcare providers in the team are made aware of each other's activities and progress during their shifts, nor how their colleagues' actions have affected the patient's condition. Thus, existing research acknowledges the interrelationship between paper scrap notes and healthcare providers' task management. However, there is a lack of synchronization between the paper, the EMR system, and the clinical workflow. In addition, all the healthcare providers do not share the same perspective on the dynamically changing patients' condition and care.

Critical care requires substantial cognitive work, and each individual patient's needs depend on the timely synchronization of people, equipment, tools, and patient–situation awareness (Nemeth, 2008; Reader et al., 2009). As such, there is limited understanding of how healthcare providers maintain constant awareness of the patients' situation, the accomplishment of the other team members' tasks, and how their work and other team member's work relates to overall goals. Further, there is a lack of understanding of how different healthcare provider teams manage and become aware of the completion or changes made over time to goal– , task– , and patient–centric activities.

1.1.2 Research gap 2: Designing to mediate task management and communication in order to improve patient–situation awareness and minimize work interruptions.

The mobile nature of medical work has resulted in several ubiquitous communication tools that support collaboration and coordination. Although these tools assist in increasing healthcare providers' patient–situation awareness, they do not assist in simultaneously informing everyone on the team . Further, research has shown that notifications delivered while communicating with these tools (for instance, with text messages) have resulted in increased cognitive load and medical errors in the ICU (Gill et al., 2012; Hall et al., 2010; Jett & George, 2003; Klemets & Evjemo, 2014; Kohn, 2000; Sitterding et al., 2012). While evidence continues to mount regarding interruptions in the healthcare environment and their adverse impact on clinical work, other studies acknowledge the overwhelming importance of the information that clinical notifications transmit to the healthcare providers (Hall et al., 2010; Myers et al., 2015; Sanderson et al., 2015; Sasangohar et al., 2012; Sasangohar et al., 2014). For example, research suggests that 11% of all interruptions from notifications contribute to increased safety, improvements in patient comfort, and increased accuracy (Sasangohar et al., 2012).

Given the importance of these seemingly contradictory research insights, there is a need to design a communication system that can help healthcare providers optimally manage notification interruptions, while still sharing or updating one another about the changing patients' condition, tasks, and goals.

1.2 Research Questions

To address the outlined research gaps, the goals of my research were to gain a conceptual understanding of (i) task management through note–making, and (ii) communication practices used to enhance patient–situation awareness among and between ICU teams. My research was also aimed at informing the design of a communication tool that can support the constant sharing of dynamically changing patients' conditions, tasks, and goals by providing more control to the healthcare providers in optimally managing notification interruptions. I investigated the following research questions

RQ1: In the context of paper note-making, what are the task management and communication practices followed by healthcare providers to stay up–to–date on dynamically changing patient conditions?

RQ2: What are the characteristics of notification interruptions generated by existing communication tools?

RQ3: Can the communication that aids in sharing patient conditions, tasks, and goals be mediated through the use of visual and tactile notification messages?

RQ4: How can such visual and tactile notification messages be effectively managed by the healthcare providers?

RQ1 aimed at gaining a conceptual understanding of how task management and communication practices maintain patient–situation awareness. This included understanding task management specific to personal note–making and note–sharing during handoff sessions, and the translation of paper–based notes to the digital realm. RQ2 helped provide an understanding of the characteristics of existing related tools, and to paint a picture of the interruptions to healthcare providers' work induced by these tools. RQ3 provided a technical understanding of how shared patient–situation awareness between all the healthcare providers can be enhanced through a novel tool that supports task management and communication of information with text messages or tactile alerts. RQ4 was more specifically geared at understanding how healthcare providers can optimally manage interruptions while sharing and keeping themselves updated about a patient's condition, tasks, and goals.

In transferring conceptual ideas to technical design, I chose to design for a mobile smartphone device because of the mobile nature of medical work and existing research on the use of ubiquitous technologies in the ICU. The rest of this section describes the multi–methodology research approach I took in responding to my research questions.

1.3 Research Approach

To answer my research questions, I examined the techniques and tools used by ICU healthcare providers to support task management and communication practices while maintaining a shared perspective on the patient's changing condition, tasks, and goals. I conducted two different, but related studies.

Study 1: The first study was an ethnographic exploration of the task management and communication practices followed by healthcare providers at the medical ICU unit of a large teaching hospital. In this study, I examined how individual and teams of ICU healthcare providers generate, manage, and disseminate patient–centric goals and tasks in the context of paper note–making. I also observed how ICU healthcare providers kept themselves updated about each other's activities and about patients' conditions through communication practices with and without support from technology (such as mobile phones). For instance, healthcare providers externalized their patient–centric knowledge, tasks, and goals as paper notes, which supported healthcare providers while they communicated patient–centric information with one another either through face–face or phone conversations. The notes can also be translated as digital medical orders in the patient EMR, and reminders to self. This study provided a conceptual understanding of the strategies and practices healthcare providers use to become aware of both other healthcare providers' activities as well as patients' conditions. Observations made in this study also pointed to the unintended consequences of technology–mediated notification interruptions to healthcare providers' ongoing activities. The findings from Study 1 led to the conceptualization and design of Study 2.

Study 2: Drawing on the findings and design implications from Study 1, I devised the second study to examine how healthcare providers used their paper notes to communicate patient goals, and tasks. In this study, I design and evaluate a mobile technology tool, named PANI (Patient–centered notes and information manager), to support communication. Through lab studies in a controlled setting, I examined how ICU healthcare providers generated, managed, and disseminated clinical tasks between one another. Based on my findings, and drawing on conceptual and design implications from Study 1, I evaluated various design features for providing a shared task and communication manager that could enhance patient–situation awareness within and between ICU teams with minimal technology–mediated notification interruptions. The multi–method approach adopted in studies 1 and 2 was helpful in providing an understanding of the generation and persistence of a shared patient–situation awareness between all ICU healthcare providers through task management and communication practices. The following sub–section provides more details about the two studies.

1.4 Research Design

As described above, I conducted two studies using different, yet complementary research methods. The first study included an ethnographic field study of the medical ICU unit of a large teaching hospital using an exploratory sequential mixed methods approach. My initial preparation for this study included reading prior literature and 10 hrs of exploratory observation (I started by observing the morning rounding activities), which helped highlight clinical work practices that might otherwise be taken for granted by an expert. Following this initial observation, for another 10 hours I observed a different ICU team to strengthen my understanding. ICU healthcare providers are often cognitively involved with their practices, and hence cannot be disturbed at the moment they are performing an activity. Thus, as a part of my observation, I conducted several ad hoc, opportunistic interviews in addition to the formal, scheduled semi–structured interviews of the observed healthcare providers.

I observed that the majority of information–sharing, communication, and collaboration on the dynamic changes to the patient's condition, tasks, and goals occurred between residents and nurses. Hence, following the initial observation of ICU teams, I pursued task–centric, role–centric, artifact–centric, and space–centric shadowing of ICU residents and nurses over a period of 60 hours. I observed clinical activities in the ICU such as rounding, handoff, general patient care, and information flow. I used contextual inquiry to observe and understand task and information management using paper notes, information and knowledge sharing with and without technology tools, and interruption management practices while receiving notifications from the technology tools.

With respect to technology usage while sharing patient–related information, I focused specifically on the (i) medium (such as pager, telephone, etc.) and nature of communicated information, (ii) practices the healthcare providers followed to keep themselves abreast of the dynamic and changing patient condition and care, and (iii) strategies the healthcare providers used to avoid disruptions to their ongoing activity when they received a phone call or an alert on their pager. Notes made during observations and audio–taped interviews were later transcribed. Notes were sometimes shared with the healthcare providers to communicate the observations, thereby gaining their trust.

Following the data collection phase, I collaborated with two expert ICU physicians who helped validate the data interpretations and consolidate findings. This study provided insight into how and when healthcare providers made and used notes to support their clinical work, the tools they used to share information and keep themselves updated, and their perceived drawbacks of existing communication technology tools when receiving some patient–related information.

In the second study, I examined personal and team–based task management and communication aimed to enhance patient–situation awareness by introducing a novel mobile technology tool named PANI. Based on the findings from Study 1, I generated two design versions of PANI. Both versions were evaluated by ICU healthcare providers in a controlled, lab setting using an exploratory scenario–based, think–aloud approach. As a replacement for paper notes and existing pagers or mobile phones, healthcare providers tested PANI for creating and disseminating patient tasks and goals, and communicating the dynamically changing information of patient's conditions to fellow team members. Based on the findings from the exploratory study, I conducted two focus group sessions with designers and ICU healthcare providers to specifically design PANI's visual notification messages to enable sharing of patient–related information.

Two significant findings resulted from this design: (i) the most current patient vital signs provided contextual information that helped healthcare providers better understand the patients' situation, and (ii) reminders to self can be better managed through tactile alerts. As a follow–up to this design phase, healthcare providers evaluated receiving and responding to textual and tactile notification messages. This formative evaluation provided insights into providing healthcare providers with more control when receiving or responding to communication attempts made by their colleagues, without interrupting their ongoing activity. Overall, Study 2 provided insights into the healthcare providers' personal and team–based task and goal management, how and when they preferred being updated and staying informed about the changing patient conditions, tasks, or goals, and design features that PANI can implement to avoid unnecessary notification interruptions in light of the goal to increase patient–situation awareness among all the healthcare providers.

1.5 Dissertation Roadmap

The remainder of this dissertation is structured as follows:

Chapter 2 provides a review of three different streams of relevant research, on: (i) scrap note–making for task and goal management, (ii) communication to improve patient–situation awareness, and (iii) existing theoretical frameworks that can be used to describe patient–situation awareness task management and communication practices. I discuss patient–situation awareness at both the individual and group levels, and point out gaps in the literature.

Chapters 3, 4, 5, and 6 describe my study on scrap note–making for task management and communication between healthcare providers aimed to enhance a shared perspective among all healthcare providers on the patient's current situation. Chapter 3 provides details about the methodology used for the study. Chapter 4 describes the research site, information sources, and people, as well as their roles and insights into the nature of work practices specific to this dissertation topic. Chapter 5 describes the adoption of a theoretical framework known as the Locales Framework (Fitzpatrick, 2003) as a lens to view the process of dynamically communicating patient–situation awareness between ICU healthcare providers with changing patient tasks and goals. The Locales Framework has been validated to understand existing collaborative work practices, and to motivate the design of new systems (Greenberg et al., 2000; Kaplan & Fitzpatrick, 1997; Scott & Alan, 2003). This chapter draws on the fieldwork using the five different aspects of the Locales Framework to understand the nature of collaborative patient tasks and goals management through technology–mediated information exchange. Chapter 6 discusses the findings and presents design implications for a novel technology tool (PANI) that can be used to expedite the process of managing patient tasks and goals (personally and as a team), in addition to efficiently sharing the dynamic changes to patient condition with minimal interruptions to ongoing activities.

Chapters 7,8, 9, and 10 describe my study on designing and evaluating PANI and its functionality. Chapter 7 provides details on the methodology used for the study. Chapter 8 discusses the focus groups (involving designers and ICU healthcare providers) that were used to design visual messages on PANI that can be used to share patient–related information between healthcare providers. This chapter also includes a discussion on the follow–up evaluation of the notification messages and tactile alerts ability to optimally manage interruptions. Chapter 9 discusses the initial exploratory think–aloud study evaluating two design versions of PANI's task management functionality. This chapter also highlights the insights gained about the utility of PANI's design features for supporting the management and optimal sharing of dynamically changing patient condition, tasks, and goals with minimal interruptions to ongoing work. Chapter 10 brings together the findings and interpretations from both the studies by summarizing the contributions of my research and discussing venues for future work.

1.6 Scope and definitions

To limit the scope of this project, I chose to observe an ICU team comprising of an attending physician (1), fellow (1), residents (1–2), medical student interns (1–2), pharmacist (1), and nurses (2–4). ICUs typically have a hierarchy, wherein the attending physician leads and advises the team, the fellow and pharmacist act as consultants, residents and interns work together in performing medical procedures or instructing nurses, and nurses carry out the instructions and work closely with the patients. Attending physicians, fellows, and residents are medical doctors, while student interns are trainees for a medical degree. Pharmacists are licensed experts, and registered nurses primarily care for and assist patients. Prior research defines awareness as “understanding the relevance of information to one’s goals” (Daneshgar and Ray, 2000a; Gross et al., 2005). Dourish & Belloti (1992) define awareness as “an understanding of the activities of others, which provides a context for one’s own activity.”

McCrickard et al. (2003) define an interruption as any event within a notification system that prompts the transition of attention from a primary task to the notification. This work adapts the definition of interruption from existing research as, “externally or internally generated, unexpected events that may cause a break in the primary task, diverting attention to a related or unrelated secondary task, which can have both negative and positive effect on the interrupter’s or the interruptee’s main task (Sasangohar et al., 2012; p. 3).” In the remaining portions of the document, I refer to the person performing an action leading to interruption as the “interrupter” or “sender,” and the person interrupting him/herself as the “interrupted” or “receiver.”

Cohen & Hilligoss (2009) define handoff as the exchange of patient information between healthcare providers accompanying either a transfer of control over, or of responsibility for the patient.

Chapter 2. Review of theoretical background

This chapter provides an overview of literature on maintaining patient-situation awareness in the ICU, with a specific focus on how healthcare providers: (1) manage or coordinate patient tasks and goals; and (2) communicate patient information between one another. This chapter's main focus is to review how ICU providers distribute information using external artifacts to maintain individual and team-based patient-situation awareness. I also outline existing research on managing interruptions from technology-based communication in the ICU.

2.1 Understanding patient-situation awareness in the context of task coordination and communication

This section outlines existing research on how ICU providers keep themselves updated about the patients' condition so they can determine and disseminate tasks and goals, and how their work relates to overall patient care. The collaborative ICU environment houses teams or groups of providers who work together and care for the same or different patients.

Gorman and colleagues (2000) report on how ICU providers organize and access "bundles" or "collections" of information to perform specific tasks and maintain patient-situation awareness. According to their work, providers value bundles comprising information gathered from multiple sources (such as physical patient records, resident's worksheets, or notes jotted on the back of an envelope or sheet or paper) for convenience, immediacy, portability, and flexibility, even if such bundles involve a substantial amount of attention, effort, and time. Based on the analysis of their field data, the authors propose a digital solution (SLIMPad, or Superimposed Layer Information Manager scratchPad) that enables providers to construct information bundles from diverse sources, which are presented and accessed as superimposed layers. However, the drawback with this solution is that bundles are less context-specific, and therefore may not provide quick and simple information to someone else from the team, or even to the provider who created it if they view it at a later date.

Reddy & Dourish (2002) identify the temporal nature of medical work, wherein the information needs of providers are interwoven with other working activities that are coordinated through a set of temporal rhythms. These working rhythms act as an orienting feature for the providers while they seek, provide, and manage information in their course of work. For instance, a resident ordering an urgent lab test for a patient will expect a result within a half hour and adjust his or her work to support this expectation. Overall, this work highlights the opportunities for incorporating cyclic and temporal information in maintaining awareness, where information systems show not only current activities, but also patterns in former actions, and expectations about future activities.

Bardram (2000) uses Activity Theory (Engestrom, 2000; Kaptelinin, 1996; Kuutti, 1996; Nardi, 1996) to discuss the temporal aspects of coordinated and cooperative work in the ICU. He defines "temporal coordination" as an activity with a goal of ensuring that distributed actions (from a collaborative activity) take place at an appropriate time. Temporal coordination is mediated by artifacts (such as a clock or calendar), which provide temporal reference frames for collaborating communities. In sum, temporal coordination is defined as a three-level activity involving synchronization, scheduling, and temporal allocation; it is modified depending on the temporal conditions arising from both the collaborative work and the temporal conflicts in the work's organizational context. For instance, the clock in a hospital is a collective representation of the official time at which all collaborative activities are recorded and synchronized. In his work, Bardram discusses a technology solution (Patient Scheduler) as a temporal coordination artifact that can be used to support the creation of work schedules. His solution falls short, however, of meeting some aspects of temporal coordination (specific to the three identified levels of activity), owing to lack of resources and socio-temporal order embedded in the hospital organization. For instance, information from the Patient Scheduler was not public and visible (possibly on a wallboard) across the different hospital units (such as ICU, surgical wards, conference room, etc.) to support the synchronization of schedules for the day. Further, although his solution can increase communication and negotiation concerning schedules, there is a gap with respect to handling unintended interruptions to the clinical workflow.

Several HCI and CSCW studies have attempted to understand cognition distributed: (1) across the members of an ICU team, (2) among internal and external structures, and (3) temporally, in which earlier events affect later events (Bang et al., 2003; Galliers et al., 2007; Hazelhurst et al., 2008; Hollan et al., 2000; McKnight & Doherty, 2008; Nahm et al., 2010; Nemeth et al., 2004; Nemeth et al., 2006; Patel et al., 2000; Xiao, 2005). The distributed cognition (Halverson, 2002; Hutchins, 2000; Hazelhurst et al., 2008; Patel et al., 2000; Rogers, 1992) approach has been reported as an effective theory for designing user interfaces for healthcare systems (Patel et al., 1998) by studying patient information flow in cognitive artifacts such as schedules, display boards, lists, and worksheets (Bang et al., 2003; Galliers et al., 2007; Nemeth et al., 2004; Nemeth et al., 2006; Xiao, 2005). For instance, Xiao (2005) discusses how artifacts are used to facilitate the collaborative work of scheduling operating rooms. He argues for the need for technology solutions to support physical artifacts' functions to aid in the distributed nature of providers' cognitive work. In the next section, I highlight the information tools ICU providers use to keep themselves abreast of patients' conditions, the patient tasks they have to complete, and the tasks that have been completed (by themselves or other team members).

2.2 Existing information tools for maintaining patient-situation awareness

Gurses and Xiao (2006) report on two types of information tools used by ICU providers: (1) patient-centric tools (Birtwistle et al., 2000; Friesdorf et al., 1994; Halm et al., 2003; Manias & Street, 2001; Weigle et al., 2001), which provide up-to-date patient information, including EMR, progress notes, bedside-monitoring devices, and nursing flow sheets, and (2) process-oriented tools (Pronovost et al., 2003; Thompson et al., 2004; Van Eaton et al., 2005; Young et al., 2000), which care providers create to support their daily work, such as rounding lists and forms for sign-out and daily goals.

ICU providers capture information and communicate with one another to maintain patient-situation awareness both by accessing and annotating patient information from clinical information systems and non-electronic tools that support their work practice. When it comes to annotating information for supporting daily activities, some tools are unstructured, informal, or temporary (such as to-do lists or scrap notes on paper), while others are structured and mandated tools (such as daily goals forms and discharge needs assessments) that support consistent communication between ICU providers of summarized information.

EMR is an information system that creates, gathers, manages, and stores digital versions of patients' information within one healthcare organization system (Shortliffe & Cimino, 2006). Studies report how EMR usage involves work practices that do not always coincide with familiar and existing clinical workflow, i.e., the work practices requiring EMR access can be rather complex, redundant, and time-consuming (Embi et al., 2004; Poissant et al., 2005). Several studies have identified a parallel practice that involves the generation of informal artifacts for supporting providers' work. One of these artifacts, known as "scraps" (Hardey et al., 2000) or "working records" (Fitzpatrick, 2004; Hardstone et al., 2004), is paper-based notes on patients' situations, which are used during shift changeover or case discussions in order to facilitate key information-sharing among providers. Rough, unstructured paper notes are unique to supporting mobile ICU work, portable, and support easy recording of patient information (Harper et al., 1997; Luff & Heath, 1998). Other artifacts identified by the existing literature include notes made on white boards hung inside or outside patient's room (Wong et al., 2009). For instance, since medical orders can be created at any time, nurses make notes on white board (hung outside the patient's room) to simultaneously manage information across multiple patients and avoid frequently logging into EMR to check for pending orders.

In general, EMR lacks the ability to document, capture, and present procedural information according to the actual clinical workflow, often leading to the use of transitional artifacts. The paper notes in particular act as transitional, mobile artifacts that carry patient information; they are often printed from the EMR, annotated with information to aid or remind activities, selectively transcribed into the EMR, and finally discarded at the end of clinical shift (Chen, 2010). Consequently, providers communicate in an artifact ecology environment (Jung et al., 2008) that comprises digital and physical artifacts interlinked in a unified system that helps maintain patient-situation awareness in the ICU (Vasiliou et al., 2015).

2.3 Understanding technology-mediated interruptions, while maintaining patient-situation awareness in the ICU

One of the significant barriers to maintaining patient-situation awareness in ICU is interruption. Previous research has shown interruptions to be prevalent in ICU (Grungeiger et al., 2010; Gurses & Xiao, 2006; Hillel & Vicente, 2003). For instance, Gurses & Xiao (2006) report interruptions as a significant barrier to communication during ICU rounding, where providers are interrupted with unrelated, non-urgent requests through phone calls or pager alerts. Existing studies discuss strategies (involving artifacts) care providers follow to distribute efforts to remember information during interruptions and to resume an interrupted task (Rajkomar & Blandford, 2012). For instance, Rajkomar & Blandford (2012) discuss the use of DiCOT methodology to support resumption when infusion administration is interrupted. They capture and generate an abstract model (a temporal resource model) for each step in the process of infusion administration to determine how a nurse can recover from an interruption. This model is based on the distributed information resources model (Wright et al., 2000) and provides constructs for analyzing the interactions between an actor and artifacts. For instance, when resuming after an interruption, the actor is concerned about the current step of a required task (goal), the most recent completed step (history), and what has to be done next (plan) – all of which can either be internally stored in the actor’s mind, or externally represented with artifacts. By analyzing the different steps of a task, this model can provide opportunities to improve the design of the external representation (artifacts) of resources for action, supporting task resumption, and reducing cognitive load. For instance, consider a scenario in which a nurse arrives in the patient room with a drug and is calculating the infusion flow rate, at which point she notices the patient calling for attention. When the nurse is ready to resume her original task, she has to either recollect from her working memory the activity she was last performing (based on Memory for Goals theory, Altmann & Trafton, 2002), or look for visual cues from the external environment for a history or list of completed tasks and goals with respect to infusion administration. In this scenario, the nurse can effectively resume her task with little cognitive effort if she is provided with a hypothetical digital checklist that changes into a graphical representation of the current goal after each step is complete.

2.4 Summary

This chapter highlighted existing research on ICU patient-situation awareness in the context of task management/coordination and communication. I discussed strategies followed and information tools used by providers in distributing their cognitive effort on external artifacts while maintaining patient-situation awareness. This chapter also included a brief discussion on handling technology-mediated interruptions in the ICU. The next chapter will provide more detail on the methodology I followed for my dissertation research.

Chapter 3. Study 1: Study Design and Methodology

The first study in this dissertation involved an ethnographic field-based approach comprising several components, including observation, shadowing, contextual inquiries, artifact modeling, and opportunistic and formal semi-structured interview sessions. The study's goal was to understand and ascertain the communication and task management practices and tools ICU healthcare providers used to maintain patient-situation awareness. An additional objective was to understand how ICU healthcare providers managed the interruptions generated from existing communication technology tools. This chapter details this study's design and methodology, describing: the rationale for qualitative design, data collection, and adopted analysis techniques (Figure 3.1).

3.1 Qualitative approach

Qualitative and quantitative research design help provide different perspectives for exploring a research problem. Whereas qualitative research helps capture the intricate interactions, actions, and social elements in collaborative ICU work, quantitative methods help clarify hypotheses or refine research questions. Further, both research designs use different sets of data collection techniques, requiring different sample sizes. To overcome the limitations of using one design over the other, Creswell (2003) proposed a systematic framework based on a mixed methods design that involves both qualitative and quantitative components. My dissertation addresses research questions that require exploration and interpretation of certain ICU practices prior to developing and testing a novel tool as a technology intervention. Hence, I chose the exploratory sequential mixed methods approach (Creswell & Clark, 2007), which comprises an initial phase of qualitative data collection and analysis, followed by a quantitative data collection and analysis phase.

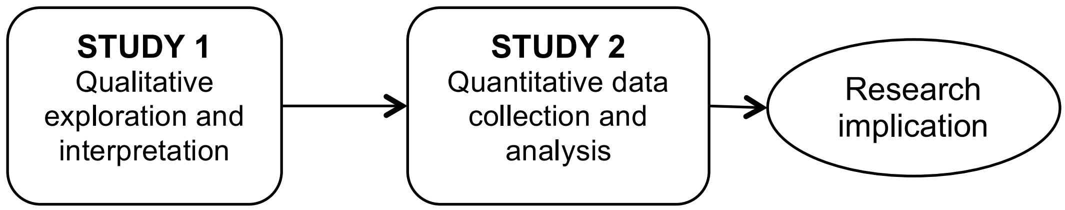

Figure 3.1: The mixed methods approach adapted in this dissertation

Since few studies have examined task management in the light of paper note-making, including how paper notes exist in supporting patient-situation awareness at individual and group levels, I did not have a concise set of research questions or hypotheses to test prior to exploring the phenomenon. Thus, owing to the collaborative nature of ICU work that involves dynamic social interactions and activities, and the exploratory aspect of my research goals, study 1 included qualitative research as a means to explore the communication, task, and interruption management practices healthcare providers followed in the ICU to maintain patient-situation awareness. Findings from study 1 laid the groundwork for the generation of clear and concise hypotheses for study 2.

3.2 Research site

Study 1 was designed as a single-site qualitative study. The research site was evaluated and selected based on whether it allowed me to (Lofland & Lofland, 1995): collect rich data, achieve familiarity with the setting, and engage in face-face interactions with the participants in their naturalistic setting to allow for effectively observing their participants' perspectives. I had an opportunity to examine various sites at three major hospitals in the downtown Indianapolis, IN, area, which included surgical ICUs, general medical ICUs, and burn/trauma units. After examining the various sites, I selected the general medical ICU (MICU) unit in one of the leading metropolitan hospitals. This selection was made because:

- The MICU is an information-rich setting where teams of multidisciplinary healthcare providers work together in improving a patient's condition
- The MICU is an educational setting that encourages researchers and innovative ideas, which made it easier for me to approach the healthcare providers and request permission for them to participate in my dissertation research. Further, the hospital's affiliation with Indiana University and my student status helped lay a solid foundation for me to conduct qualitative research in the research site for an extended duration.
- The MICU work practices are highly collaborative and dynamic, owing to the frequently changing conditions of patients; this workflow fit well within the criteria for this dissertation.

The richness of the MICU work setting provided me with a tremendous opportunity to explore in full detail the communication and task management practices followed by healthcare providers, while maintaining patient-situation awareness. I acknowledge that the ICU practices at the study site can differ from other ICUs. The chosen study site, however, is one of the leading providers of health care in the US Midwest. Hence, one can expect the findings to be representative of a typical ICU environment. Future studies at multiple ICU settings will enable wider generalizability of the findings for ICUs.

3.3 Data collection

The primary goal of study 1 was to learn about the healthcare providers in the ICU and their work practices involved with communication and task management while maintaining patient-situation awareness. This learning allowed me to delve deeper into exploring how and why ICU healthcare providers followed certain work practices while maintaining awareness of dynamically changing patient conditions. Study 1 employed qualitative research methods used by several past ethnographic field observations discussed in the Computer Supported Cooperative Work (CSCW) literature (Blanford et al., 2014; Fitzpatrick & Ellingsen, 2012). Ethnographic observations help provide a deep understanding and support the development of a rich description of a phenomenon as part of an iterative cycle of observation and analysis (Strauss & Corbin, 1999). As such, ethnography has been used to report on medical work and its collaborative nature (Bardram & Bossen, 2005; Nyssen, 2007; Reddy et al., 2006; Strauss et al., 1985).

Data collection took place over the period from September 2014 through May 2015, with preliminary fieldwork occurring between September and December of 2014. Data specific to the research questions detailed in Chapter 1 were collected from January to May of 2015. Study 1 included understanding the task management practices specific to paper note making, and communication among team members, with and without technology devices, to keep themselves updated on patients' dynamically changing situations. I studied the transfer of information between electronic and non-electronic realms, usage of pagers and mobile devices, and the handoff of patient information between healthcare providers. A variety of data collection techniques were used as summarized in Table 3.1.

Table 3.1 Data collection techniques adapted for Study 1

Data collection method	**Specific examples**	**Duration/units**
Observation	Observed ICU team during rounding, handoff session, general patient care	4 months
Opportunistic interviews	Informal questions based on healthcare providers' actions during/after observation	
Shadowing and contextual inquiries	Task-centric, role-centric, artifact-centric, and space-centric shadowing of residents and nurses. I asked informal questions based on their actions and context while shadowing	Shadowing 5 doctors 5 nurses
Semi-structured interviews	Formal, scheduled interview sessions	12
Artifacts collection	Paper notes, rounding sheets, sign-off/handoff sheets	50

The data collection techniques are described below:

- **General observations** – I spent one month informally observing in the ICU to gain a general idea of healthcare provider roles and responsibilities. This included observing and making field notes of an ICU team while rounding, handoff of patient information between residents, and handoff between nurses belonging to the team during shift change. I also observed the general patient care work practices the team members followed. My initial observations took place primarily between 6 a.m. and 7 p.m.; the most active period of work in the unit was during the day. My understanding of the work practices during the informal observation was also supported by my background work with respect to reviewing existing research. Following the initial observation, I went back to observe another ICU team during rounding, handoff, and other patient care practices. I also covered a few night shifts to learn the work practices at night. My second round of observations were more specific to understanding the note-making process, how healthcare providers managed their tasks and communicated information between one another as tasks and patients' situation changed. This observation also included the use of technology devices such as pagers, telephones, and mobile phones during communication, and how healthcare providers managed disruptions (if any) to their workflow. I made notes during observations, which were later transcribed for analysis. The notes were sometimes shared with the healthcare providers to communicate the observation and thereby gain their trust.

- **Opportunistic interviews** – I did not obtain formal ethical clearance to observe patients or their family members; the observation was limited to hallways, nursing stations, and conference rooms in the medical ICU. This also limited observation in other locations, e.g. the emergency room (ER), trauma/burn unit, operation theatre, and other medical wards. Hence, there was often a break in the sequence of observational notes. I used ad hoc opportunistic interviews to fill in the gaps where the healthcare providers were asked to recal actions outside the ICU unit.
- **Semi-structured interview sessions** – I conducted formal semi-structured interviews with the healthcare providers observed to obtain a deeper insight into their task

management and communication practices. This entailed interaction with one healthcare provider at a time, lasting about 30 to 45 minutes in length. The questions were often driven by a previously prepared set of questions that were used to guide topics, such as patient-centered tasks generation and management, modification of tasks as the day progressed with respect to patient's situation, and if and how patient-centered information was communicated to everyone on the team. The interview sessions were audio-recorded and transcribed for analysis.

- **Shadowing and contextual inquiry** – Following the general observations and semi-structured interview sessions, I shadowed healthcare providers, specifically focusing on their roles and responsibilities, the artifacts they used to support their work, and the locations within the unit where communication or patient care occurred. For instance, a typical shadowing session with a resident started with watching the resident make notes on a paper by examining the patient, checking the patient EMR, or conversing with the patient's nurse. This was followed by the handoff session with the night-shift resident, and interactions with the rest of the team during rounds. I also followed the resident during the rest of the shift, which included other patient care practices like procedures/interventions, making phone calls to consult or follow-up on a patient's condition with a specialist or sub-specialist, documentation activities on the patient EMR, and so on. I conducted a total of 10 shadowing sessions with 2 residents, 1 nurse practitioner, 2 attending staff, and 5 nurses. These sessions varied in duration from 1 to 8 hours.
- **Artifact collection** – One of the significant insights from the general observations, interview, and shadowing sessions was the use of electronic and non-electronic

information sources that healthcare providers used to support their workflow. I observed a lifecycle of information from "paper to digital to paper," which helped healthcare providers distribute their cognition while supporting their activities. This was especially noticeable when information was recorded on EMR print-outs, such as rounding sheets and sign-off sheets, which were later transcribed back into patient EMR. I collected rounding and sign-off sheets at the end of every shift in addition to a print out of the digitally transcribed notes/medical orders. During the course of the study, I asked healthcare providers to describe all the information resources they used; I also often asked them to show me how they used these resources.

The above-mentioned data collection methods helped me gather rich and informative data, and multiple methods helped ensure the findings were balanced and unbiased. Further, I collaborated with two expert ICU physicians who helped validate the data interpretations and consolidate the findings.

3.4 Data Analysis

Numerous studies report using Grounded Theory (Strauss & Corbin, 1990) for analyzing ethnographic data (Reddy et al., 2004; Reddy et al., 2006; Randall et al., 2007). Grounded Theory is premised on developing a conceptual understanding by inductively coding, categorizing, and relating recurring phenomenon grounded in the data. Coding, which is a systematic and continual process, is often done while collecting data, which leads to categories or themes that are strengthened to evolve a hypothesis. However, Grounded Theory does not provide a theoretical perspective, because it does not provide a particular lens through which to look at the data; rather, it is a way to approach ethnographic analysis of data from interviews and observations. Hence, there is a need for a framework to understand the data at a more abstract level. Other common theoretical approaches used to provide a framework in understanding social and cooperative work in ethnographic data include ethnomethodology, symbolic interactionism, activity theory, and distributed cognition.

Ethnomethodology has been widely used within CSCW research for examining ethnographic data; it is the study of the moment-by-moment nature of work practices in a sociotechnical environment. Symbolic interactionism involves understanding the symbolic meanings people attach to situations and how they evolve over time through communication between people. Both ethnomethodology and symbolic interactionism do not consider the cognitive dimensions of work, since they are based on what is observed as opposed to understanding what is going on inside an individual's head (Roger's & Ellis, 1994).

Activity theory has also been widely used in CSCW research to understand social activity – it is based on cultural historical theory established by Russian psychologists. The primary unit of analysis is a socially distributed activity system, in which the activity system is composed of subjects, objects, actions or operations, and community. While the subject is the individual performing an activity, and community defines those who share the activity object, the object is the environment that is to be transformed through the activity. Existing research has argued that Activity Theory offers a unit of analysis that can account for individual and social levels of activities within one framework. Actions defined by this theory are abstracted from the moment-by-moment descriptions from ethnomethodology, making the findings easier to use for designing information systems (Kuutti, 1992).

Distributed cognition is based on considering the cognitive properties of the system as a whole, as opposed to an individual or "distributed collection of interacting people and artifacts." (Nardi, 1995) This approach is based on propagation and transformation of representational states between people and artifacts within a system that is used to meet a goal. Distributed cognition (DC) also focuses on human and artifact-mediated communication in cooperative work (Nardi, 1995). However, DC approach is not effective in understanding the ICU work distributed among teams of providers.

Blandford & Furniss (2005) developed a structured methodology and representational system, also known as DiCOT (Distributed Cognition for Teamwork) to support the distributed cognition analysis of a team of members. The DiCOT methodology combines the theoretical framework of DC with a contextual design (Beyer & Holtzblatt, 1999) approach to provide an effective tool for investigating and understanding human behavior in a socio-technical environment. According to this methodology, three models are generated to understand the interaction and interdependencies between a team of providers and artifact ecologies based on: (1) organization of collaborative activities in the physical layout (physical model), (2) flow of information without considering the design of mediating artifact (information flow model), and (3) the detailed design of individual artifacts that are important within the cognitive system (artifact model). Previous research has applied the DiCOT methodology for evaluating and improving healthcare technology in collaborative ICU work (Rajkomar & Blandford, 2011, 2012).

Although the existing above-mentioned theoretical approaches provide a different worldview by focusing on a phenomenon at hand, and provide rich insight into the nature of work, none have been specifically developed for supporting systems design. As such, none can meet the needs of a designer in helping develop a set of design requirements for an information system (Kuutti, 1992; Fitzpatrick, 2003). One of the key goals of this dissertation is not only to understand sociotechnical work with respect to task management and communication in maintaining patient-situation awareness, but also to design an information system that can more effectively support the identified workflow. Hence, to support both the goals of this dissertation at a more abstract level, I used a specific framework, known as the Locales Framework, to both understand the data and design an information system to support work.

The Locales Framework was developed by Fitzpatrick (2003) to understand the nature of social activity and how a locale (or place) supports the activities. It is based on both grounded theory and Strauss' theory of action, and comprises five aspects: locale foundations, civic Structures, interaction trajectory, individual views, and mutuality. Detailed description of the Locales Framework can be found in chapter 5. According to this framework, a social world is comprised of a group of people in a site of collaboration, using some means to communicate, while sharing a common purpose. A locale is the actual site in which a group collaborates, the actual means by which people communicate, and the actual means by which the work is achieved. For instance, a resident and a nurse with the goal of advancing a patient out of the ICU would form a social world. If the resident and the nurse met in a conference room while discussing the patient's condition, the room and its artifacts (such as a whiteboard, workstation, notes, etc.) would form a physical locale. If, however, the resident and the nurse had a phone conversation, then the call would form an audio locale.

The Locales Framework has been validated as both a way to understand existing collaborative work practices, and to motivate the design of new systems (Greenberg et al., 1999; Kaplan & Fitzpatrick, 1997; Scott & Alan, 2003). Further, the Locales Framework is concerned with the principled design of CSCW systems, where the framework helps provide a coherent image of system requirements and inform their construction (Fitzpatrick, 2003). For instance, Greenberg and colleagues (1999) used the Locales Framework to view groupware systems through the lens of different social worlds, helping in the development of design heuristics for evaluating groupware. In a similar manner, I view the situated nature of ICU work using the idea of dynamic social worlds, in turn helping me focus on the interaction at hand. In the findings section, I draw on my fieldwork using the different aspects of Locales Framework to understand the nature of collaborative work mediated through information exchange using technology. Based on the findings, I propose design implications for a novel mobile health technology (MHT) tool that can be used to expedite the process of managing patient tasks and goals (personally and as a team), in addition to efficiently sharing dynamic changes to patients' conditions with optimal interruptions in the ICU.

3.5 Summary

I studied the work practices of healthcare providers in the medical ICU of a leading hospital in downtown Indianapolis, which provided me with an opportunity to capture rich data. To gather data, I used qualitative research comprising methods such as observations, opportunistic interviews, formal semi-structured interviews, shadowing and contextual inquiries, and artifact collection. I analyzed the gathered data using the Locales Framework to understand the work practices and derive design guidelines for an information system that can be introduced to support healthcare providers' work.

In the next chapter, I discuss the organizational background of MICU, study participants, nature of work in MICU, how patient tasks are generated, disseminated, and managed by ICU teams, and how patient information is communicated to ensure all healthcare providers' patient-situation awareness.

Chapter 4. Study 1: Research site

The previous chapter discussed the research design and methodology for study 1. In this chapter, I discuss the study site, including details on the staff and layout, information sources, and communication tools used for maintaining patient-situation awareness in the ICU.

4.1 Study Site: A metropolitan hospital

The study site is a medical intensive care unit (MICU) at one of the leading healthcare providers in Midwest United States, located in the heart of the metropolitan city of Indianapolis. As such, the hospital is affiliated with the medical program of the prestigious educational institution, Indiana University. The hospital is also a Level 1 Trauma Center and a regional Burn Center with over 22,000 annual admissions and 5,200 ICU admissions. It is comprised of: an adult medical ICU, a surgical/trauma ICU, a burn unit, a progressive ICU that also serves as a step-down unit, and a special care nursery as a part of the neonatal ICU. Besides providing patient care, healthcare providers at the hospital are also actively engaged in education and several research projects in a wide variety of areas, including sleep apnea, pulmonary and critical care, traumatic brain injury, Alzheimer's and other dementias, and so on.

4.1.1 Medical Intensive Care Unit (MICU)

The MICU comprises 24 patient rooms split on either side on the same floor. The floor includes two nursing stations in the middle of the hallway, after every 12 patient rooms. Each patient room has an entrance (that can be closed for privacy) facing the nursing station, allowing direct outside view of the patient and equipment in the room. The floor also includes two conference rooms at both ends of the unit, to allow ICU teams to collaborate and perform documentation tasks. The unit also includes other rooms like a nurses' lounge, equipment rooms, medicine storage, and so on.

The MICU holds patients who are critically ill and require frequent mechanical ventilation, multiple interventions, constant monitoring, and ongoing support to ensure no further complications develop. The MICU is a busy unit, with an average of 12 out of 24 beds occupied on a daily basis. In most cases, patients on average stay in the ICU for at least a week. The goal of MICU is to stabilize these patients so that they can be safely moved to a step-down unit. In most cases, patients are in a critical state that is very dynamic, with minor changes to the patients' condition leading to severe adverse implications. Hence, to prevent and/or address developing problems, the ICU healthcare providers must constantly stay up-to-date with respect to the patient's ever-changing condition.

4.1.2 MICU: Staff

Patient care is highly collaborative in any ICU, with a team of members performing duties based on different roles. The team has multiple members, such as attending ICU physicians, fellows, residents, specialists, sub-specialists, surgeons, nurses, respiratory therapists, lab technicians, and so on. The MICU has 2 total ICU teams. Each ICU team is comprised of: an attending physician (1), fellow (1), residents (2), medical students (1-2), and pharmacist (1). The MICU typically has a hierarchy, wherein the attending physician leads and advises the team, the fellow and pharmacist act as consultants, residents and students work together in performing medical procedures or providing instructions to the nurses, and nurses carry out the provided instructions and work closely with the patient to improve the patient's health condition. Attending physicians, fellows, and residents are medical doctors (MDs), while students are trainees in medical school who have not yet obtained a medical degree. Pharmacists are licensed experts who provide advice and expertise on medications' administration, adherence, reconciliation, and associated adverse effects for a patient. Registered nurses primarily take care of and assist patients in recovery.

The MICU has 4 residents who are each assisted by 2-3 students and 1 nurse practitioner. The residents and students take turns in assuming the role of "on-call" each day; the on-call shift starts when the resident arrives in the morning and lasts for 28 hours. Each resident and student are on-call every fourth day. The on-call resident and student work together in taking care of all the patients in the MICU, and admitting new patients. The patients in the MICU are often split among the residents, nurse practitioner, and students in a fair and even manner. The student is assigned a fewer number of patients, and is responsible for some aspects of patient's care under the supervision of the resident. That is to say, the students' work often has be verified or "signed off" by their supervising residents. Patients are also assigned to the resident, who is responsible for all facets of the patient's care under the fellow's supervision.

The fellows are in the middle of the hierarchy. Fellows are doctors who have completed their internal medicine residency and are undergoing three years of specialized training in the intensive care. Each fellow is responsible for all the patients assigned to the ICU team; therefore, they are expected to know all the patients' conditions assigned to the team. Further, fellows (or the attending physicians, depending on the availability of the fellow) discuss patient information in the "huddle" session, where the members from both the ICU teams and other personnel (such as charge nurses, social workers, dieticians, etc.) update each other on the most recent status of all the patients in the MICU.

The fellows, residents, and students are supervised by attending physicians, who have completed their training in the field of intensive care medicine and have years of work experience in the intensive care. Attending physicians rotate or are “on service” at the MICU every 2 weeks. Between 7 am to 5 pm, two attending physicians are present in the ICU, each leading his or her ICU team. After 5 pm, there is always one attending physician on-call until 7 am the next day. The ultimate responsibility for success or failure in MICU lies with the attending physicians. However, attending physicians spend the least amount of time providing direct patient care, as they are often required to perform activities (such as procedures or interventions) outside of the MICU.

The MICU is structured to have a 1:2 nurse to patient ratio, in which a nurse is assigned to simultaneously care for two patients. Registered nurses work 12-hour shifts in a 24-hour work period. They may or may not be assigned to the same patient for every shift, depending on their qualifications or abilities and the patient’s condition (although a patient is assigned to the same nurse as much as possible). Nurses’ responsibilities include patient assessment, monitoring, medication administration, and so on.

Each ICU team at MICU also includes a pharmacist. The pharmacist rounds with the team every morning and participates in the multidisciplinary “huddle” session. Residents and student interns rely heavily on the pharmacist’s expertise to help make the appropriate medication decisions. The pharmacist ensures all the patients assigned to the team have the required medication, and looks out for allergies or reactions as the patient’s condition changes over time.

4.1.3 MICU information sources and communication tools

The study site also comprises of a large number of electronic and non-electronic information sources that the ICU healthcare providers use in their course of work. The electronic sources include a patient electronic medical record and computerized order entry system, patient charting and order notification system, and bedside physiological monitors and infusion pumps. The non-electronic sources include whiteboards, printed copies of patient records placed outside the patient rooms, paper checklists, rounding materials, and printed copies of EKG charts. The healthcare providers access electronic information through workstations placed at different locations in the hospital (such as at the nursing stations, inside and outside the patient rooms, and in conference rooms). Stationary workstations are placed outside every patient room and at the nursing stations and conference rooms. Mobile workstations are placed inside every patient room to allow nurses to chart patient vital signs. Additionally, two mobile workstations assist ICU teams during rounds. The non-electronic sources provide patient information in addition to the activities and procedures followed in the MICU. As such, the MICU environment contains an artifact ecology (Vasiliou et al., 2015) that is rich in a heterogeneous mixture of digital and physical artifacts, which are interlinked and may be used for a variety of clinical tasks while supporting the ICU workflow. For instance, a patient's record may be printed, notes may be made on the printout, and the written notes may be used to perform an activity and later translated back to the patient EMR (Srinivas et al., 2015).

In addition to all the sources mentioned above, the ICU healthcare providers serve as information sources to each other. Further, patients also act as important information resources in helping provide feedback on their care (such as pain level) to the ICU healthcare providers. The existing technology systems supporting communication between ICU healthcare providers at the study site include electronic resources such as landline telephones (placed outside patient rooms, at nursing stations and conference rooms), hospital-owned mobile phones, pagers, and secure communication tubes (at each nursing station to send patient samples for lab testing and receive medication to administer to the patients).

4.2 A day of a resident in the MICU

Rupa, a resident, walks into the MICU at 6 am. As she makes her way to the conference room (which is at the other end of the floor), she peeps into her assigned patients' room to see how her patients are doing. She drops her bag at the conference room, and prints off rounding sheets for all her patients. Rupa is responsible for four patients: she flips through the rounding sheets, which provide a summary of the patient's condition, the tests or interventions performed with results, and medications administered so far. Rupa checks back and forth between the digital EMR system and the rounding sheet and starts to make some personal notes on the blank side of the printout (backside); these notes are based on the patient's objective measures she captures and interprets from the patient EMR. Once she is done making notes, she walks over to the nursing station to talk to the patient's nurses—this gives her a general idea of the patient and overnight events. During this process, Rupa uses the workstation outside the patient room or at the nursing station to look up information based on the conversation with the nurse. By the time she is done having a face-face conversation with the patients' nurse, the resident who worked overnight approaches her to hand-off information about her patients. The hand-off is a fairly quick process lasting about 2-3 minutes per patient, where quick information is conveyed to Rupa (she adds information to her notes, most of which can include subjective or objective measures of the patients). It is about 7 am, and Rupa is ready to physically examine and talk to her patients. Rupa visits each of her patients, physically examining them to jot down their objective measures (such as vital signs), and assessing their pain and sedation level, complaints, and so on. After visiting all of her patients, Rupa comes back to the conference room and comes up with an assessment and plan for each patient for the rest of the day. She generates a prioritized list of issues based on her notes from examinations, conversations with the night-shift residents, nurses, and patients, and creates a proposed plan to address them. Around 7:30 am, the MICU team starts to gather around for the morning rounds.

Rounds on patients are a structured, essential duty performed in every ICU (Khairat & Gong, 2011). They typically involve an ICU team meeting either in a conference room or outside the patient room in the ICU hallways. During rounds, a resident presents a patient's condition from the previous day. The team then collaboratively works to identify a 24-hr plan of action comprised of patient-centered tasks/action-items, which can change as the day progresses. The action-items can include medical orders (e.g., laboratory tests or administering medication), a collection and summarization of patient physiological measures, a follow-up/consultation with specialists, and other clinical duties. Typically, an assigned team member completes the list of action-items. For instance, residents play a key role in placing medical orders and caring for the patient, nurses implement the orders and collect results, and the fellow completes and supervises assigned medical procedures. Common to university hospitals, rounds also involve an educational component, with the attending staff or fellow who teaches and distributes significant clinical knowledge relevant to patient care to the residents and medical students.

Today, the MICU team meets in the conference room. Rupa presents her patients' subjective and objective assessment and plan to the rest of the team[1] during morning rounds. The team deliberates over the assessment and plan with respect to the patient's condition, and comes up with a plan of action for the rest of the day. The attending physician advises Rupa to follow up with a specialist for one of her patients. The attending physician also questions Rupa and the other resident and student interns about a condition her patient is experiencing and provides education. Rupa adds to her notes the tasks she has to do after rounds, more information on the new concept she learned, and people she has to follow up with for consulting about her patient. After her, the other team members present their patients, and the team begins to visit each patient at their bedside.

The patients assigned to the team are often not situated close to one another, requiring the team to walk to different points of the floor. Some patients assigned to the team are often not in the MICU, and may be located in the burn, trauma, or a step-down unit. Hence, the MICU team usually walks between the different floors of the hospital. Oftentimes, the MICU team members have informal discussions about the patients or their conditions on their way to the patient's room. These conversations also include an educational component, in which the attending physician or fellow shares knowledge.

Two of Rupa's patients are on the MICU floor, one is in the progressive ICU, and another is in the burn unit. The attending physician advises Rupa to discharge her patient

[1] Medicine.mc.vanderbilt.edu. Guidelines for Presentation [Internet]. 2015 [cited 9 March 2015]. Available from: https://medicine.mc.vanderbilt.edu/coremedicine_presentationguidelines

in the progressive unit to home. After visiting all her patients, Rupa finds a workstation outside a patient's room in the MICU floor (while the rest of the team is busy with the other resident's patient inside a patient room) and begins creating medical orders for lab testing for some of her patients so that she can see a result before afternoon. Meanwhile, one of her patient's nurse approaches her and requests a "verbal order" for a medicine, since the patient had been complaining of intense pain. Rupa quickly consults with the pharmacist, who is also waiting outside the patient's room and proceeds to sign an order for the nurse's request. Rupa proceeds to check off items from her notes as she progresses with her work. The morning rounds end when the team has visited all the patients assigned to them.

Rupa returns to the conference room and starts documenting "progress notes" for all her patients in the digital EMR system using a workstation. She first prepares the exit documentation, termed the discharge summary, for her patient who is being sent home, so that all the required paperwork can be completed by the end of the day.

It is 11 am, and MICU members start to gather inside the conference room for a quick "huddle" session. This interdisciplinary session is attended by ICU personnel such as the charge nurse, social workers, dieticians, physiotherapists, one representative each from the two ICU teams (generally the attending physician or the fellow); they summarize all the patients' conditions. Each session lasts about 30-40 minutes on average: duration depends on the number of patients currently admitted to MICU, those that are expecting to be admitted in the near.

Although she is physically present in the conference room, Rupa does not participate in the "huddle" session, since she has to complete many post-round tasks.

After addressing the immediate post-round issues, Rupa takes a quick lunch break with the fellow around 12:30 pm. Following this, she proceeds to place a phone call to consult with a specialist. Rupa talks to one of the specialists about her patient; he mentions that he will upload his consultations to the patient EMR. Rupa waits until she can see the consultation report, checking the EMR to see the consultation report whenever she remembers to. On receiving the report, she approaches the fellow. During their conversation, Rupa receives a phone call on her mobile phone. Since she does not know who is calling, she answers the call, thus interrupting her conversation with the fellow. The phone call is from a nurse about Rupa's other patient's lab result. Rupa hangs up after the conversation and proceeds to a workstation to place a medical order. Following this, Rupa walks back to the fellow; they start over with their conversation and decide to make some changes to the patient care plan.

Rupa spends the remainder of the afternoon responding to phone calls from nurses, checking on her patients, and finishing up documentation work, such as signing medical orders, typing out digital progress notes, and so on. It is 3:30 pm and Rupa does a final check of her notes to ensure she does not have any more work to do for her patients. She makes some important notes on a blank "sign-off" or "doctor-patient list" document that she can hand-off to the resident who will be working on-call for the day. The "sign-off" notes are kept to a minimum, comprising a one-line description of the current status of the patient, with some critical and required action-items that the on-call resident can complete overnight. Rupa approaches the on-call resident, hands over her notes, fills in the resident on her patients' condition and what needs to be done for them. Following this, Rupa heads home to catch up on rest after a tiring day.

During her shift, Rupa interacted with other healthcare providers and technology in the unit. The patient care plan that was originally decided on during the morning rounds for a patient changed during the day; this change was based on a follow-up consultation that was not necessarily communicated to everyone on the team. Further, the patient's condition at the end of her shift was also not communicated to everyone on her team. Rupa was interrupted from her work numerous times when she received phone calls on her mobile phone. She responded to all the phone calls, since she did not know who was calling, and, given that she is covering the ICU with critically ill patients, the information may have been pivotal for the ongoing patients' management. The information conveyed to her during the phone conversations were at times useful for her task at hand, but also disrupted her ongoing activity.

4.3 Summary

The study site is one of the leading healthcare providers in Midwest United States, with extensive intensive care units servicing a wide range of care. The MICU is a 24-bed unit with specialized, multidisciplinary staff and technology support to provide care for critically ill patients who require constant monitoring. This chapter discussed in detail the study site layout and staff, the information sources, and communication tools that are used by healthcare providers in maintaining patient-situation awareness in the ICU.

In the next chapter, I describe a theoretical framework, known as the Locales Framework, that can be used as a lens to view the day-day work practices followed by ICU healthcare providers in generating, disseminating, communicating, and managing dynamically changing patient tasks and goals, while maintaining patient-situation awareness.

Chapter 5. Study 1: Using Locales Framework to understand ICU task management and communication practices for maintaining patient-situation awareness

In this chapter, I present findings from my study on understanding the process of maintaining ICU patient-situation awareness. I first address the question “what are the task management and communication practices followed by healthcare providers to keep themselves up-to-date with the dynamically changing patient’s condition?” by discussing occasions of note-making and communication. Next, I address the question “what are the characteristics of notification interruptions induced by technology usage for communicating in the ICU?” Findings from this study help in understanding the barriers or breakdowns with existing work practices, which will be used to motivate the design of a novel system in chapters 6–9.

5.1 Occasions for maintaining patient-situation awareness

Collaboration, coordination, and communication are deeply intertwined activities that play a vital role in maintaining patient-situation awareness in the ICU. I was interested in exploring how healthcare providers manage their tasks individually and as a team, and how they communicate with each other while providing patient care. I found that healthcare providers generated and managed to-do lists or action-items as paper notes, which were later transcribed to the digital realm. Healthcare providers communicated when they wanted to know more or to inform another healthcare provider(s) about a patient-related activity or episode. A significant component of communication included conversing about the patients’ most recent condition and condition history. Communication involved either face-face or technology conversations during (i) structured work practice such as rounding or handoff, and (ii) general patient care during any clinical shift.

In the following section, drawing on observations from work involving rounding, handoff, and general patient care in a clinical shift, I explain the paper note-making and communication work practices healthcare providers follow to manage their tasks and communicate patients' condition.

5.1.1 ICU Rounding

Rounds on patients are a structured, essential duty performed by ICU healthcare providers every morning (Khairat & Gong, 2011; Pryss et al., 2013). Rounds typically involve a team of healthcare providers (physicians including faculty, residents/interns, fellows, and/or students, nursing, respiratory therapists, and pharmacists) meeting either in a conference room or outside the patient room in the ICU hallways (Figure 5.1).

Figure 5.1: The ICU team gathers for morning rounds to exchange patient information

During rounds, the resident presents a patient's "story" to the team. Significant effort is required on the resident's part to reconstruct and interpret a patients' story, owing to (1) the distributed nature of the patient's record (EMR, details from bedside devices, written notes, etc.), and (2) knowledge re-used from communication and coordination mechanisms (such as examining the patient, conversing with the nurse or the doctor on night duty, recalling from memory based on past experiences, and so on). Thus, a resident performs certain routine activities prior to rounding, such as: (1) checking patient details by referring to the EMR, (2) having a face-face conversation with the nurse and resident on night duty to become aware of the patients' overnight condition, (3) physically examining the patient, and (4) generating a prioritized list of issues and a proposed plan to tackle them. Typically, residents scribble notes while familiarizing themselves with the patient. The set of activities performed pre-rounding help the resident to prepare the patients' story to be shared during rounding.

Rounding typically comprises a two-step process with an iterative information exchange for achieving common ground, followed by visiting and examining the patient. During the routine morning rounds, the residents typically take turns presenting their patients' story with the help of paper-based artifacts. When the narrated stories require further support, they use the patient EMR to access digital documents such as X-rays or test results. This form of directing attention is easy when the team exchanges information in a conference room equipped with a large-size display. After presenting the story, the resident also describes a prioritized list comprising an assessment and a proposed plan of action to tackle each item on the presented list.

The patient stories the residents present are usually delivered in a structured format [(such as SOAP[2](subjective, objective, assessment, plan)] as the team is brought to a common understanding of the patient's condition. The other members, in addition to being passive listeners, interact based on their role in the patient's care, their prior knowledge, and the current status of the patient's condition. In general, the team performs actions such as reviewing the patient information (primarily paper-based and printed off the patient's electronic medical record), annotating or writing down notes on paper, and visually examining the patients themselves. As such, the team collaboratively works to identify a 24-hr plan of action comprised of patient-centered tasks/action-items, which can change as the day progresses. The action-items can include medical orders (e.g., laboratory tests or administering medication), a collection and summarization of patient physiological measures, a follow-up/consultation with specialists, and so on. Typically, an assigned healthcare provider completes the list of action-items. For instance, residents play a key role in placing medical orders and caring for the patient, nurses implement the orders and collect results, and the fellow completes assigned medical procedures. Common to university hospitals, rounds also involve an educational component, with the attending staff or fellow teaching and sharing significant clinical knowledge with the residents and medical students.

The nurses, who are generally present at the patient's bedside, participate during rounding by providing the most recent patient information. In some cases, the team might not have already discussed the information conveyed by the nurse. The nurse also plays a key role in advising the team to change a medication dosage for a patient-related event,

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[2] http://www.emrsoap.com/definitions/soap/

based on their work experience or knowledge gained from previous similar patient-related events. The vignette below illustrates how the nurse (N) requests a "verbal order" during rounds:

Nurse approaches the team as they are rounding on a patient. She mentions to the attending staff that the patient reported severe pain.

N: Can I order Tylenol for the patient?

AP: Yes, I can sign it later

5.1.2 Handoff sessions

Handoff sessions include a brief face-face exchange of patient information between healthcare providers (who play a similar role) during a shift change. A handoff session typically involves a healthcare provider whose shift is ending handing over the patient to the healthcare provider beginning their shift by rapidly summarizing the patient's condition over the previous shift, with some pointers on what has to be done in the next shift. For instance, a day-shift resident will communicate to the incoming resident what to look out for or what should be completed as part of patient care. The handoff process is supported with a written sign-off sheet (prepared by the resident leaving), comprising a one-line summary of the patient with some action-items for the incoming resident to perform during his/her shift. Typically, healthcare providers spend about 5 minutes or less discussing each patient, with more time spent ensuring both healthcare providers come to a common understanding of the patient. A resident often populates the information in the sign-off sheet from his/her paper notes, occasionally supplemented by minimal information obtained from the patient EMR.

5.1.3 General patient care

Post-rounding, healthcare providers proceed to perform actions according to their notes created during rounds. For instance, residents perform actions such as: (1) documenting the discussion made during the rounds as "progress notes" in the EMR, (2) working on the action-items recorded prior to and during the rounds, such as creating medical orders or consulting with a specialist, (3) receiving patient hand-off from the resident who is post-call, (4) following-up with patient management or performing medical procedures, and (5) handing off patient care (to the resident on-call) at the end of the shift. As the clinical shift progresses, the action-items originally generated during rounds are completed or modified with respect to the patients' changing condition. The vignette below depicts a scenario in which the resident attempts to remove a patient's breathing mask:

Resident (R) wants to try and take the breathing mask off the patient. She walks over to the patient's room and finds it difficult to remove the mask. R walks outside the patient room to the nursing station to find the patient's nurse (N). The R finds a respiratory therapist (RT) instead and asks him about the N. The RT does not know where the N is. The R looks for the ASCOM phone number at the station and calls the N. The phone call is unanswered. Unable to decide on her own, the R walks back to the conference room to consult with the fellow (F). A face-face conversation is established: the F advises the R to either follow a 4hr mask-on and mask-off technique while also informing the nurse about the care plan, or to leave the mask on for the day. Following this advice, the R calls the N again. A phone conversation is established and the R conveys the fellow's advice to the N.

R: How are patient's current vitals?

N: Temp is at 101 ^{o}F, blood pressure is 90 over 40, heart rate is 95, and blood oxygen saturations are 90%. Respiratory rate is 20.

R: Let's leave the mask on for the day. I will sign an order for the fever.

After hanging up, the R promptly proceeds to create and sign a medical order for a fever medication.

5.2 Task management through scrap note making on paper

Although the study site has several stationary and/or mobile workstations, with the EMR facilitating the completion of action-items, paper-based artifacts are also commonly used as an external aid in managing information through the note-making process (Saleem et al., 2009). I refer to the content of the notes written on paper-based artifacts (written during ICU rounding) as "information scrap notes" (ISNs). ISNs are personal/informal notes made every day before, during, and after ICU rounding. They do not replace the standardized, digital notes documented every 24 hours as a part of the patient EMR. ISNs aid in externally distributing information (usually transferred as part of digital notes). Paper-based artifacts afford manipulability and portability (Harper et al., 1997). Hence, ISNs serve as an efficient tool that aid in scribbling notes without losing track of what is being said during a rounding conversation.

The contents of the ISNs are usually modified and transferred/converted into digital form. For instance, an ISN with the content "chest x-ray" scribbled by a resident on a rounding checklist (for patient X), represents an action-item to create a medical order requesting a chest x-ray. The resident then transfers this action-item as a medical order for the patient using the EMR (which will be executed by the nurse by contacting and sending the patient to the radiology department). Following this, the content in the resident's ISN is modified to "þchest x-ray," signifying its completion (Figure 5.2).

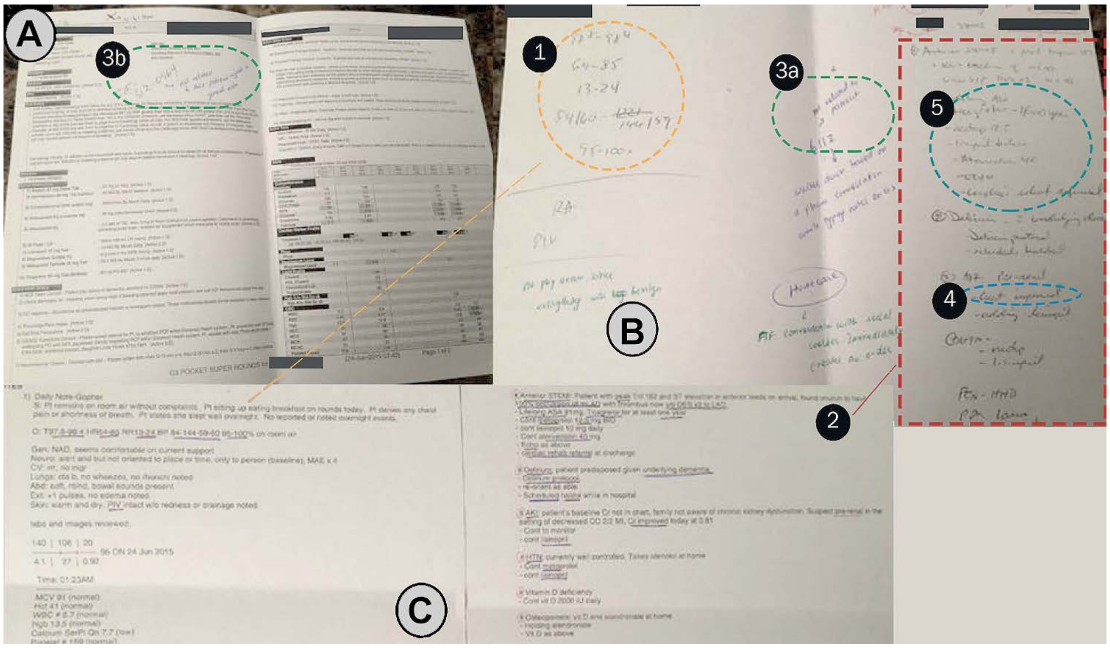

Figure 5.2: ISN lifecycle from paper printed off EMR back to EMR

ISN content types include: (1) action-items, (2) pointers that help jog one's memory, (3) reminders that one wants to follow-up or consult with, and (4) reminder notes that serve as a note to self. These findings overlap with other content types recognized in office-work domains [6]. ISN content purposes include: (1) type out post-rounding action-items as orders/progress notes using the EMR, (2) consult specialists/subspecialists on topics raised during rounding, (3) update the team on general patient care based on the result of action-items, (4) hand-off to fellow members during the change-over, and (5) remember to perform an activity (e.g., calling someone) at a later time.

Each ISN goes through a lifecycle as it is transferred from the digital to physical realm, and back to the digital realm. Healthcare provider notes are transferred from the original paper-based artifact printed off patient EMR (A) to the ISN written on the backside of the paper artifact (B) to a translation of some of the written notes into digital form (C). From the figure:

(1) Depicts the patient's subjective, vital information written before rounding, from EMR and paper artifacts (A). This information will act as an external aid during rounding presentation, and is later translated with exact numbers in the digital progress note.

(2) Depicts the assessment plan for the day written before rounding, used as an external aid to present during rounding, and serves as a prime to jog memory while translating the assessment plan as a part of the digital progress note (C).

(3a) and (3b) denote information to self that may/may not be related to the patient.

(4) Depicts the reminder to self to consult with a specialist.

(5) Denotes the action-items, which are created as medical orders in addition to being translated as part of the digital progress note.

5.3 Communication for maintaining patient-situation awareness

Healthcare providers communicate when they want to know more or to inform another healthcare provider(s) about a patient-related activity or episode. The current medium of communication during rounding or handoff sessions is face-to-face conversation, which provides the members participating in the sessions a shared perceptual access to the rich environment of the patient and other electronic patient information. Further, the participants already have an established relationship, or at the very least, knowledge of the other's skill levels and areas of expertise, on which to base their level of trust in the information conveyed.

As mentioned in the previous section, communication during the ICU rounds is often structured, wherein, before a collaborative decision is made, an initial presentation is made, and a shared understanding is generated and summarized based on contextual information provided by the nurse. This can be related to Hazelhurst and colleagues' (2007) verbal information exchange structure as shown in Table 5.1. Observed during fieldwork and ascertained through existing research (Sexton et al., 2000), verbal face-to-face communication among healthcare providers is often interrupted and poor in quality, especially during the rounds and handoff sessions. This can lead to inefficiencies and potential error in the ICU, where rapid and accurate communication is essential for delivering safe patient care (Winters et al., 2012).

Table 5.1 Relating Hazelhurst's verbal information exchange to the information exchange in a typical ICU round

Verbal information exchange	Typical ICU round
Direct an action: to transition the activity system to a new state	Resident begins the structured presentation, comprising the patient's medical history, diagnosis, treatment assessment, lab study results, clinical assessment in the past 24-hr period in the pre-defined order of physiological systems. This will transition the critical care team to a state where everyone is

	informed of the past 24-hr progress.
Sharing goals: to expect a desired future state	All the members of the team expect to have received the patient's information about all the physiological systems in the same order as expected towards the end of the presentation.
Conveying shared understanding: to identify the status of current state	Verbal updates from the nurse will convey a shared understanding of the patient's condition to the team.
Alerting: to convey abnormal or surprising information about the current state	The nurse alerts the team about orders that need to be entered into the EMR.
Explaining rationale: to understand current state	The nurse in with the help of some other team members will summarize and explain the rationale to the team regarding the patient's progress based on contextual information.
Reasoning: to understand current state of the system	Often times, the critical care team will require interdisciplinary information exchange, in which team members retreat into discipline-specific silos. In cases where a patient condition requires the establishment of a common ground by all

	the team members, one or more members of the team will have to reason and explain the state of the condition.

The resident (R) checks his ISN and notices an action-item requiring him to check on a lab result. He looks at the patient EMR for a result, but cannot find one. The R walks over to the patient room to check on the patient. Following this, the R moves to the nursing station to talk to the patient's nurse (N).

R: What's going on with Mr. Smith? Are his lactate results back?

The nurse refers to the display monitor with patient vital signs and looks over at the patient EMR before responding.

N: His fever has not reduced, it has been at 101, blood pressure is 90 over 40, heart rate is 95, and blood oxygen is 90% on ventilator. His respiratory rate is 20. Lactate was 4 this morning. We don't have a recent result. The patient has been complaining of pain.

R: Yes, I just checked on him. He did complain of pain. Give him Ibuprofen. Send a blood sample for CBC. Keep me informed when the result comes.

R proceeds to call the Fellow to discuss more on what has to be done next.

In the above vignette, the resident was interested to know more about his patient's lab result (a patient-related activity or episode). Since he could not find any information, he proceeds to ask the nurse. The nurse refers to the display monitor and the patient EMR before responding to the resident's questions. The conversation includes a discussion about the patient's past and current condition. The resident conveys an action to the nurse (administer fever medication), without creating a medical order. The resident makes a phone call to consult with the fellow on next steps. The updates to the patient's treatment plan (CBC test and medicine administration) are not communicated with the rest of the team.

5.4 Locales Framework

Fitzpatrick (1996) developed the Locales Framework to understand the nature of social activity and how a locale (or place) supports activities. It is comprised of five aspects: (1) locale foundations, which identify the social world of interest with spaces and resources, (2) interaction trajectory, which identifies the dynamic and temporal aspects of the living social world and the interactions within and across locales, (3) individual views, which identify the different perspectives assumed by the participants of the locale, (4) mutuality, which identifies the awareness achieved through communication and coordination mechanisms, and (5) civic structures, which identify the relationships between the social worlds and the locales. According to this framework, a social world is comprised of a group of people in a site of collaboration, using some means to communicate, while sharing a common purpose. A locale is the actual site in which a group collaborates, the means by which people communicate, and the means by which the work is achieved. For instance, a resident and a nurse with the goal of advancing a patient out of the ICU would form a social world. If the resident and the nurse meet in a conference room while discussing the patient's condition, the room with its artifacts (whiteboard, workstation, notes etc.) forms a physical locale. If the resident and the nurse have a phone conversation, it forms an audio locale.

The Locales Framework has been validated to understand existing collaborative work practices, and to motivate the design of new systems (Greenberg et al., 2000; Kaplan & Fitzpatrick, 1997; Scott & Alan, 2003). The Locales Framework is concerned with the principled design of CSCW systems, wherein the framework helps provide a coherent image of system requirements and informs their construction (Fitzpatrick, 2003). I viewed the situated nature of ICU work using the concept of dynamic social worlds, which helped me to focus on the interaction at hand. In the following section, I draw on the fieldwork using the five different aspects of the Locales Framework to understand the nature of collaborative work mediated through information exchange using technology.

To support my discussion, I use an example scenario involving a resident and a nurse as direct interactants, and other healthcare providers as peripheral members. Both the resident and the nurse are on their day shift and not physically co-located; while the nurse is at a nursing station with access to a computer, the resident is on his way to the operation theatre and lacks immediate access to a computer. The patient of interest in this scenario is actively cared for by the nurse, and was recently assigned to the resident at the beginning of his shift. In this scenario, the nurse is attempting to contact the resident once the lab results are uploaded to the patient's electronic medical record (EMR). The nurse is using a landline phone, while the resident is using a hospital-owned mobile phone.

5.4.1 Locales Foundations

For the purpose of this study, I view the ICU as a social world. I refer to the locale in the example scenario as the "patient management locale." The key members of this locale are the resident and the nurse, who initiate the conversation through a phone call. Each member has his or her own representation and understanding of the patient. Interaction is initiated by the nurse calling the resident; verbal communication is used to share patient data. Other healthcare providers can also participate in such a foundation in a more peripheral manner, e.g., the lab that helped obtain the results for the patient, the fellow who oversees the patient's condition, and so on. The locale is a discontinuous audio space lasting the duration of the phone call, or possibly the synchronous face-to-face conversation if the nurse and resident can meet physically. In both cases, the medium can facilitate the merging of the peripheries of the participating ICU worlds for a period of time, thus setting up a context for sharing information.

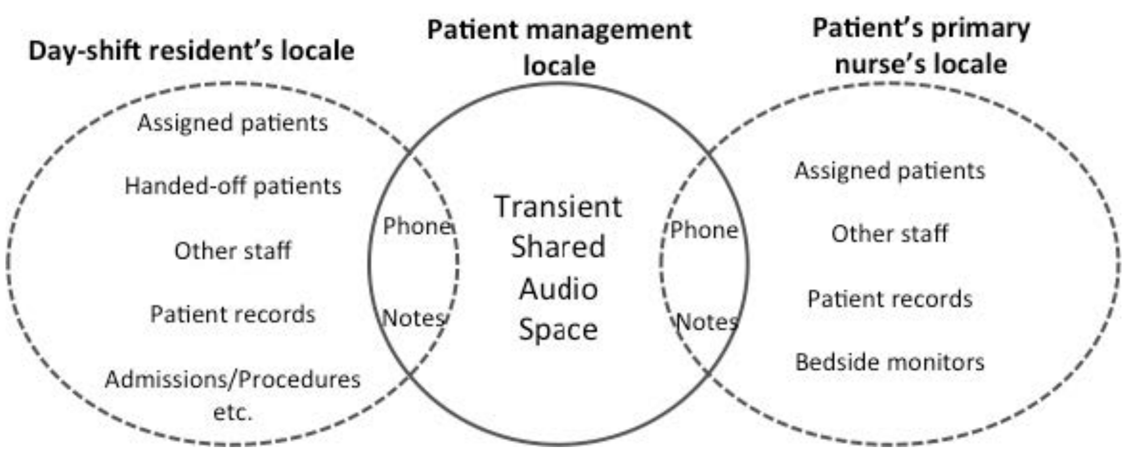

Figure 5.3: Patient management locale between a patient's primary nurse and the resident to whom the patient was handed-off during shift change

Similar to an observation by Kaplan and Fitzpatrick (1997), the locale continues to persist beyond the end of the phone call: the resident or the nurse can return to it several times, and there can be changes in the locale membership (Figure 5.3). Further, there is a lack of shared awareness outside of the phone call. Information is held in the memory of the locale members, or in scrap notes made on paper [16,31,32], and later digitally documented by one of the members.

5.4.2 Civic Structures

This aspect of the Locales Framework helps determine how a locale is positioned in the overall organization, with consideration for the impact on the activities occurring within the locale. In the example locale, both the resident and the nurse operate in their own ICU worlds, but share a collective goal of patient management. The ICU is a rich structure comprised of a set of policies, rules, and regulations governing its operation and the manner in which activities enfold within the clinical work practice.

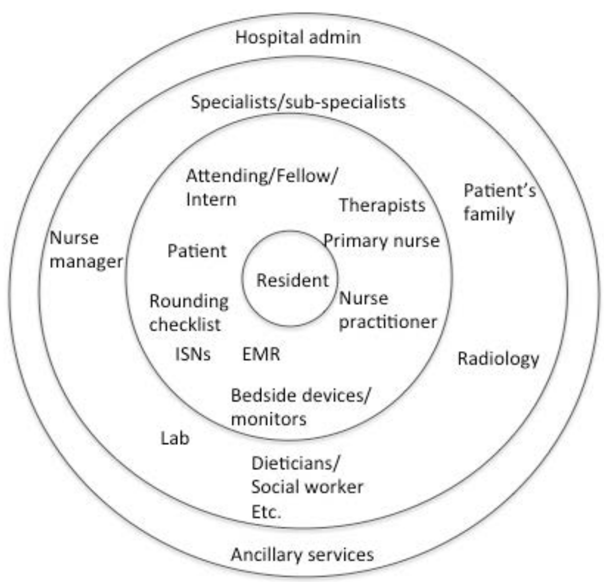

Figure 5.4: Civic structure depicted from a resident's perspective as conditional matrix for the patient management scenario

Civic structure can be depicted as a conditional matrix, for instance, from the perspective of the resident in the ICU, where the elements closest to the center closely impact the resident's participation in administering patient care, and the more distant elements have less impact (Figure 5.4). For instance, the civic structure for labs impacted the locale between the resident and the nurse. The locale was established when the nurse initiated the call after the lab uploaded and flagged the results to the patient EMR. In addition, the lab personnel and the nurse had an already established locale that informed the nurse of the patient's lab results.

5.4.3 Interaction Trajectory

This component of the framework considers the temporal aspects of the locale and its associated objects. There are several interaction trajectory perspectives in ICU rounding: the trajectory of hand-off, the trajectory of patient management, the trajectory of medical orders, the trajectories of individual healthcare providers, and so on (Reddy et al., 2006). Specific to the example scenario, the patient management locale can comprise a trajectory that is an unscheduled event dependent on the patient's condition and the availability of the participating resident and nurse. Conversations related to patient management, such as informing about an abnormal lab result and obtaining feedback, tend to be short, lasting about 10-15 minutes. Following patient identification (such as referring to a patient by name and ICU room number), the format of the conversation includes a report on the lab result and a discussion of the next set of steps. The outcome of such a conversation is usually a collection of suggestions or a decision on patient management. In some cases, the resident is not at a workstation to access the lab result that has been uploaded to the patient EMR. Conversations in such instances usually depend on additional effort from the resident to familiarize themselves with the patient's past and current conditions, or the nurse's ability to verbally describe the patient's condition, while constructing a shared understanding of the patient.

Given the observation and contextual inquiry sessions with the resident, if the resident expects to hear from the nurse about his lab order (that he had signed earlier that day), he will more likely interrupt his current activity to respond to the notification (nurse's phone call). However, the resident does not know that the call is from the patient's nurse until he responds to it. Further, the phone call is immediately delivered to the resident, without considering that he is scheduled for a medical procedure and is about to enter the operation theatre.

5.4.4 Mutuality

The mutuality aspect helps identify the shared awareness of people, objects and trajectories in a locale. ICU healthcare providers are often peripherally aware of the patient's condition and the activities occurring in the ICU [33,34]. Based on an observation and contextual inquiry session, a provider lacked the following aspects of awareness information: patient's current condition (such as vital signs) if the provider is not present closer to the patient room or is not accessing patient EMR, hands-on access to the patient EMR irrespective of location, information on the most recent medical orders and/or medical intervention(s) and their corresponding results (such as labs, x-rays, reaction to a drug etc.)

Communication often included only two people (for instance the resident and nurse from the example scenario) who can directly participate in a follow-up phone conversation, for instance, with both simultaneously available. Other members who are physically co-present (e.g., fellow working independently while sitting next to the resident in a conference room) can indirectly participate by overhearing one side of the conversation. Other members potentially impacted by the call must rely on the participating resident to pass on the necessary information after the call. Further, the exchange of information does not necessarily occur as it has been prioritized. For instance, the nurse may not have conveyed an abnormal lab result to the resident, since the resident was busy performing a procedure on a different patient. Consequently, the timeliness of handling the abnormal result largely relies on the resident remembering to monitor patient orders, or the nurse remembering to reach out to the resident again.

5.4.5 Individual Views

The individual views of all the members in the ICU differ (Reddy et al., 2002). Both the resident and the nurse hold their own unique perspective of the patient management locale. Compared with the resident, the nurse has a more detailed knowledge of the patient with respect to, for example, specific physiological responses to medicine dosage. On the other hand, the resident has a more detailed knowledge of multiple patients in the ICU, as compared to the nurse, who primarily cares for her/his assigned patients. In the example scenario, the nurse has to explain the patient's current condition in relation to the lab result, about which she initially called the resident. And the resident performs one of the three tasks: (i) uses his/her sheet of paper to make notes [16,32], (ii) mentally holds information while developing a plan of action for the nurse to follow, (iii) moves to a computer to access the patient EMR to clearly understand the patient's situation before providing suggestions to the nurse. Although the resident is mobile, with limited access to the patient EMR, he can still construct in his head or scribble notes on a sheet of paper a view of the patient's condition that contains the relevant points the nurse chose to relay, thus building a contextualized and personalized substitute for patient record. The notes resulting from this conversation are usually trashed at the end of the shift, or used while handing off patients to other residents, if the information is thought to be highly important.

5.5 Barriers or breakdowns

The Locales Framework helped guide my understanding of the dynamic, situated work in the ICU. This section summarizes the pain points, barriers, or breakdowns that were identified in applying fieldwork data to the Locales Framework.

ICU healthcare providers are remarkably skilled at understanding a patient's condition and administering patient care through collaborative and coordination mechanisms, but, even so, difficulties, breakdowns, and uncertainties arise. A double record consisting of redundant information exists both in paper (as a checked action-item) and digitally (as a medical order). Duplicate records can cause several awareness and coordination problems (Reddy et al., 2002), such as poor contextual situating of healthcare providers in regard to a patient's on-going care. For example, a resident may be forced to physically find a nurse and initiate a face-to-face conversation to change a patient's medication dosage. This practice of finding the nurse becomes difficult if the nurse is not present near the patient's room or at the nursing station.

The residents' paper-based notes are not shared with anyone on the team. The only paper-based information shared by the residents is the notes made on the sign-off sheet for every patient during shift change. The sign-off sheet notes are incomplete single-liners that describe the patient to the resident receiving information. Ultimately, the success of communication relies on the residents' ability to paint the patients' condition from complex clinical information either verbally or in writing.

ISNs have a short life, typically as long as the critical care team member's shift. They are not archived, but rather discarded at the end of the shift. Hence, potential information recorded in ISN can be lost. Further, incomplete action-items from the ISN are often transferred as changeover occurs within the ICU team. This requires re-writing content onto a standardized paper-based sign-out sheet, which can again result in potential information loss. Further, boundaries between the tasks and roles are not tightly drawn [5]. For instance, a nurse may suggest a medication dosage (through a verbal order) and complete the administration even before the resident has formally signed her request on the EMR.

Not all healthcare providers in the team are always present during the rounds or handoff sessions. Furthemore, not everyone on the team is always actively focused on the patient's care. Previous studies indicate that the priorities of an action-item decided during a conversation are at times implied or not prioritized as intended (Reader et al., 2009). Special coordination mechanisms or a shared, persistent, digital system would effectively ensure that everyone on the team can achieve a shared understanding of the patient's condition.

Communication is often performed to enhance the patient-situation awareness among the healthcare providers involved in the conversation. Not everyone on the team is constantly kept updated about the patients' changing condition or treatment plan. Healthcare providers are often forced to immediately respond to phone calls, thereby disrupting their ongoing activity, due to the lack of information on who is calling or the details of the conversation. The rate of disruption may be low when a healthcare provider is in downtime or expecting a phone call. For instance, a resident cannot avoid an initiated phone call; the mobile device does not include caller information, thus creating a challenge for the resident to identify the significance of the message that will be conveyed and its relation to a patient's treatment plan. Thus, the resident's workflow will be disrupted if he is busy performing an unrelated activity when the phone call is initiated, in turn impacting his performance (Stanton et al., 2001). If, however, the resident is on downtime, the information from the call can allow for effective and timely diagnosis of a patient's abnormal condition.

5.6 Summary

This chapter summarized the data collected from fieldwork (Study 1), and applied the Locales Framework to understand the dynamic and situated ICU work specific to task management and communication while maintaining patient-situation awareness. Barriers and breakdowns for maintaining patient-situation awareness were identified and summarized. Chapter 6 will include a more detailed discussion on deriving and establishing general design recommendations for a novel system that can overcome the barriers this chapter identified.

Chapter 6. Study 1: Design implications using Locales Framework

In Chapter 5, I applied data collected from Study 1 to the five different aspects of the Locales Framework in order to understand the collaboration, communication, and management of patient tasks and goals. In addition to understanding the situated nature of dynamic social world, the Locales Framework can also be applied to motivate the design of new systems (Greenberg et al., 2000; Kaplan & Fitzpatrick, 1997; Scott & Alan, 2003). One of the goals of this dissertation is to design a novel technology tool to help ICU healthcare providers improve patient-situation awareness while managing tasks and expediting communication with minimal interruptions. Aligning with this goal, and given the mobile nature of ICU work, in this chapter I derive a set of design guidelines for a novel mobile application. This chapter will conclude with the description of a clinical tool based on the derived design guidelines.

6.1 Design guidelines

This section proposes a set of design guidelines for effectively maintaining ICU patient-situation awareness with task management and communication, derived from the five aspects of Locales Framework and motivated through cognitive theories, models relating to attention and memory, and human factors principles for different modalities of communication.

I use an example from my fieldwork to describe the derivation of the design guidelines. Consider the creation of two different locales (L1, L2) in different physical locations. In L1, a nurse (N) at a nursing station is performing a documentation task. She notices that her patient's EMR has a new lab result. Meanwhile, in L2, a resident (R) is in the conference room involved in a face-to-face discussion with the fellow (F) about one of his patients (not the same patient as the one N is calling about). The N calls the R using a landline phone, while R is using a hospital-owned mobile phone. R is interrupted from his conversation with F, since he is not expecting a call from N. Also, since R cannot determine who is calling (the callerID is unknown), he answers the call. This results in the creation of a new locale, with members R and N. I report an excerpt of this phone conversation.

N: I am calling about Mr. Smith in room 160 with lactate 4.

R: What are his current vitals?

N: He has fever with temperature 101, blood pressure is 90 over 40, heart rate is 95, and blood oxygen is 90% on ventilator. His respiratory rate is 20.

R: What is his white blood count?

N: 4000.

R: Was there an earlier test?

N: Yes, lactate was 2.3 three hours ago.

R: Ok, let's redraw in 30 minutes and see what's going on. I will sign the order shortly.

N: Ok.

6.1.1 Virtual patient awareness

The example locale is a discontinuous audio space for the duration of the phone call. The conversation thread can persist beyond the end of the phone call; the resident or the nurse can return to it several times (through multiple phone calls), or there can be changes in the locale members if another healthcare provider is consulted. There is, however, a lack of shared awareness for the healthcare providers on the patient's team, since the locale members hold the information in memory or make paper notes (Chen, 2010; Malhotra et al., 2007; Srinivas et al., 2015). Information shared during the phone call is not immediately digitally documented to keep the other healthcare providers informed about the patient's progress. The existing notification system does not automatically inform the nurse when the resident has signed an order for her to process. This lack of knowledge of team members' work in relation to the patient's current condition can potentially impact patient safety (Stanton et al., 2001).

Paper notes have a short life, typically lasting as long as the healthcare provider's shift. They are not archived, but rather discarded at the end of the shift. Hence, potential information recorded can be lost. Further, incomplete action-items from the notes are often transferred as change-over occurs within the ICU team. From my observations at the study site, change-over or shift change always requires re-writing content onto a standardized paper-based sign-out sheet, which, again, can result in potential loss of information. Boundaries between the tasks and roles are not tightly drawn (Reddy et al., 2002). For instance, a nurse may suggest a medication dosage (through a verbal order) and complete the administration before the resident has formally signed her request on the EMR/CPOE. Hence, there is a need to create a centralized system that allows any healthcare provider to create and disseminate tasks, and that allows everyone to see what each team member should complete by the end of the day.

One way to enhance awareness among co-workers is to take advantage of technology solutions that mediate task management and communication (Bardram & Hansen, 2004; Hong et al., 2009; Kohn, 2000; Munoz et al., 2003; Tang et al., 2001). For instance, the system can allow healthcare providers to create patient-specific locales, where they can create and disseminate tasks, and exchange information seen by everyone on the team within each locale, thereby keeping everyone abreast of the patient's condition. This guideline (based on Locale foundations, civic structures, and mutuality) creates virtual and persistent patient locales, which allow ICU healthcare providers and information resources (such as tasks or messages) to co-exist, thus keeping others informed through notifications and improved shared awareness.

6.1.2 Asynchronous awareness

From Study 1, information documented on paper as notes is not immediately translated to the patient EMR. Further, healthcare providers manage their tasks or to-dos using paper notes that are not shared among the team. Thus, there is a lack of synchronization between both the paper-based and digital representations (Trigg et al., 1999). For instance, the nurse from the example locale can make a note or action-item on her paper sheets to send the patient sample for another test during the phone conversation. This note will help her externalize the information she has to remember and focus more on the conversation. When the resident signs the order for the follow-up test, not everyone on the team is notified that such a test has been ordered unless they make an effort to look at the patient EMR (which, as the contextual inquiry sessions revealed, was considered a cumbersome task). Consequently, this guideline (based on Locale foundations and civic structures) proposes connecting the system to the patient EMR, thus allowing constant updates and ubiquitous access to real-time patient-centered data.

Even though the nurse checks off the action-item on her personal notes (e.g., after sending a patient sample for another laboratory test), the resident or others on the team are not necessarily notified that the action-item has been completed. This forces the healthcare providers to update the others through external communication means (e.g., through phone). The creation of the example locale is dependent on the resident responding to the call initiated by the nurse. The resident cannot avoid the call; the mobile device at the study site does not include caller information, thus creating a challenge for the resident to identify the significance of the message and its relation to the patient's treatment plan. Thus, the resident's workflow will be disrupted if he is busy performing an unrelated activity when the phone call is initiated, in turn impacting his performance (Stanton et al., 2001). If, however, the resident is on downtime, the information from the call can allow him to effectively and promptly diagnose a patient's abnormal condition.

This potential disruption in the form of a mobile phone notification (phone ringing) can be overcome with asynchronous communication. Existing research has identified ways to manage interruptions caused by technology-based notifications, such as: (i) an interruption impact reduction paradigm, in which software-based agents prevent or block a notification for a specific time period (Gillie & Broadbent, 1989; McFarlane, 2002; Robertson et al., 2004), and, (ii) an interruption value evaluation paradigm, in which a preview of a notification is provided so that the interruptee (person receiving a notification) can decide to either continue or temporarily stop an ongoing task (Grandhi & Jones, 2010; Grandhi & Jones, 2015).

Hence, this guideline uses the interruption value evaluation paradigm, so that the interruptee can evaluate every interruption. This is supported by results that not all ICU notifications are unwanted interruptions (Klemets & Evjemo, 2014; Sasangohar et al., 2012). As phone calls are more disruptive than text or voice messages (Ho & Intille, 2005), notifications may be provided through a combination of visual (Phansalkar et al., 2010) or tactile cues (Oulasvitra & Erricson, 2009) that occur at a time determined by the receiver to minimize disruptions to an ongoing activity. For instance, the resident can state that he is "busy" until 11 am and prefers receiving less urgent messages after 11. In this case, the technology will batch and provide all the less urgent information after 11 am. Urgent messages can be generated as text messages (visual notifications) for the resident, irrespective of time. Urgency of messages can be computed based on the patient's current vital signs (from EMR) and a priority measure (such as high, medium, low) explicitly stated by the sender.

6.1.3 Locales-specific awareness

In the example of locales, the resident and the nurse can be members of multiple locales, but share a collective goal of managing a patient. This guideline (based on civic structures) proposes the need for a clear distinction and easy movement among multiple locales.

Existing research has already identified several strategies that are followed by people for maintaining awareness when switching between tasks while receiving notifications. These include: (i) encoding in the long-term memory of the receiver, (ii) rehearsing information prior to switching, or (iii) relying on environmental cues when resuming a task (Beach, 2006; Erricson, 2004; Iqbal & Horvitz, 2007; Oulasvitra & Ericsson, 2009; Trafton et al., 2003). Similar strategies could be applied when switching between multiple locales, irrespective of whether a notification is received. For instance, the different patient locales can be color-coded for a resident to encode patient information based on color. When the nurse sends the resident a message about a lab result, the color of the text message can be used as a retrieval cue in reducing the memory demand for the resident, thus allowing him to simply “glance at” the message while determining which patient the message concerns.

Communication of patient information or notifications can be tailored to each locale. Appropriate content can be presented for the resident to effectively and efficiently understand and interpret information, e.g. a patient room number coupled with the patient’s initials can be an accompanying visual cue to differentiate among locales. Others on the team who are not notified directly can still remain updated by visiting the virtual patient locale. The system can also buffer less urgent messages based on the location of the receiver. For instance, a resident walking into a patient’s room can receive the buffered notifications specific to the patient to provide a context.

6.1.4 Temporal awareness

In the example, the resident suggests that the nurse perform the lab test again after 30 minutes. Hence, the resident will expect a phone call from the nurse in 30-40 minutes. From the contextual inquiry sessions, if the resident expects to hear from the nurse, he will more likely interrupt his current activity and respond to any notification (which may not be the nurse’s phone call). Thus there is a temporal structure to the resident’s workflow. Research identifies ICU work as temporally organized, since healthcare providers seek, provide, and manage information in their daily work (Reddy et al., 2002; Reddy et al., 2006). Hence, the system should allow healthcare providers to be aware of activities and interactions evolving over time, including: control over past, present, and future aspects of work; how people coordinate their activities over time; how people learn from past experiences and breakdowns, and how processes are supported.

Providing information about a communicated message can improve the contextual and situational awareness in the dynamic and temporal nature of clinical work. Research on context-aware computing and interruptibility define interruption context by considering the situation of the interruptee (Dey 2001; Grandhi & Jones, 2009; Horvitz et al., 2004; Schilit et al., 1994) based on social (Fogarty et al., 2005; Ho & Intille, 2005), cognitive (McFarlane & Lotorella, 2002), and relational factors (Avrahami et al., 2007; Fogarty et al., 2005). This guideline (based on interaction trajectory and mutuality) proposes an extra patient-centric factor in the context of caring for the critically ill, i.e., factors that have the potential to impact patient safety and long-term care. These factors include a patient's past and current condition, recent vital signs, previous and recent intervention results, and time between a medical order creation and execution. If the resident from the example locale had been provided with a visual cue containing the lab result, vital signs, and priority of the message before initiating a phone call, then the nurse would have less disruptively conveyed the information. This approach would improve contextual awareness and provide more information to the resident about when to respond. In addition, this would also provide freedom to the resident in deciding when to respond to the nurse.

6.1.5 Healthcare provider-tailored empathic awareness

Each healthcare provider can hold a unique perspective reflecting her/his participation in a patient locale (Reddy et al., 2002; Srinivas et al., 2015). In the example, when compared with the resident, the nurse has a more detailed knowledge of the patient, e.g., with respect to specific physiological responses to a medicine dosage or pain level. The resident has a more detailed knowledge of multiple patients in the ICU. This difference in perspectives influences healthcare providers to participate differently within shared locales. The nurse will notify the resident of an abnormal lab result based on her knowledge of the patient's current condition and normal limits of results. The nurse might consider even a 0.5 increase above a normal value as important to be communicated to the resident. The resident, on the other hand, might not be aware of the patient's current condition and will prefer responding to this 0.5 increase when he has completed an important conversation with the fellow on another patient who is relatively more ill.

Specific to task management between healthcare providers, previous studies indicate that the priorities of the action-items formed by the team are at times implied or not prioritized as intended (Reader et al., 2009). For instance, the nurse may not immediately receive and process an important medical order created by a resident that is prioritized as "urgent." This is because he/she may be away from her workstation attending other patients, and/or was not immediately notified. In this example, while the nurse has to be immediately notified to carry out the task that requires an action, others on the team are only required to know that the resident to the nurse has disseminated a particular task or action-item, through, for instance, a "for your information" (FYI) tag.

This guideline (based on individual views) proposes tailoring task management and communication specific to healthcare providers by considering their responsiveness. To provide an overall bird's eye view of patient care and support shared awareness of patients' situations, the system can include a visual bread crumb path of the flow of action-items between the healthcare providers, based on their role, as they are created, assigned, forwarded, and completed. Further, the system can tailor empathic and polite notifications based on a healthcare provider's perspective of a locale in a way that reflects their degree of focus and participation. Research identifies that responsiveness to notifications depends on what the interruptee is doing at the time (Fogarty et al., 2005), the emotional state of the interruptee (Hudson et al., 2002; Mark et al., 2008), and the modality of the notification (Hudson et al., 2002). Bickmore et al. (2007) ascertain the need for an appropriate level of politeness while interrupting users in order to maximize long-term effectiveness. Hence, the system can use different modalities of notification (visual, tactile, etc.) based on explicitly identified message importance, current patient's condition, and healthcare provider participation in the locales, so that non-active members in a locale can be notified differently compared to active members. For instance, a resident who is an active member of a patient locale may receive a tactile alert from a wearable device in addition to a visual text message explicitly stated as important by the nurse. A less active attending staff may receive only a visual text message. This guideline is motivated by the human factors principles of Phansalkar et al. (2010) concerning placement of information, prioritization, and usage of color and textual information.

6.2 Mobile technology for the study site

The studied ICU environment comprises of an artifact ecology (Vasiliou et al., 2015), rich in a heterogeneous mixture of digital and physical artifacts that are interlinked and used for a variety of clinical tasks while supporting the ICU workflow. For instance, as seen from the shadowing sessions, a patient's record may be printed and annotated, and the written notes may be used to perform an activity and then later input into the patient EMR. Paper-based artifacts have been found to offer affordances such as manipulability and portability (Harper et al., 1997). This was observed during the shadowing sessions, in which healthcare providers rapidly made notes on paper without losing eye contact. In addition, ascertained through shadowing sessions and previous research, healthcare providers were observed making notes (which they preferred not to share) on paper, which were never documented to the patient EMR and served only to help them externalize the amount of information they had to remember. Hence, the design of the tool that results from Study 1 findings cannot only be a mobile software application that replaces paper notes in an attempt to enhance patient-situation awareness in the ICU. The tool can, however, digitally mediate paper notes when needed. For instance, healthcare providers can digitally share patient information during the "handoff" sessions, as opposed to making notes on sign-off sheets. Healthcare providers can also make personal notes on information they wish to re-visit after a couple of days, giving them the freedom to not be mandated in discarding their paper notes at the end of every shift. Consequently, based on the findings from Study 1 and existing research, I began to explore the design of a clinical tool that includes the ecology of both technology and paper artifacts.

I envisioned a clinical tool, named PANI (patient-centered notes and information manager) that integrates the use of a mobile application, paper-based artifacts, and a wearable device in one system, which supports the management and communication of notes and action-items that are generated throughout a typical ICU clinical shift. PANI was envisioned to organize healthcare providers' notes, create and disseminate action-items within and between ICU teams, and provide anytime, anywhere access to patient information through a connection to the EMR (Figure 6.1).

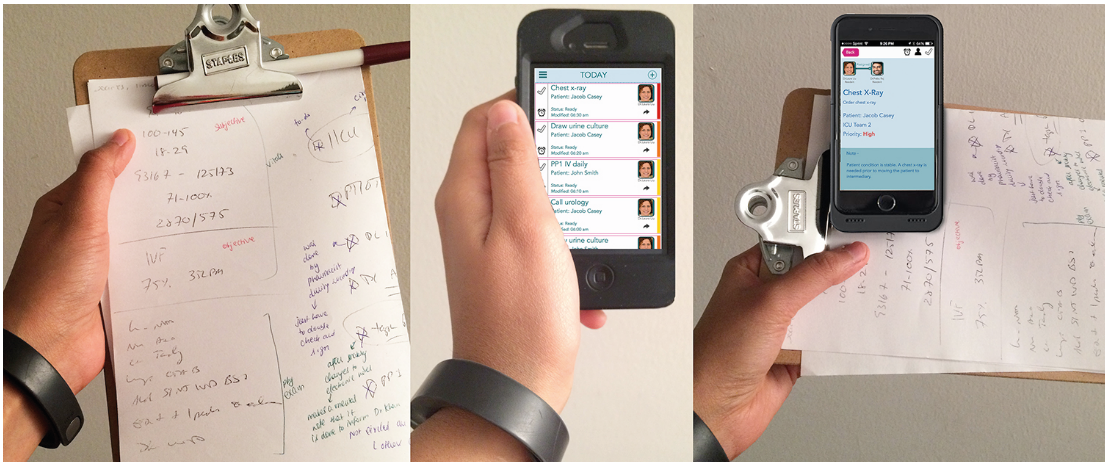

Figure 6.1: Proposed concept of PANI

The paper-based component is loosely structured to include any form of paper artifacts, including printed patient EMR, rounding sheets, or blank sheets of paper. Hence, although PANI was envisioned as a mobile add-on tool to the existing patient EMR, healthcare providers could print off rounding sheets to refer to a patient's history, while rapidly creating or disseminating action-items. This was done because the original goal of PANI was not to replace patient EMR, but rather to enhance patient-situation awareness through effective task management and communication. Given this, PANI was envisioned to also include a writing pad that is lightweight, easy-to-carry, fits ergonomically within a person's hand, can be placed without difficulty in a lab coat pocket, and holds sheets or paper for easy note-making.

PANI also includes a mobile device powered with a software application that digitally mediates task management and communication between ICU healthcare providers. To enable quick access to digital information while viewing or annotating the paper notes, PANI was envisioned to include a smartphone as the mobile device component. This was done because all the healthcare providers at the ICU already owned and were very familiar with using a smartphone. In addition, smartphones are in general ergonomically easy to hold and facilitate rapid means to input or access digital information.

The design guidelines discussed in the previous section propose the introduction of tactile cues as a means to effectively remind healthcare providers of personal tasks and to support communication with minimal interruptions in the ICU. The mobile device may have the ability to produce tactile vibrations. However, it is possible that the healthcare provider may miss the tactile cue if the device is placed somewhere where the tactile feedback is not noticed (for instance, inside the doctor's pocket). Consequently, PANI was envisioned to include a wearable device configured and paired with the mobile application, to provide tactile notifications while receiving a message from a colleague or to act as personal reminder alerts. FitBit, a commercially available wearable device, was used to represent the wearable component of PANI, since it had the "silent alarm" feature that can effectively provide tactile feedback that can only be felt by the person wearing the FitBit. In reality, FitBit may be replaced with any other wearable device capable of providing similar "silent" tactile feedback.

Overall, the three components of PANI discussed above were envisioned to be detachable and used separately or together as a whole, owing to the different functionalities they serve, and to enhance patient-situation awareness through task management and communication with minimal interruptions, by integrating into the existing ICU workflow.

6.3 Summary

In this chapter, I applied the findings from Chapter 5 to derive design guidelines and propose a mobile, clinical tool that can be used to enhance ICU healthcare providers' patient-situation awareness specific to task management and communication work practices. The proposed clinical tool, named PANI (patient centric notes and information manager), will be evaluated in the following chapters.

Chapter 7. Study 2: Study Design and Methodology

Study 1 identified the work practices ICU healthcare providers follow when creating, disseminating, and managing patient-centered tasks. Healthcare providers make personal scrap notes on sheets of paper to support their workflow. Such scrap notes are often not synchronized with the information on the patient's EMR, consequently resulting in redundant work, double record-keeping, and reduced patient-situation awareness from all the ICU team members. Hence, there is a need to design and evaluate a task management tool that accesses and generates information in the patient EMR in order to help healthcare providers create and manage patient-centered tasks.

Healthcare providers tend to access the patient EMR from stationary workstations when they seek to know more about ongoing care in relation to the patients' current condition. Information access is cumbersome, since the patient EMR is not structured to effectively provide information on the patient's most recent condition in relation to ongoing care. As such, no tools exist to provide hands-on, anytime-anywhere information related to a patient's condition or ongoing care that ensures everyone on the ICU team has the same awareness. Hence, there is a need to design and evaluate a shared tool that can generate information from the patient EMR in real time.

Findings from Study 1 also provided an understanding of how healthcare providers disseminate patient-centered tasks and information to their colleagues through face-face or phone-based conversations, and how healthcare providers handle technology notification interruptions in the ICU. Technology devices used by healthcare providers include landline phones, hospital owned mobile phones (ASCOM), and pagers (callback phone numbers are shared between healthcare providers as pager messages). As such, communication is synchronous and involves the generation of patient-situation awareness only for the parties involved in the conversation (or those physically co-present during the conversation) at any point. This synchronous nature of communication results in interruptions to healthcare providers' ongoing activities. Consequently, there is a need to design a communication system that can help healthcare providers maintain patient-situation awareness while optimally managing technology notification interruptions.

Overall, findings from Study 1 led to the generation of design guidelines for a novel technology tool, known as PANI (**Pa**tient-centered **N**otes and **I**nformation **M**anager). The goal of Study 2 was to develop and test PANI; I conducted four small studies that helped design and evaluate PANI and its functionality. In this chapter, I provide an overview of the design methodology for the four studies. Subsequent chapters provide a detailed description of the individual studies, findings, and discussion.

7.1 Research Design

Study 1 identified two key functional requirements for PANI: (i) ability to communicate information between healthcare providers for maintaining patient-situation awareness with minimal notification interruptions, and (ii) ability to generate, disseminate, and manage patient-centered tasks at an individual and team level.

I chose a mixed-methods approach comprising both qualitative and quantitative data collection methods to: (i) explore novel design venues and (ii) perform evaluations of the resulting design that can be quantified with additional insights on why a design feature functions effectively or needs improvement. To this end, four small studies were conducted: (ii-a) Study 2a used focus group sessions to explore the design features of the communication functionality of PANI through visual and tactile notification messages;

(ii-b) Study 2b used a web-based experiment to evaluate the visual notification messages (identified in Study 2a) and determine the design features that must be present in the messages to help healthcare providers optimally manage interruptions; (ii-c) Study 2c included testing the visual notification messages (with design features identified from Study 2b) and tactile alerts (identified in Study 2a) in a simulated, controlled setting, and (ii-d) Study 2d included evaluating the task management and communication functionalities of PANI in a controlled setting (Figure 7.1).

7.2 Ideation

Prior to beginning the four studies, I performed design ideation along two different tracks related to the communication and task management functionalities. These included:

- Sketching multiple versions of visual notification messages and prototyping instances for tactile alerts. These artifacts were used as probes for Study 2a.
- Generating two interactive prototypes for a shared, task management tool that can be used by healthcare providers when creating, disseminating, and managing patient-centered tasks and information. Both the design versions were used as technology probes for Study 2d. One version (experimental probe) was based on the implications derived from Study 1, while the other (control probe) was based on features derived from several frequently-used software project management applications (software projects are often team-based, requiring task management and communication while maintaining awareness, and involve members working remotely).

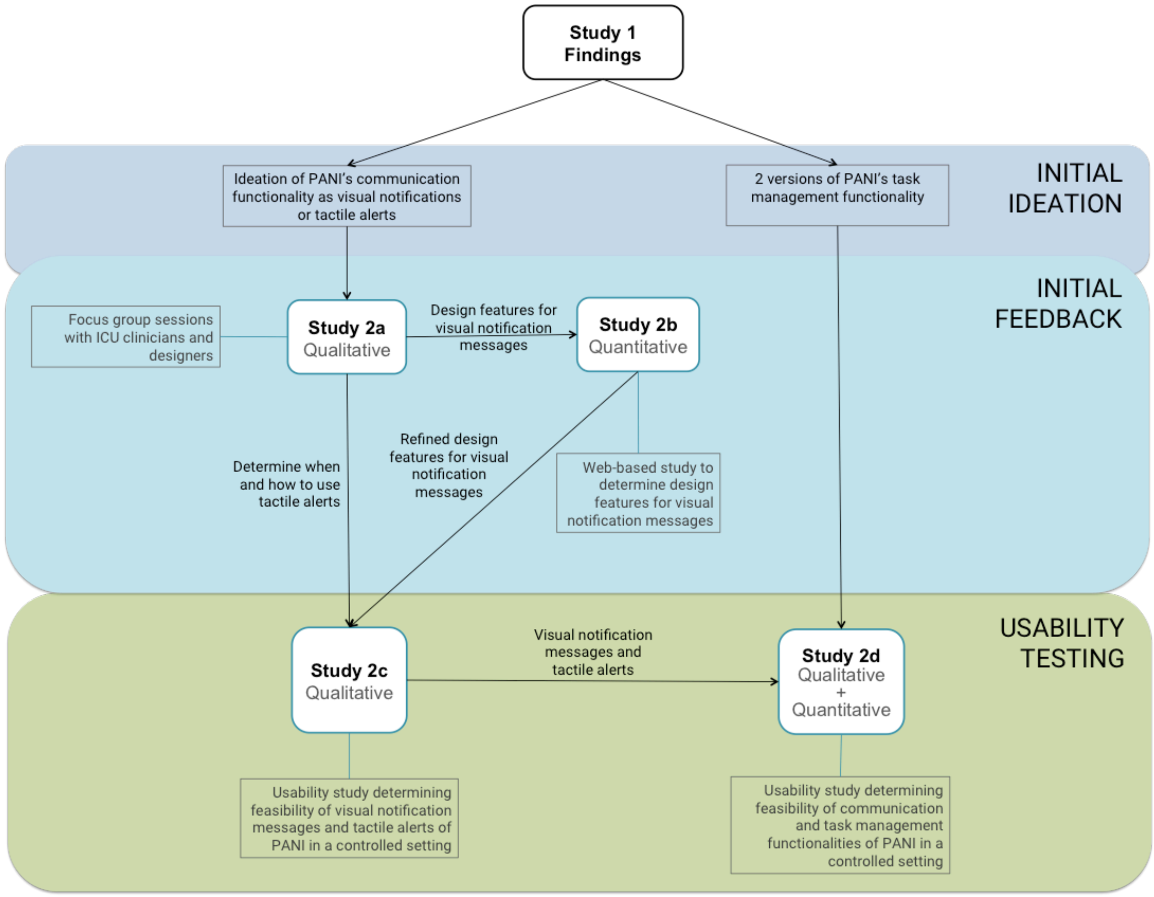

Figure 7.1: Study 2 research design

7.3 User feedback on ideation

The design ideas sketched during the ideation phase were later used as probes for obtaining initial user feedback. For instance, the sketched ideas for visual notification messages and prototyped sample scenarios of tactile alerts used as a part of PANI's communication functionality were sshown to ICU healthcare providers for feedback. Study 2a completed two focus groups sessions. One session involved six ICU healthcare providers (comprising attending staff, residents, fellows, and nurses) who helped (i) identify the information content that can be presented in visual notification messages and when tactile alerts can be used, and (ii) define sample case scenarios in which the communication functionality and notifications may occur in the ICU workflow. This was followed by a second focus group session with five user experience and designers and six ICU providers who worked collaboratively in the visual design of information that can be presented in a text message notification.

One of the key requirements for PANI is to use technology-based communication to aid ICU healthcare providers in maintaining patient-situation awareness with minimal notification interruptions. Hence, it was important to ensure this requirement was satisfied by the design refinements resulting from Study 2a. Prior to directly implementing and evaluating the findings from Study 2a in the ICU, I chose to create a controlled study (Study 2b) that helped understand the perceptions of when a healthcare provider would expect to send/receive or respond/discard a visual message. Findings from this study helped identify design features that can empower healthcare providers to receive messages and respond appropriately (immediately or at a later point in time) –this feature would contribute to the effective management of notification interruptions from mobile text message communication in the ICU.

7.4 Usability evaluation

Studies involving initial user feedback resulted in refinements to the visual design of PANI's communication messages and the nature of its tactile alerts. I conducted Study 2c to determine the feasibility of PANI's communication functionality. The refined changes from studies 2a and 2b were tested in real time in a controlled setting, in which ICU healthcare providers performed documentation tasks (such as a conference room) while also receiving visual communication messages or tactile alerts about fictitious patients (patients were fictitious owing to a lack of access to existing patient details in the ICU). Healthcare providers were prepped about their fictional patients prior to the study, creating a more realistic experience. Each healthcare provider from Study 2c was given a smartphone (that can receive visual communication messages) and a Fitbit (that can generate tactile alerts), enabling receive rapid user feedback with minimal time investment in tool development, and the notifications and alerts were pushed to the devices using the Wizard of Oz technique. Study 2c also included a follow-up interview phase, in which healthcare providers reported on their experience. Findings from this study helped ascertain the significance of communication in maintaining patient-situation awareness and the need for minimizing interruptions while keeping everyone on the ICU team constantly updated.

Another significant finding from this study examined the interconnection between communicating healthcare providers' tasks and the patients' conditions, while maintaining patient-situation awareness. Healthcare providers reported the need to create and disseminate tasks between one another while communicating the dynamically changing patients' condition. Subsequently, I used the findings from Study 2c, along with my original ideation based on findings from Study 1, to design and evaluate two interactive prototypes of PANI with both task management and communication functionalities (Study 2d). Similar to Study 2c, this study used fictitious patient information, and the ICU healthcare providers were prepped in advance about the patients. Study 2d included a participatory evaluation, in which healthcare providers evaluated two design versions of the interactive PANI prototypes by "thinking-out-loud" as they completed the tasks. Scenario-based user testing methods in a controlled environment help explore and identify problem areas in the system's design. However, such tests do not necessarily give any clear indication why a certain interface aspect poses a problem to a user or how to improve the interface. Hence, it is imperative to identify and use a method that will help provide insight into the underlying causes for problems users encounter. One such method that is widely accepted is the "think-aloud" scenario-based method to evaluate an interactive system's design against user requirements (Beul et al., 2014; Eapen & Chapman, 2015; Nahm et al., 2004; Sheehan et al., 2012; Wu et al., 2008). Hence, I chose to use an exploratory, think-aloud, scenario-based testing technique to obtain both qualitative input and quantitative input (such as time on task and accuracy) to obtain rich user feedback. This study helped identify the feasibility of both the communication and task management functionalities of PANI in a controlled setting (such as conference room). Findings from this study also pointed to various design implications and insights that are discussed in Chapter 10.

7.5 Summary

Findings from Study 1 led to the generation of design guidelines for a novel technology tool, known as PANI (**Pa**tient-centered **N**otes and **I**nformation Manager). To design and test PANI and its functionalities, I conducted a series of four small studies that contributed to Study 2. This chapter provides an overview of the research design and methodology adopted for Study 2, and the rationale for the four studies. Subsequent chapters will provide more details on each study, the data collection and analysis methodology, and the corresponding findings. Chapter 8 will outline information on Studies 2a, 2b, and 2c, while Chapter 9 will discuss Study 2d.

Chapter 8. Designing and evaluating the communication functionality of PANI

This chapter outlines the original ideation process and describes the research design and findings from Studies 2a, 2b, and 2c. Findings from the studies were used to refine the design of PANI's communication functionality.

8.1 Initial ideation process

PANI consists of an interactive mobile device application that allows healthcare providers to set up, manage, or disseminate patient-related tasks, and share patient-related information and notes with colleagues. Inspired by fieldwork findings and the design guidelines derived from Study 1 (Chapter 6), I developed a prototype for the communication functionality of PANI. The prototype was designed to support asynchronous communication of patient-centric information (such as a lab/radiology result or question about next steps, etc.) as text that included: (i) the message, (ii) patient details such as name and the most recent abnormal vital signs (if any), and (iii) the sender's perception of the patient's current condition. As such, the prototype introduced the concept of patient-centric notifications as mobile technology artifacts (text messages) that allow healthcare providers to communicate patient information and maintain patient-situation awareness with minimal interruptions. According to this prototype, healthcare providers either type or automatically pull patient information from the EMR in a text message. Figure 8.1 shows an example notification seen as a text message notification in the mobile device of PANI. For example, a nurse might want to report a patient's abnormal lab result to the resident. PANI will allow the nurse to send a text message to the resident with content comprising of: (i) the lab result (which could be pulled automatically from the EMR or manually typed), (ii) the patient's identity (automatically derived from the EMR), and (iii) the most recent abnormal vital signs (if any, automatically derived from the EMR), and the nurse's perception of the patient's current condition (manually entered). The text message was designed to (i) display a picture of the sender, and (ii) present a time when the message is received on the recipient's device, (iii) present two response options, namely "Respond" and "Dismiss," and (iv) use color-coding to explicitly highlight information content that needs more attention.

8.2 Study 2

I began my exploration into refining PANI's patient-centric messages or notifications by conducting a three-phase formative study with ICU healthcare providers and user experience (UX) designers contributing to the design process. In order to better understand the content and type of messages communicated between ICU healthcare providers, what difficulties are inherent in the current practices, and how the situation could be improved, I conducted focus group interviews and participatory design sessions (Study 2a). These sessions helped develop design templates for PANI's communication functionality and refine the content presented in the patient-centric notifications.

Two types of patient-centric notifications were developed: (i) visual text message alerts delivered through the mobile device, and (ii) tactile alerts delivered through a wearable device. Following this, I used a web-based experiment (Study 2b) to understand how visual patient-centric notifications can minimize healthcare providers' effort in perceiving information from a text message prior to making a decision on whether they should ignore it—thereby optimally managing disruptions to ongoing work. Findings from Studies 2a and 2b and inclusion of tactile alerts were used to understand the feasibility of patient-centric notifications in a controlled and simulated ICU setting

(Study 2c). This chapter provides a discussion of the findings from each study and the corresponding design considerations aimed at helping ICU healthcare providers optimally manage notification interruptions while communicating with one another.

8.3 Methods

I employed a three-phase study process, summarized in table 8.1. The goal was to generate concrete design ideas, through participatory involvement, on how technology can be used to communicate patient-centric information that improves ICU healthcare providers' patient-situation awareness with minimal technology-mediated disruptions.

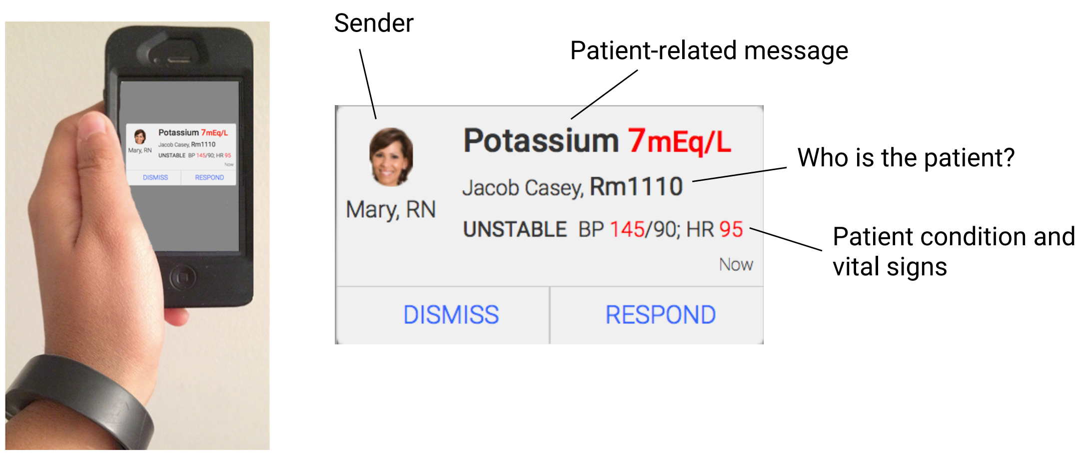

Figure 8.1: Initial ideation of text messages using patient-centric notifications

Table 8.1: Methods and activities for each design phase

Research Phase	Methods	Participants and Activities
Phase 1 (Study 2a)	Homogeneous focus group	• Group #1: ICU healthcare providers (4 men, 2 women) Discuss type and content of information exchanged between healthcare providers Review and critique ideation designs Goal: Design requirements and considerations • Group #2: UX designers (3 men and 3 women) Review and critique ideation designs based on the requirements derived from Group 1 Goal: Collaborative design refinement • Overall outcome: Patient-centric notifications (visual and tactile)
Phase 2 (Study 2b)	Online study	• Group #1: Doctors (4 men and 2 women) • Group #2: Nurses (5 women and 1 man) • Self-report on response strategies related to scenario-based, sample visual patient-centric notification messages • Goal: Reduce uncertainty between sending and receiving a response • Overall outcome: Design refinement to visual patient-centric notifications

Phase 3 (Study 2c)	Controlled, simulated evaluation using Wizard of Oz	• Participants: 3 doctors, 2 nurses • Evaluate visual and tactile patient-centric notification messages

8.4 Study 2a: Designing patient-centric notifications

Focus groups are an informal technique used to elicit user needs, requirements, and feelings. Focus groups typically comprise six to nine participants discussing issues and concerns, in addition to spontaneously reacting and generating ideas for systems development. I conducted two focus group sessions: one with ICU healthcare providers to elicit user requirements for a communication system in the ICU; and the other with ICU providers and UX designers to collaboratively refine the existing design based on the obtained requirements.

Six ICU healthcare providers, comprising a resident, attending physician, fellow, nurse practitioner, and nurse, participated in the first session to discuss the current practices in relation to the type and content of patient information exchanged between healthcare providers. This session used several scenario-based text messages (from the ideation phase) as design probes to facilitate and anchor the discussion towards technology-mediated communication and interruption management needs in the ICU.

Healthcare providers actively engaged with the design probes and came up with situations and messages they would exchange using PANI's patient-centric notifications. Significant insights on the potential benefits of and barriers to the adoption of PANI's communication functionality in the ICU were revealed through this session. Benefits include: (i) rapid communication of patient information, thus increasing patient-situation awareness, (ii) asynchronous means of communicating information, thus avoiding disruptions to the receiver's ongoing work, and (iii) color-coded content to quickly direct the attention of the receiver to the most important information. Potential challenges include: (i) patient and healthcare provider privacy, (ii) differences in perceptions between healthcare providers on the patient's condition, and (iii) limited information that can be communicated through a text message.

The second focus group session was conducted for collaborative design between six UX designers and ICU providers. This session resulted in design refinements of PANI's patient-centric notifications based on the insights derived from session 1.

8.4.1 Study 2a: Results

Through the focus group session with ICU healthcare providers, I gained a better understanding of healthcare providers' needs in regards to the ideal patient information to share in order to maintain patient-situation awareness in the ICU. Findings from Study 2a helped derive design guidelines for optimally sharing patient information and managing notifications from a communication system used in the ICU. I summarize the benefits and challenges perceived by healthcare providers in adopting PANI's patient-centric notifications.

Benefit 1: Increased patient-situation awareness through rapid communication

PANI is designed to support rapid sharing of patient information between ICU healthcare providers with the dynamically changing patients' conditions. It is meant to actively engage healthcare providers in keeping each other constantly updated, yet without interrupting each other's ongoing activities. Findings from the focus group activity suggest that PANI will support expediting the time required to obtain patient-situation awareness not only during rounds or hand-off sessions, but also during any clinical shift in general.

A resident said: “Sometimes I wait until afternoon to discuss with the fellow about some patient details. To support this discussion, I tend to make a mental note or write down some pointers on my rounding sheet. I feel like this application will definitely offload that work practice, where I can quickly convey the information to the fellow instead of making a note. Also, the amount of time we spend ensuring both of us know the same information about the patient can probably be reduced if both of us had the access to real-time changes in patient care. Each person on our team usually waits until the following morning for sharing information with the rest of the team on how the care plan progressed. Often, not all of us are on the same page with respect to what has been going on with the patient. Of course, all the patient details are present in the EMR, but it is extremely cumbersome for someone to go in there and look for every detail.”

Benefit 2: Asynchronous communication

Healthcare providers agreed on the value offered by asynchronous communication in reducing disruptions to task at hand. A nurse noted that: “Currently I try to call the patient’s resident on his ASCOM when there is an abnormal lab result. If I am unable to reach him, I just have to remember why I wanted to contact the resident in the first place and keep trying. This can be an issue if the resident is busy with some kind of procedure when I am trying to contact him. In such cases, it will help if I can just leave him a message.”

Benefit 3: Explicitly expediting attention to important contents of the message

Healthcare providers agreed on the value of using color-coding to rapidly direct attention and expedite information processing. A resident noted that using red to indicate abnormal vital numbers was desirable because the healthcare providers did not have to perform mental calculations to understand if a vital sign was normal or abnormal. The resident also added that a similar color-coding practice was followed in the patient EMR system. The resident suggested that the usage of terms such as “stable” or “unstable” might not be useful, since healthcare providers can already implicitly identify a patient’s condition based on vital signs. Instead of conveying information only related to the abnormal vital signs, participants suggested sharing all the five key vital signs of patient (such as temperature, blood pressure, heart rate, respiratory rate, blood oxygen content) irrespective of whether they were normal or abnormal.

Challenge 1: Patient and healthcare provider privacy

Healthcare providers engaged with PANI and quickly generated situations in which they could use the technology. However, healthcare providers expressed concern about privacy. “I think sharing the full name of the patient is inadvisable.” This echoes other findings related to privacy concerns in computer-mediated healthcare communication for patients (Ren et al., 2010). As an alternative, similar to their existing work practice, healthcare providers suggested either using the patient’s initials or last name in combination with the patient room number to uniquely identify them.

Some healthcare providers also raised the issue of sharing a personal photograph with each message. They noted that they did not prefer sharing their picture along with every message they communicated using PANI. Further, they suggested that including the photograph of the sender might not necessarily contribute to increasing effective and rapid readability of the text message.

Challenge 2: Differences in perceptions

As stated earlier, healthcare providers did not find the terms “stable” or “unstable” very useful for understanding the patient’s situation, since they did not explicitly explain why and how the patient’s condition was calculated. Further, a nurse practitioner noted that different healthcare providers perceive patient’s conditions in a different manner: “a nurse, might consider a slight increase above a normal lab result as something that needs immediate attention, while the resident might not think the same way.”

To address this issue, healthcare providers suggested adding information on the most recent patient vital signs that are often considered when understanding a patient’s condition, including heart rate, blood pressure, temperature, respiratory rate, and blood oxygen content. This concept allows healthcare providers to effectively perceive and develop an understanding of how the patient is doing at the moment a message is shared.

Challenge 3: Limited vs. overwhelming communication

While most participants reacted favorably to the idea of quick and easy sharing of patient information, the results also indicate challenges for PANI. This process of constant communication was concerning to some healthcare providers because it may result in too many messages, which can overwhelm healthcare providers who are already cognitively overworked. An attending physician said: “I manage a team with at least 8-10 patients at a time. I will be really overwhelmed if I see notifications for every change in every patient’s condition or plan of care all at once.”

To reduce the cognitive load in simultaneously receiving and interpreting several messages, the system may allow healthcare providers to receive messages in different bins, based on the patient or urgency with which they have respond to the messages. For instance, residents simultaneously sharing information on 3 patients can categorize the information based on urgency to help the attending physician prioritize his attention while receiving the messages. Healthcare providers also proposed taking advantage of the wearable device's ability to produce tactile alerts, in which vibration feedback may be provided in addition to visual text messages that require urgent response.

Contrary to the above challenge, healthcare providers raised the concern that, while a text message can support asynchronous communication that avoids disruption to the ongoing activity of the receiver, it is limited by communicating reduced information. That is, a phone conversation may communicate multiple topics, whereas a textual message limits the information communicated. Healthcare providers suggested the need to overcome this challenge.

8.4.2 Study 2a: Discussion

By interacting with my design probes from the ideation phase, ICU healthcare providers' were able to articulate the patient information content that ought to be shared to enhance patient-situation awareness in the ICU. Both the benefits in adopting the patient-centric messages or notifications and healthcare providers' suggestions to overcome challenges served as inputs to the collaborative design session with the UX designers and healthcare providers. I summarize the design refinements made to the patient-centric notifications and the overall communication functionality of PANI in this section.

8.4.2.1 Template-based creation of patient-centric text messages

Some of the challenges perceived by the healthcare providers specific to the content of patient-centric text messages included: (i) patient privacy concerns due to the display of patient-identifiable information, such as name, (ii) un-useful information conveyed through the inclusion of the sender's photograph, and (iii) the difference in perceptions of a patient's condition between the healthcare providers sending or receiving patient-centric messages. Healthcare providers also expressed their concern in understanding how the content for a patient-centric message or notification is generated. This dilemma was addressed through the introduction of template-based message creation, in which healthcare providers create minimal content. Figures 8.2 and 8.3 depict a sample patient-centric notification generated from a template comprising the following components: (i) patient initials and room number, to uniquely identify the patient without compromising patient privacy, (ii) sender name and role to implicitly identify the sender's relationship with the patient, (iii) actual message, which could include a question, statement, or intervention result (e.g., lab or radiology result), and (iv) most recent patient vital signs that are color-coded to explicitly depict abnormal values.

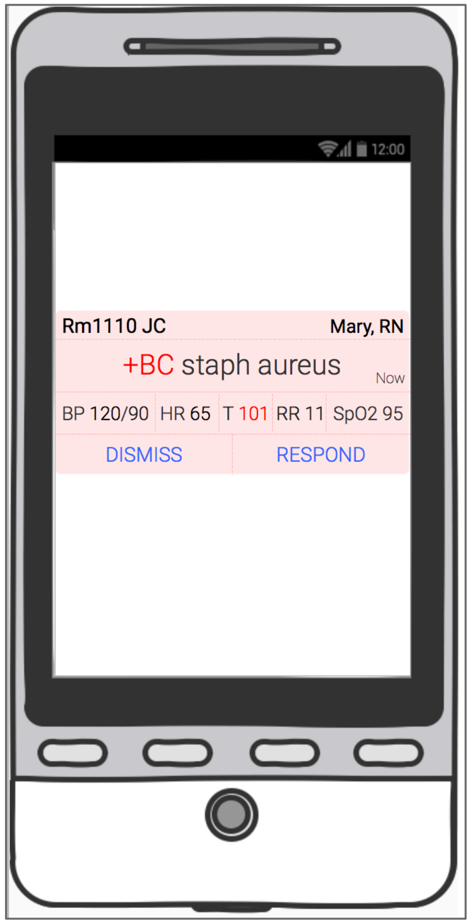

Figure 8.2: Patient-centric notification or message presented as a "preview"

8.4.2.2 Categorized patient-centric notifications

Healthcare providers noted the overwhelming nature of receiving multiple simultaneous messages while being constantly updated about the patients in the ICU. To reduce the cognitive load in simultaneously receiving and interpreting several messages, categories (based on patient or urgency) can be used to differentiate patient-centric messages in the mobile device's notification panel. For instance, a healthcare provider sharing multiple patient-centric messages can classify and color-code them based on urgency or priority with which a response is needed (such as normal or immediate). Such a classification can help healthcare providers receiving patient-centric notifications effectively pay more attention to messages that need it (Figure 8.4).

Findings from focus group sessions 1 and 2 also included discussions on providers "missing" or "not noticing" notifications in instances in which their mobile device is out of sight. The focus group attendees suggested providing an additional tactile feedback for notifications that require immediate attention and have not been responded to by the recipient within a set time period of sending. This included providing tactile feedback through a wearable device worn by the receiving healthcare provider. The focus group attendees suggested that the time to send an alert may be determined by the sender of a message.

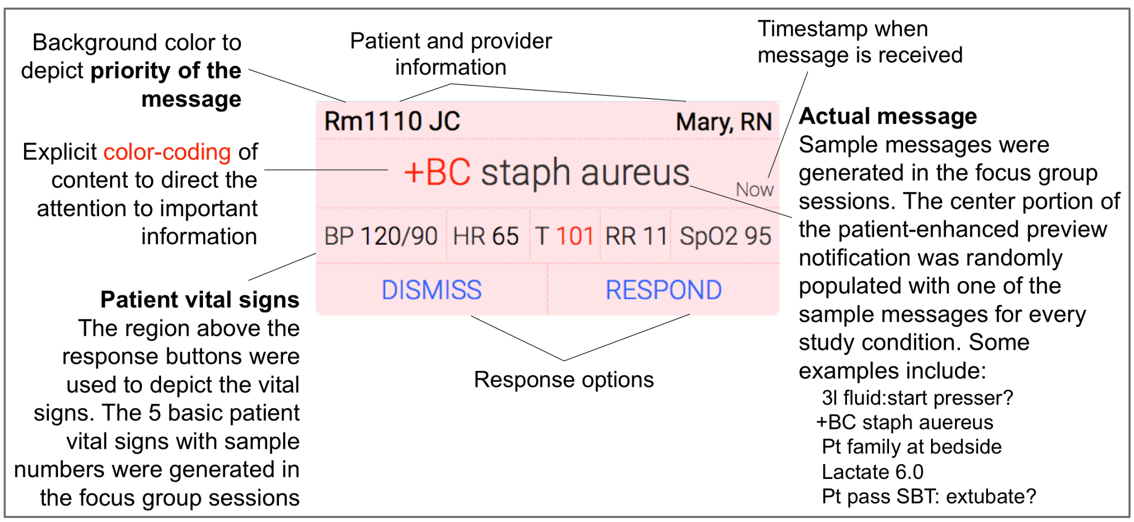

Figure 8.3: Example of a re-designed text messages from Study 2a. Background color is used to explicitly depict the importance of the message. Explicit color-coding in red is used to direct the healthcare provider's attention to important information. The patient-centric notification depicts an actual message (+BC staph aureus) that could be shared as simple SMS along with additional information, such a vital signs and message priority (red background color). Content is explicitly color-coded to direct attention to parts of the actual message (+BC) and vital signs (101).

8.4.2.3 Extend text-based patient-centric notifications to support synchronous response

Healthcare providers noted a phone conversation can communicate multiple topics, whereas a text message limits communication to a single topic. Hence, although asynchronous text messaging can avoid disruptions to ongoing activities, there is a need to support the communication of multiple topics. This challenge was addressed by allowing the receiving healthcare provider to “respond” by either replying with a text message or placing a phone call once the task at hand is complete.

8.4.3 Study 2a: Summary

I conducted two focus group sessions to explore the initial ideation design for the communication functionality of PANI as patient-centric messages or notifications. Findings from the sessions led to design refinements. Two types of patient-centric notifications were designed: (i) visual text messages delivered through a mobile device, and (ii) tactile alerts delivered through a wearable device.

In the next section, I describe a follow-up online study (Study 2b) that was conducted to understand how visual patient-centric notifications can minimize healthcare providers’ effort in perceiving information from a text message prior to making a decision to respond to or ignore it. The interventions (scenarios and sample messages) used in this study were developed with help from the healthcare providers (from the focus group sessions).

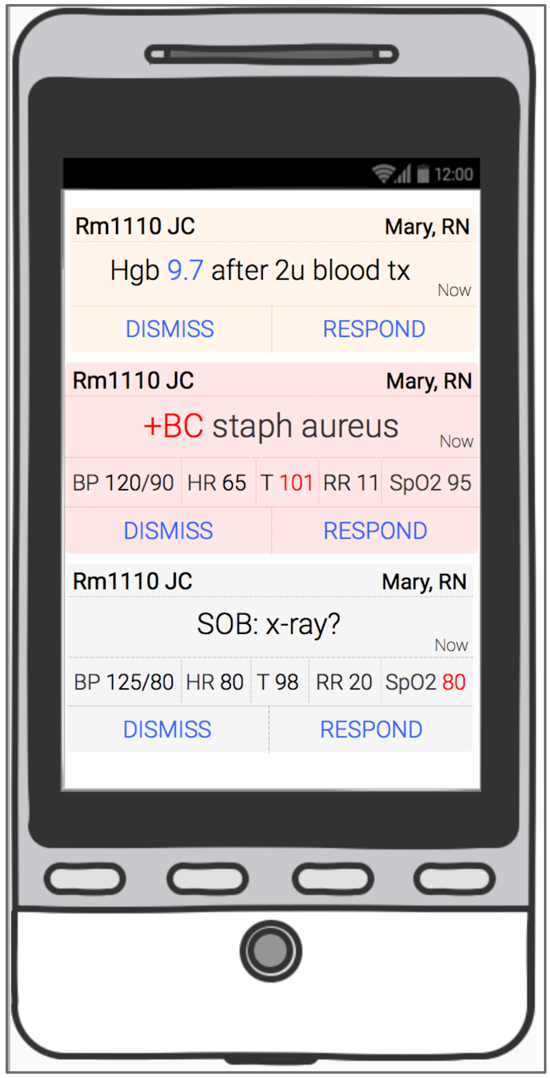

Figure 8.4: Figure depicting the arrival of patient-centric notifications on the recipient's mobile device.

8.5 Study 2b: Evaluating PANI's visual patient-centric notifications or text messages

Existing research identifies the disruptive nature of phone calls, since callers can easily place calls at inconvenient and disruptive moments for the receivers (Avrahami et al., 2007). PANI overcomes this challenge with the introduction of asynchronous text messages. Text messages, however, introduce uncertainty on when a receiver will respond. To overcome this uncertainty, PANI proposes adding patient-centric information (such as patient vital signs) to text messages. Thus, the need to ascertain how additional patient-centric information can reduce the mismatch in expectations between healthcare providers sending and receiving text messages became the underlying goal for Study 2b. In the rest of this chapter, I refer to healthcare providers communicating, sharing, or sending patient-centric text messages as “senders,” and the healthcare providers receiving or responding to a patient-centric text messages as “receivers.”

Study 2a helped (i) identify information content that is often communicated between healthcare providers, and (ii) refine the design of patient-centric text messages. Following this understanding, I conducted Study 2b to determine how the information content presented in the patient-centric text messages (designed in Study 2a) can aid healthcare providers in effectively making the decision to disrupt their current work.

Study 2b was conducted to examine what text messages healthcare providers (as receivers) in a given situation prefer and what information they “glance at” before deciding to disrupt their ongoing activity. Further, Study 2b was designed to rapidly determine when healthcare providers communicate information and when healthcare providers respond if they receive a text message about a patient.

To capture immediate feedback solely based on the information content of visual patient-centric notifications, Study 2b was structured as a survey administered in an online environment. Images of text messages with corresponding scenarios were provided to capture healthcare providers’ preferences on (i) when they would send or receive the messages, (ii) when they would expect a response from their colleague, and (iii) how they would respond to the messages. Specifically, Study 2b examined how patient-centric information (such as vital signs and urgency with which a response is expected) in addition to a message (such as a statement, question, or intervention result) can provide more context for the receiving healthcare provider on the patient's condition. This study also investigated inherent differences in sender and receiver motivations (O'Conaill and Frohlich, 1995; Palen et al., 2000).

8.5.1 Study 2b: Method

Research questions

To compare text messages from PANI with an existing asynchronous communication system in the ICU, this study evaluated images of pager and smartphone text messages. This study investigated the following research questions:

- What information do ICU healthcare providers want to know when:
  - Receiving PANI or Pager messages?
  - Responding to or ignoring text messages?
- How does patient-situation awareness impact notification management?
  - Can patient-centric information presented in text messages support effective decision-making when receiving and responding to text-based notifications?
  - How much information should be presented to the recipient to "glance at" to help them decide whether to respond to/ignore a visual patient-centric notification?

8.5.2 Study 2b: Procedure

ICU healthcare providers played the role of sender and receivers of text messages. The order in which this role was assumed was randomized. The relationship between the sender and receiver was described as that of colleagues. This allowed the investigation of messages that were primarily work-related and patient-centric. The study consisted of three phases: the pre-testing, testing, and post-testing sessions.

8.5.2.1 Pre-testing session

All healthcare providers indicated their preference for responding to alerts within 8 seconds after viewing an snapshot of a text message. Preferences included: respond immediately vs. respond later vs. do nothing. The purpose of this session was to understand participants' first impressions.

8.5.2.2 Testing session

Participants who assumed the role of receivers chose an option to answer survey questions on

- whether a particular message in a given situation should be delivered immediately or at a scheduled time (Hameed et al., 2009; McCrickard et al., 2003; Sasangohar et al., 2012; Sasangohar et al., 2013; Sendelbach, 2012).
- how they would react to a notification message (immediately vs. respond later vs. do nothing).

Participants who assumed the role of a sender chose an option to answer survey questions on

- when they expected a response from the receiving healthcare provider (respond immediately vs. respond later vs. will not expect a response).
- when they would send a message (such that it appears immediately on the receiver's device vs. send the message such that it appears at a scheduled time).

All the participants rated their perception of the urgency of all messages presented to them as images on a scale from 1 – 10.

In addition to varying the specific content of the message and additional patient-centric information, I also varied the situational and environmental context through scenarios. Scenarios required the participants to imagine either the receiving/sending healthcare provider's situation (cognitively over-worked vs. not cognitively over-worked) and environment (canteen vs. patient room). For instance, a healthcare provider playing the role of a sender was presented with the following scenario and image: You are about 6hrs into your shift. You are currently in the patient room, cognitively involved with physically examining a patient. You receive the following smartphone notification message from your colleague. The healthcare provider was then asked to report on when he/she would respond (immediately vs. later vs. do nothing).

8.5.2.3 Post-testing session

Healthcare providers responded to demographics-related and open-ended debriefing interview questions after the testing session. Open-ended questions queried healthcare providers about (i) their overall experience interacting with PANI's patient-centric notifications, (ii) the benefits of additional patient-centric information while understanding and improving patient-situation awareness, and (iii) how the patient-centric information aided in deciding when and how to respond to an alert or notification.

8.5.3 Study 2b: Messages

The focus group sessions included discussions on information typically shared between healthcare providers. Healthcare providers typically share messages that include a statement or a question or an intervention result (lab/radiology or response to medication administration). The messages presented to the participants in this study were pruned from an initial set of 10 generated in Study 2a (with help from ICU healthcare providers). The rated urgency of these messages tended to be of low variance across the raters and did not cause confusion. The messages used in the study can be found in Figure 8.3.

8.5.4 Study 2b: Conditions

To compare text messages from PANI with the existing system in the ICU, this study tested images of pager and smartphone text messages. In addition, specific to smartphone text messages, I varied the amount of patient-centric information to assess the value of particular types of added information. Hence, this study also focused on providing the following four levels of patient-centric information in smartphone text messages:

1. None: In this condition, healthcare providers saw only the message with no additional patient-centric information.
2. Priority: This condition provided additional information, such as the priority associated with the message. The levels of this condition included: Low and High.
3. Vitals: This condition provided additional information on patient vital signs, such as heart rate, blood pressure, temperature, respiratory rate, and blood oxygen content. The levels in this condition included: With and Without.
4. Combination of priority and vitals: This condition included a combination of conditions 2 and 3 (Low vs. High and With vs. Without).

8.5.5 Study 2b: Data collection and analysis

The data collected in this study was stored in a backend database. Participant responses to the survey-type questions were coded for performing descriptive and inferential analysis (Receiver: 1 = respond immediately, 2 = respond later, 3 = do nothing; Sender: 1 = immediately, 2 = later, 3 = will not expect a response). Participant responses to the debriefing interview session was audio-recorded and later transcribed for analysis. Quantitative data was analyzed using SPSS v.21 and qualitative data was analyzed using ATLAS.ti.

8.5.6 Study 2b: Results

I present results in two stages. The first explores a receiver's willingness to respond immediately to a message with different types of additional patient-centric information. Next, I examine the degree of agreement between senders and receivers, and explore ways in which these differences interacted with the range of additional patient-centric information.

8.5.6.1 Participants

Twelve ICU healthcare providers (six doctors and six nurses; 58.3% Female, 41.7% Male) participated in this study. More details on the demographic information of the participants can be found in the Table 8.2.

8.5.6.2 Receiver's preferences in responding to text messages

I used Friedman's test to examine the receiver's response preferences. Tested factors included priority (low vs. high), vital signs (with vs. without), combination of priority and vital signs (priority vs. vitals), perceived urgency of message (1 – 10), situational (cognitively over-worked vs. not cognitively over-worked) and environmental (canteen vs. patient room) contexts, designation of the participant (doctor vs. nurse), and message viewing order (1 – 10). Participants were modeled as random effect.

There was no significant difference in perceptions of healthcare providers responding to messages with and without additional priority information ($Z = -1.630$, $p = .103$). That is, healthcare providers did not pay attention to the color-coding used to depict priority of messages (Gray: messages with no priority information, Red: messages with high priority, Yellow: messages with low priority). Specific to messages that had additional priority information provided as high or low, healthcare providers preferred immediately responding to text messages (Z = –3.503, *p* = .04) if the priority of the message was depicted as high (M_{High} = 67.19%) as compared with those depicted as low (M_{Low} = 32.81%). Further, more healthcare providers preferred responding later if they knew the priority of the message (M_{High} = 26.32%, M_{Low} = 73.68%) and all the healthcare providers chose to do nothing and continue with their task at hand when they received a low priority message.

No significant difference in response preferences was noticed based on situational (cognitively over-worked vs. not cognitively over-worked) and environmental (canteen vs. patient room) contexts, or based on the designation of the participant (doctor vs. nurse).

Overall, no significant difference was identified when comparing the response preferences reported during the pre-testing and testing sessions (Z = –1.649, *p* = .099). Healthcare providers preferred immediately responding to messages (Z = –3.645, *p* = .037) when vital signs were included (M = 60%) as opposed to not including the vital signs (M = 40%) with the actual message. Healthcare providers preferred responding later (M_{With} = 91.30%, $M_{Without}$ = 8.70%) or continuing with the task at hand (M_{With} = 88.57%, $M_{Without}$ = 11.43%) when vital signs were not provided. This result provides an indication for how the presence of patient vital signs can contribute to increasing the healthcare provider's understanding of the patient's condition when deciding to respond to a text message. No significant difference in response preferences was noticed based on situational (cognitively over-worked vs. not cognitively over-worked) and environmental (canteen vs. patient room) contexts, and the designation of the participants (doctor vs. nurse).

Table 8.2. Summary of participant demographic information

Demographic information	Frequency or percentage
Roles	Resident: 2 Nurse practitioner: 2 Fellow: 2 Registered nurse: 5 Staff nurse: 1
Age group	20 – 30: 58.3% 31 – 40: 25% 41 – 50: 16.7%
Average work experience (in years)	1 – 5: 4 6 – 10: 3 11 – 15: 2 16 – 20: 1 21+: 2

A more detailed exploration of the interaction between the presence and absence of priority and patient vital signs demonstrates that while the presence of patient vital signs affected healthcare provider's preferences in responding immediately to text messages, a similar effect was not noticed with the presence of priority information explicitly stated through color-coding (χ^2 (3) = 9.510, p = .023). These findings suggest that providing patient vital signs will aid healthcare providers in making informed decisions on how to respond to text messages they receive. In addition, explicitly color-coding text messages (with no other contextual information, such as vital signs) to portray priority of text messages might not necessarily help healthcare providers determine their response.

8.5.6.3 Differences or similarities between sender's and receiver's preferences

I examined the difference in preferences between senders who expect an immediate response and receivers who report they will respond immediately to text messages for all the study conditions. This analysis in turn helped examine how similar sending and receiving healthcare provider's choices were. That is, the difference will help identify the degree to which senders accurately conveyed patient information and anticipated receiver's preferences for immediate response. I began by computing the difference score between the average proportion of receiver's reported immediate responses and sender's expectations of immediate response. The difference scores were calculated by subtracting from every sender's choice (scored 1=Immediate, 2=Later, 3=Will not expect a response) the corresponding average choice given by receivers for the same message in a matching situation (for the None and Pager condition, the average by message was used).

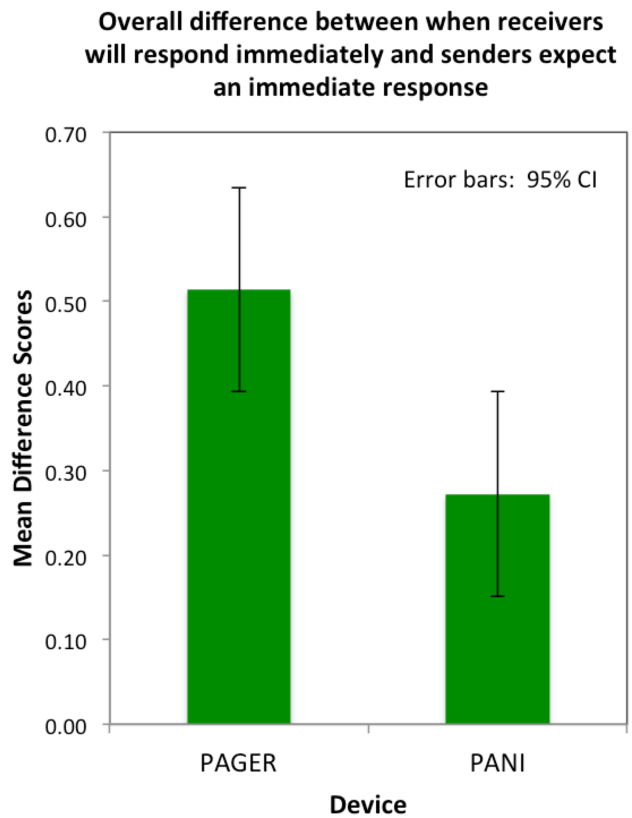

Figure 8.5: Graph depicting the overall difference between receivers and senders in preferences for immediately responding to messages from PANI and pagers. Reduced bar height indicates a better understanding between sending and receiving healthcare providers while communicating.

The mean absolute differences between senders and receivers for the existing system (pager) and the proposed concept (PANI) are depicted in Figure 8.5. From the figure, lower bar height depicts a decrease in difference scores between senders and receivers. That is, senders will be able to more accurately anticipate how receivers will respond to their messages.

A similar decrease (Figure 8.6) in difference between senders' expectations and receivers' response was identified with additional patient-centric conditions; the difference was least when both priority and patient vital sign information was provided in addition to the message.

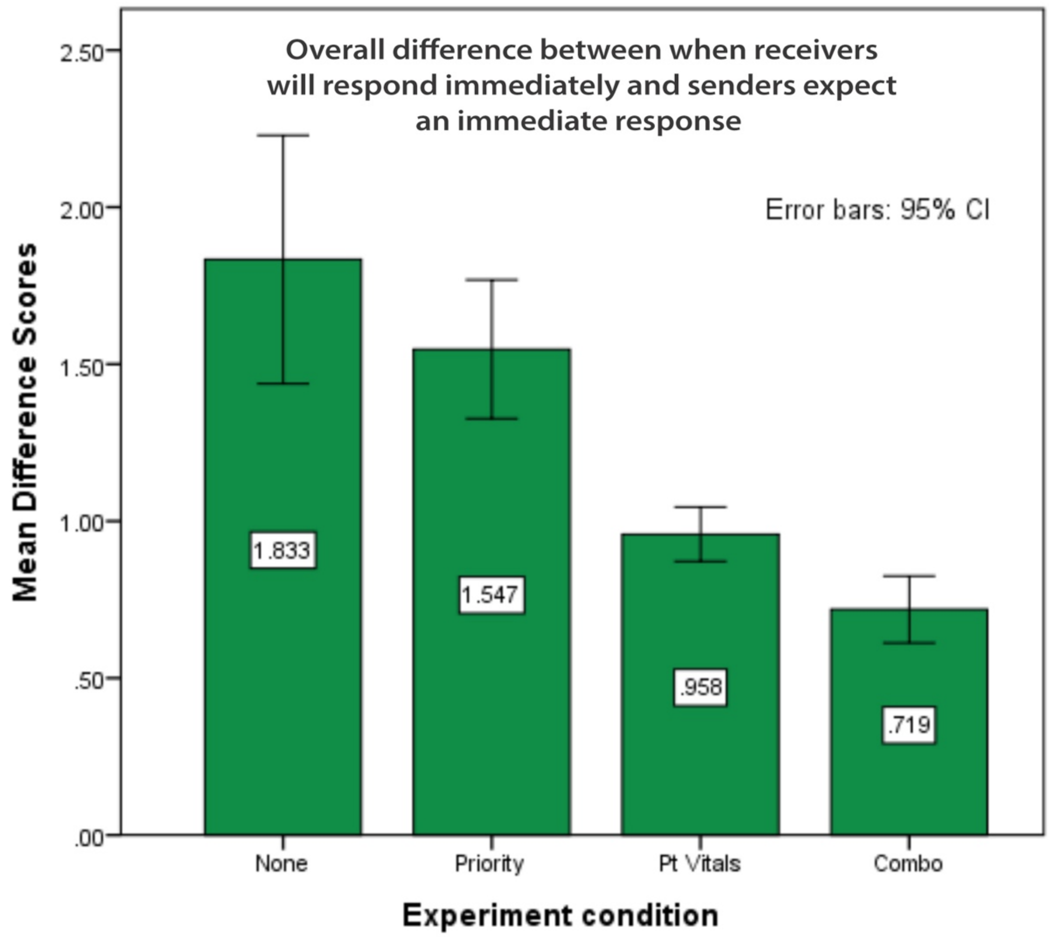

Figure 8.6: Graph depicting the overall difference between receivers and senders in preferences for responding immediately to PANI messages under different study conditions. Reduced bar height indicates increased understanding between sending and receiving healthcare providers while communicating.

These findings suggest that providing additional patient-centric information can result in improvements in the communication patterns between senders and receivers. Healthcare providers sending a message will know when a receiver will respond, and healthcare providers receiving a text message with additional patient-centric information will respond according to sending healthcare provider's expectations, thus ensuring effective communication. This will reduce time wasted waiting for a response and provide quick information to the sender on whether the receiver has seen his/her message.

8.5.6.4 Qualitative findings

Debriefing interview sessions after the study provided more information on how the additional patient-centric information provided along with the actual message aided in deciding when and how to respond to a text message alert or notification. Healthcare providers reported not paying attention to the color-coding of text messages used to explicitly indicate the priority of the message. For example, a resident noted, "the patient vital signs are enough for me to know how important the message is. Besides, I might think a message is not really important while a nurse might consider the same message as really important."

***Color-coding*:** Providers found it easy to rapidly understand and perceive the information conveyed through colors in patient notifications. For instance, P5 noted, "*if I see something colored red, I automatically think it is abnormal. I was able to quickly understand that a vital sign is abnormal. Although I don't really need the coloring, I know what is normal and abnormal. I think the color will help me improve my speed with which I perceive the information presented. This can be very helpful when all I have to do is glance at the phone while I am in the middle of something.*"

Using patient vital signs: Providers reported patient vital signs as important information that they can use to rapidly understand a patient's condition from the message. For instance, P2 noted, "*the first thing I want to know when a patient's lab* *result is abnormal is his current vitals. Instead of trying to look into EMR or call the nurse, it will greatly save me time and effort if I can just glance at my device and see the message and vitals together. This will help me to quickly determine what has to be done next, do I respond to the message at the moment or continue with whatever I was doing.*"

Providers reported glancing at patient vital signs to rapidly determine the time they had to respond to the message. For instance, P1 noted, "*if I am in the middle of rounds and if I receive a message with say a lab result and current vital signs, then I will be able to quickly understand the patient's current condition and how it relates to the lab result, what has to be done and when. If it is something important and needs immediate attention, then I can step away from rounds, otherwise I can respond later to the message. However, I am concerned if I will remember to respond later, you know what I mean?*" (this has been addressed as a design suggestion in Table 8.3)

Explicitly stating information on the urgency of a message shared: Providers reported not paying attention to the background color of patient notifications used to explicitly indicate the priority of the message. For instance, P1 noted, "*the patient vital signs are enough for me to know how important the message is. Besides, I might think a message is not really important while a nurse might consider the same message as really important. This is probably why I never noticed the background color of the messages. This might be useful if I see a series of text messages all together. That way I can differentiate which ones are important and which ones are less important.*"

Overall, participants reported positive preference for receiving a text message with color-coded patient vital signs during the interview session. In addition, participants provided suggestions, which was used to derive design suggestions for improving the evaluated design of the patient-enhanced notifications (Table 8.3).

Table 8.3 Design Suggestions

Description	Design Suggestion
Nurses suggested that the information that is often shared between one another is related to repeated interventions, such as, labs. P8 noted, "*Sometimes I prefer comparing a previous lab result just to see how the patient has been doing over time. Possibly it will be helpful if I could see just the previous and current lab result. I would anyways do this by going to the EMR if the results don't look good.*"	Display a previous intervention result in addition to current result to provide clearer understanding of the patient's progress over time.
Nurses found the term "Dismiss" unclear. They wanted an option that will allow a sender know that the receiver has seen his/her message. P5 noted, "*let's say the resident is busy and can't respond to my message immediately. If I can see that the resident has acknowledged my message, then I can move on and work on other activities since I have completed my part of work.*"	Replace the response option "Dismiss" to "Acknowledge" (Figure 8.7)

All providers reported on the value of sending and receiving a response to a specific question from the colleague. However, “Dismiss” and “Respond” buttons were found not to support this functionality. P2 noted, “*it will make more sense to me if I see a question in the message and I respond with a yes or no, maybe for the no option, I can explain why I chose that response to the recipient.*”	Dynamically change the response options to “yes” and “no, respond” if the actual message is a question (Figure 8.8).
Nurses raised the issue of difference between communicating multiple topics within a phone conversation as opposed to conveying a single topic through a text message.	Change “Respond” option to allow providers to choose from a set of options: Callback and Text.
Residents and nurses raised the issue of trying to remember to respond to a patient notification if they chose “Acknowledge” at any point of time.	Add an option, in which providers can set a time for the patient notification to pop up again; such as, “Remind me in 1 hr.”

8.5.7 Study 2b: Discussion

In general, the information shared between ICU healthcare providers includes lab/radiology results, patient’s response to medication, procedure completion and corresponding patient’s condition, and follow-up/consult with a specialist. ICU healthcare providers preferred immediately responding to notifications that provided more contextual information, such as patient vital signs, to the primary message.

The additional contextual information tested in this study included patient's current vital signs and priority of the message shared. Priority portrayed using color provided an opportunity for the healthcare providers to simply "glance at" a notification. However, healthcare providers reported that explicitly stating priority might not be helpful when a single message appears on the mobile device, since priority attributed to a message is dependent on the ICU healthcare provider's perception. Further, healthcare providers reported that they could perceive the priority of a message implicitly based on the patient vital signs and the actual message.

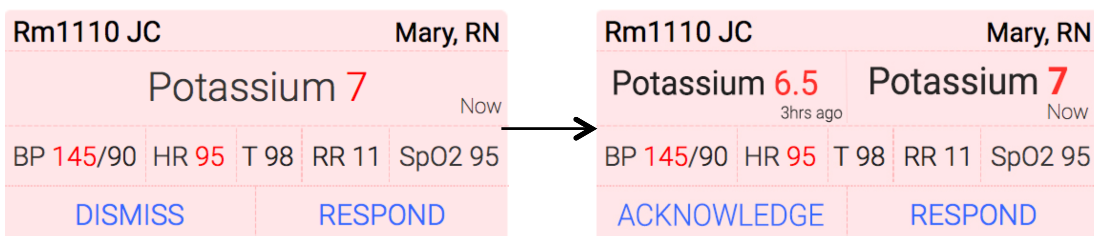

Figure 8.7: Modifications to the text messages to include past intervention results and thereby provide additional patient-centric information for repeated interventions

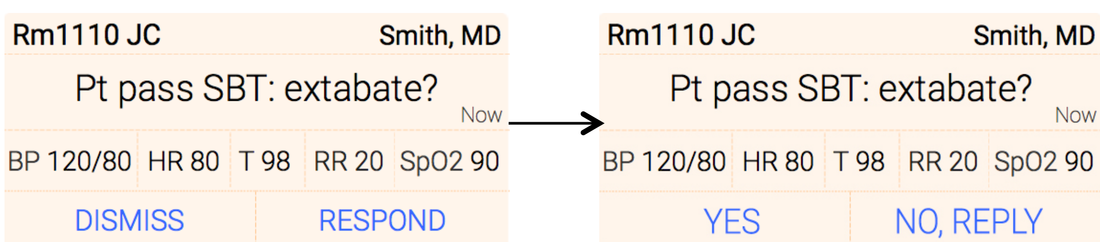

Figure 8.8: Modifications to the response options for patient-centric text messages with questions

Healthcare providers acknowledged the inclusion of the patient vital signs with a text message as a significant contributor aiding their decision on how to respond to the message; patient vital signs were considered important information that can be "glanced at" during the decision-making about any patient-centered activity. In summary, the inclusion of patient-centric information to a message shared between healthcare providers decreased the difference in sender's behavior and receiver's response. The difference was least for the combination condition that included patient vital signs and priority information, indicating that the sender could predict when and how a receiver would respond based on additional patient-centric information. This is expected to reduce time wasted waiting for a response by providing quick information to the sender on whether the receiver has seen his/her message.

Findings from this study also led to design refinements of PANI's visual patient-centric notifications. In addition to suggesting changes to how one can respond to a text message, healthcare providers also suggested including previous intervention results along with the primary message, especially for lab or radiology interventions that are cyclic, thus providing a more linear understanding of a patient's progress over time. Finally, healthcare providers raised the issue of the difference between communicating multiple topics within a phone conversation as opposed to conveying a single topic through a text message. Consequently, the communication functionality was refined to allow healthcare providers to call back in addition to the option to reply via text message.

In the next section, I describe a follow-up lab-based study (Study 2c) conducted to understand how healthcare providers perceived and managed interruptions from PANI's patient-centric notifications, and how tactile feedback can contribute to understanding the priority of a shared message.

8.6 Study 2c: Evaluating PANI's communication functionality for optimal notification interruption management

Study 2b helped refine the design of PANI's patient-centric visual notifications shared between healthcare providers for maintaining patient-situation awareness in the ICU. Findings from the online experiment conducted in Study 2b concluded a decrease in mismatch between a sending and receiving healthcare provider, in which the sender could predict when and how a receiver would respond. Study 2b also suggested that, by providing additional patient-centric information (such as vital signs) healthcare providers could simply "glance at", PANI's patient-centric notifications can help in deciding whether to continue or disrupt a task at hand in order to respond to the shared message. However, as discussed during focus group sessions and repeatedly expressed by participants in Study 2b, it was unclear how PANI's patient-centric notifications will help manage interruptions if the mobile device is out of the provider's sight (e.g., when inside the provider's coat pocket). Focus group sessions suggested the inclusion of tactile alerts as a means to direct a receiving provider's attention to his/her mobile device. To determine the feasibility of PANI's communication functionality in the ICU, I conducted Study 2c, which helped determine how the information content presented in text messages (from Study 2b) and tactile feedback (proposed in Study 2a) aid healthcare providers in effectively deciding whether to/not to disrupt ongoing work.

While healthcare providers identified patient vital signs as important information that can add more context to a shared message, color-coded message priority was not perceived as useful in Study 2b. One reason for this finding might be that healthcare providers were presented with only one message at a time, and thus the presence of color did not really stand out as explicit information for their attention. Another reason might be because healthcare providers attribute priority to patient-related information or activities based on their role in the ICU. For instance, a nurse might consider a slight increase in a lab result as an important message, while a resident might consider his ongoing activity as more important. In addition, healthcare providers reported implicitly understanding the importance of a message through the patient vital signs. Hence, a sender explicitly stating the importance of a message is effectively indicating to the receiving healthcare provider that a message needs immediate or less immediate attention.

In addition, healthcare providers must view or "glance at" the mobile device to identify and respond to messages that need immediate attention. Further, healthcare providers noted in Study 2a the overwhelming nature of receiving multiple simultaneous messages and the need to categorize them. Consequently, there is a need to identify an alternative technique for visually categorizing messages while also implicitly delivering priority information. I speculated that the visual patient-centric text message notifications with some form of tactile feedback (proposed in Study 2a) would provide more information and context for healthcare providers to understand and perceive when and how to respond to the shared messages. PANI was envisioned to generate tactile feedback based on (i) a priority selection made by the sending healthcare provider, and (ii) machine-generated priority information based on the patient's most recent vital signs. The tactile alert would be sent to the receiver based on a delay time period set by the sender. The purpose of the delay time period is to wait for a receiving healthcare provider to complete an ongoing task. For instance, a nurse flags a patient's lab result as "high priority," and sets the delay time period as 15 minutes while sending a patient-centric message to the patient's resident. Because the nurse chose "high priority" and the patients current vital signs are abnormal, PANI will know that the message sent requires immediate attention. PANI will initially present a visual patient-centric notification on the resident's mobile device. If the resident does not respond within 15 minutes of receiving the nurse's message, PANI will send a tactile alert. Upon receiving the vibration, the resident will "glance at" the mobile device.

8.6.1 Study 2c: Method

8.6.1.1 Research questions

This study investigated the following research questions

- What are healthcare providers' perceptions of interruption caused by PANI's communication module when used in a controlled setting?
- Does the introduction of a tactile feedback to PANI's visual text messages increase healthcare providers' perception of the message's priority?

8.6.1.2 Study Procedure

Healthcare providers completed a demographic questionnaire at the beginning of the study in which they reported their age, role in the ICU, and their preferences for how they would like to be notified if they were to use an asynchronous communication technology. This study was structured to occur for 30 minutes in a controlled setting, such as a conference room, where ICU healthcare providers were given a smartphone powered with PANI's communication functionality and a wearable device (such as

FitBit). Healthcare providers performed their regular computer-based work while they received visual notification messages through smartphone and tactile alerts through FitBit. Visual and tactile notifications were delivered to the devices in real-time using the Wizard of Oz technique (tactile vibrations were pushed through FitBit using its 'silent alarms' feature).

To determine the efficacy of PANI's patient-centric notifications, three types of notifications were tested: (i) PANI's patient-centric visual text messages, (ii) PANI's high priority visual text messages with tactile feedback, and (iii) control text messages, with only the primary message and no patient-centric information. The study was broken into six 5-minute segments with randomly generated notifications, and healthcare providers were instructed to find more information on notifications they perceived to be of high priority. This required healthcare providers to turn their attention to the smartphone device regularly and respond to questions after every 5 minutes; questions included: (i) what information the high priority notification contained, (ii) how they discovered more details about the notification, and (iii) whether they noticed something new on the mobile device when the FitBit buzzed. In addition, healthcare providers also reported on the level of interruption they perceived (on a scale from 1 – 5) while receiving the notifications at every 5-minute interval. Each 5-minute segment involved healthcare providers receiving multiple visual text messages at random intervals. The study ended with a debriefing interview session in which healthcare providers provided additional feedback on PANI's communication functionality.

8.6.2 Study 2c: Results

Participants

Five ICU healthcare providers (3 doctors and 2 nurses; 60% Female, 40% Male) participated in this study. More details on the demographic information of the participants can be found in the Table 8.4.

Perceived interruptions

Healthcare providers' responses to questions at the end of every 5 minutes were coded for accuracy on a 0-1 scale, where a correct response was coded as 1, partially correct response was coded as 0.5, and incorrect response was coded as 0 (Figure 8.9).

Table 8.4. Summary of participant demographic information

Demographic information	Frequency or percentage
Roles	Resident: 2 Nurse practitioner: 1 Medical student: 1 Registered nurse: 1
Age group	20 – 30: 40% 31 – 40: 60%
Notification preference based on priority of information conveyed	High: Immediately (100%) Medium: Immediately (20%) Based on the moment of receiving (80%) Low: Based on the moment of receiving (100%)

Overall, healthcare providers were more accurate (Figure 8.10) in responding to the questions related to PANI visual text messages with (M = 92%, SD = 13.166) and without tactile feedback (M = 81%, SD = 26.854) as compared with the control notifications (M = 75.5%, SD = 9.265). A Wilcoxon signed rank test identified a significant difference (Table 8.5) in feeling interrupted, with healthcare providers feeling more interrupted while receiving control messages (M = 4.2, SD = 1.033) as compared with text messages including patient-centric information such as vital signs (M = 2.9, SD = .568) with and without tactile feedback for high priority messages (M = 2.6, SD = .699).

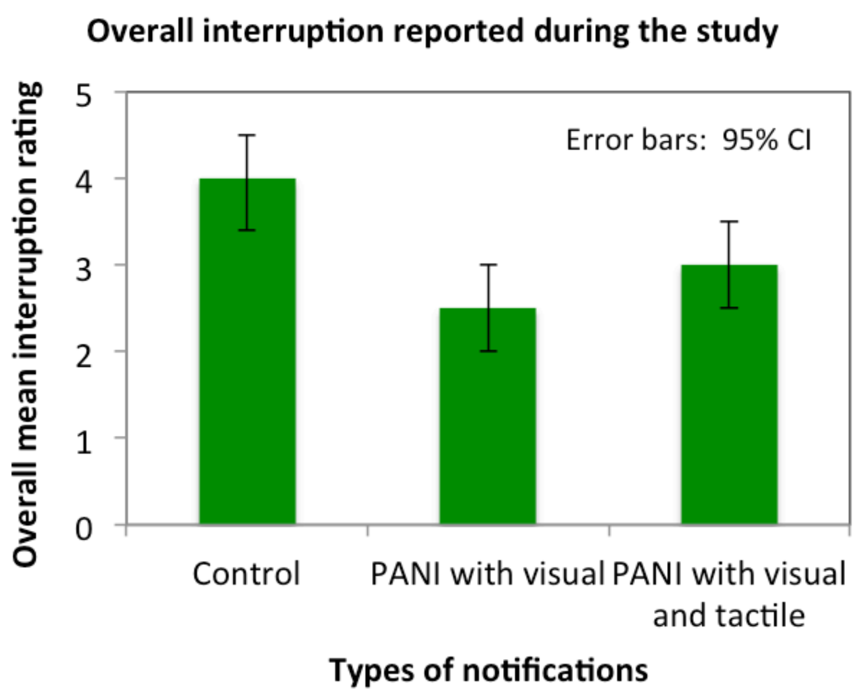

Figure 8.9: Graph depicting the difference in interruptions perceived by healthcare providers on comparing regular smartphone text messages with patient-centric text messages and tactile feedback.

8.6.3 Study 2c: Discussion

This study was conducted to understand healthcare providers' perception of interruption induced while communicating patient information with PANI's visual and tactile text message notifications or alerts. Three types of notifications were tested in this study: (i) text messages without additional patient-centric information such as patient vital signs, (ii) PANI text messages with patient-centric information such as vital signs without tactile feedback, and (iii) PANI text messages with patient-centric information such as vital signs and tactile feedback specifically for high priority messages.

Healthcare providers were required to switch their attention to the smartphone device to respond to questions every 5 minutes. Overall, healthcare providers reported more correct responses when they saw PANI visual notifications with or without tactile feedback as compared to when they only saw the visual messages without patient-centric information such as patient vital signs. One reason for this could be that the control text messages did not contain detailed information about the patient. Hence, healthcare providers had limited information to respond to the questions raised every 5 minutes.

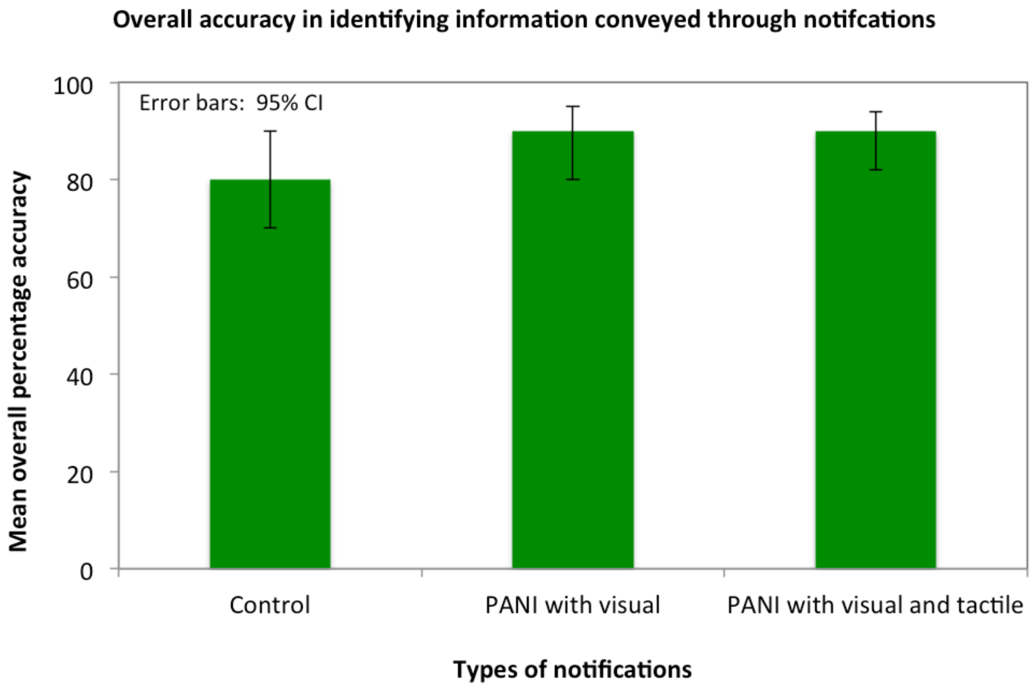

Figure 8.10: Graph depicting the difference in overall accuracy in identifying information communicated through notifications

Further, control text messages consisted of only the primary message and did not include any priority information, forcing the healthcare providers to disrupt their documentation activity more frequently and for longer durations to ensure they comprehend as much information as they could for determining the message's priority. Consequently, healthcare providers reported experiencing more interruption in the control condition.

PANI visual text messages without tactile feedback were reported as less disruptive compared to the control messages, since healthcare providers could glance at the smartphone and rapidly understand the priority of the message both implicitly depicted through patient vital signs and explicitly depicted through color-coding of incoming messages. However, healthcare providers reported (during the debriefing interview session) the need to remember to switch their attention in a timely manner to see the messages of high priority. Three out of five healthcare providers reported noticing a relationship between the tactile feedback provided by FitBit and a high priority visual notification on the smartphone. Although not as interruptive as control messages, overall healthcare providers reported experiencing more interruption when receiving PANI messages with tactile feedback as compared with those without tactile feedback. One reason might be because of high interruption ratings by one healthcare provider. This healthcare provider noted during debriefing session, “I think the vibration on the FitBit is interrupting and frustrating.”

Table 8.5 Wilcoxon signed rank test summary for interruption rating

	Control – PANI visual	PANI visual – PANI visual and tactile	PANI visual and tactile – Control
Z	2.701	1.134	–2.414
p	.007*	.257	.016*

* significant with $p < .05$

Overall, healthcare providers reported being able to rapidly notice and comprehend patient details from PANI visual notifications, with tactile feedback informing the receipt of high priority notifications.

Table 8.6 Wilcoxon signed rank test summary for accuracy

	Control – PANI visual	PANI visual – PANI visual and tactile	PANI visual and tactile – Control
Z	1.511	.000	–1.058
p	.131	1.000	.290

A resident noted, "ASCOM is highly disruptive. I have to answer a phone call no matter what since I don't know who is calling me and how important the message is going to me. If I was given your system, I will be able to quickly glance at my device whenever needed and still stay informed about all the messages sent to me. Besides, I like this idea of vibration, which will nudge me to glance at the device if something important is sent to me. I feel this is less disruptive and more informative as compared to ASCOM."

8.7 Summary

Study 2 used a three-phase approach to designing and evaluating PANI's communication functionality:

(i) Study 2a used focus group sessions to identify design implications and refine the design of PANI's patient-centric notifications,

(ii) Study 2b used an online platform to examine the efficacy of PANI's visual patient-centric notifications and identify corresponding design refinements,

(iii) Study 2c helped examine the efficacy of PANI's visual and tactile notifications to communicate patient information in a simulated, controlled setting.

Findings from all the three studies helped refine and evaluate the design of both visual and tactile patient-centric notifications used to communicate information between healthcare providers with minimal notification interruptions. The next chapter discusses the inclusion and evaluation of the communication functionality (designed from Study 2) in ICU task management.

Chapter 9. Designing and evaluating the task management functionality of PANI

Chapter 8 discussed the original ideation and Studies 2a, 2b, and 2c, which were conducted to refine and evaluate the design of PANI's communication functionality. Findings from these studies led to the design of patient-centric visual text messages as a technique for notifying or communicating information between healthcare providers while maintaining patient-situation awareness in the ICU. Tactile alerts were proposed and designed as a means of indicating to the healthcare providers the importance or priority of visual messages. In sum, Chapter 8 introduced and discussed novel techniques for using visual and tactile notifications to aid healthcare providers in (i) "glancing at" and (ii) rapidly comprehending information conveyed. Findings reported in this chapter contributed to helping healthcare providers in optimally managing notification interruptions in the ICU.

In this chapter, I discuss the process I followed to design and evaluate PANI's task management with added communication functionalities (learned from Chapter 8).

9.1 Initial ideation process

Inspired by the design guidelines derived from Study 1, I developed a prototype for the task management functionality of PANI. This functionality includes the creation of personal tasks or action-items and the ability to disseminate action-items that need to be completed by fellow healthcare providers. A significant findings from Study 1 includes the paper note-making process followed by healthcare providers while managing their tasks related to their patients. The paper-based notes are personal/informal notes made every day during a clinical shift that aid in externally distributing information (usually transferred as a part of digital notes) that must otherwise be remembered by healthcare providers. They do not replace the standardized, digital notes documented every 24 hours as a part of the patient EMR. A typical setup in hospitals includes an EMR and CPOE that does not replace paper-based notes generated during clinical shift. The contents of the notes are usually modified and transferred/converted into digital form. For instance, a note with the content "chest x-ray" scribbled by a resident on a rounding checklist (for patient X), represents an action-item to create a medical order requesting a chest x-ray. The resident then transfers this action-item as a medical order for the patient using the CPOE. Following this, the content in the notes is modified to "þ chest x-ray," signifying its completion. Consequently, a double record, consisting of redundant information, exists both on paper (as a checked action-item in a sheet of paper that is never shared) and digitally (as a medical order).

Study 1 identified different types of content for paper notes: (1) action-items, (2) pointers that help jog one's memory, (3) reminders that one wants to follow-up or consult with, and (4) reminder notes that serve as a message/info to self. Study 1 also identified different types of paper note content usages: (1) digitize post-rounding action-items as orders/progress notes using the EMR, (2) communicate with specialists/subspecialists, (3) communicate to the team about general patient care based on the result of action-items, (4) 'hand-off' or communicate to fellow members during shift change, and (5) remember to perform an activity (e.g., calling someone) at a later time.

I began design exploration based on the above-mentioned findings from Study 1. The ideation process for task management in the ICU was supported by the design implications discussed in Chapter 6. Since task management is highly intertwined with communication, I adopted the findings from Chapter 8 to refine task dissemination to include visual and tactile patient-centric notifications. As such, the prototype included the following task management features mapped directly from the guidelines proposed in Chapter 6:

- Virtual patient awareness -> a scrollable, persistent list of action-items based on patients.
- Asynchronous awareness -> link to digital patient EMR (e.g., labs, x-rays), allowing constant updates and ubiquitous access to real-time patient-centered data.
- Locales-specific awareness -> color-coding of patient locales to convey information in a less intrusive manner in addition to prioritizing the importance of information conveyed
- Temporal awareness -> conveying real-time patient information to healthcare providers irrespective of when it started or if in-progress in the real world.
- Healthcare provider-tailored empathic awareness -> visual depiction of the flow of action-items between the healthcare providers based on their role in patient's care as they are created, assigned, forwarded and completed, to support shared awareness of patients' situation between all the healthcare providers.

Following the findings from Studies 2a, 2b, and 2c, communication functionalities were also added to the original ideation design. This was done based on the understanding that ICU patient-situation awareness is maintained using both communication and task management work practices. The design features of the refined prototype of PANI with communication and task management functionalities are shown in Table 9.1.

Table 9.1. Summary of design features prior to conducting Study 2d

Study 1 design implications	Design feature
Virtual patient locales	Scrollable, persistent list of action-items that can be modified based on patients and healthcare providers
Asynchronous awareness	Link to digital patient EMR (e.g., labs, x-rays), allowing constant updates and ubiquitous access to real-time patient-centered data.
	Ability to communicate information and disseminate action-items through asynchronous text messages.
Locales-specific awareness	Visual depiction of action-items in a less intrusive manner by means of prioritizing the importance of information conveyed in the message.
	Directing the attention of healthcare providers to urgent or important information through tactile feedback.
Temporal awareness	Conveying real-time patient information to healthcare providers irrespective of when it started or if in-progress in the real world.
Healthcare provider-tailored empathic awareness	Visual depiction of the flow of action-items between the healthcare providers based on their role in patients' care as they are created, assigned, forwarded and completed to support shared awareness of patients' situations between all healthcare providers.

To determine the efficacy of the ideated prototype, I generated another design version as a control. The control version was based on popular task management smartphone applications used for software project management. I chose to create a control design based on existing project management tools because of the similarity between software projects and collaborative patient care. Both are often team-based, require task management and communication while maintaining awareness, and involve members working remotely. Consequently, Study 2d included an evaluation, wherein healthcare providers evaluated two design versions of the interactive prototypes (developed using Axure[3]) by "thinking-out-loud" as they completed the tasks. Findings from this study helped identify the feasibility of both the communication and task management functionalities of PANI in a controlled setting (such as conference room). Findings from this study also pointed to various design implications and insights that are discussed in Chapter 10.

9.2 Study 2d: Research Design

Scenario-based user testing methods in a controlled environment help explore and identify the problem areas in the system's design. However, such tests do not necessarily give any clear indication as to why a certain interface aspect poses a problem to a user, or how to improve the interface. Hence, it is imperative to identify and use a method that will help provide insights into the underlying causes for problems users encounter. One such widely-accepted scenario-based method for evaluating an interactive system's design against user requirements is the "think aloud" method (Beul et al., 2014; Eapen & Chapman, 2015; Nahm et al., 2004; Sheehan et al., 2012; Wu et al., 2008). Consequently, this study included a participatory evaluation, in which healthcare providers evaluated

[3] http://www.axure.com

two design versions of the interactive mobile prototype by "thinking-out-loud" as they completed the tasks.

Unlike traditional desktop applications, applications in a mobile context impact both the user's personal physical mobility as well as their operation of the mobile application. Therefore, it is important to consider both dimensions when studying mobile application usability. Hence, this study also measured the amount of cognitive processing required by the user, also known as cognitive load.

The design study used a mixed-methods approach comprising quantitative and qualitative measures. Quantitative measures included: (1) user performance, such as time on task and accuracy with which task is completed, (2) overall workload, using NASA-TLX scale, and (3) user satisfaction and system usability, using the System Usability Scale. Qualitative measures included: (1) a pre-test questionnaire assessing mobile device expertise and patient information management, (2) users' verbal utterances while completing tasks, and (3) post-task retrospective interview sessions.

9.2.1 Measuring the perceived usability

The ISO's (International Organization for Standardization) definition of usability is "the effectiveness, efficiency and satisfaction with which specified users can achieve specified goals in particular environments" (ISO 9241-11, 1998). From users' perspectives, how they judge a product's usability is described as *perceived usability*. McGee, Rich, and Dumas (2004, p. 909) suggested that perceived usability is "the users' perception of how consistent, efficient, productive, organized, easy to use, intuitive, and straightforward it is to accomplish tasks within a system." One of the most popular ways to measure perceived usability is to ask users to complete a questionnaire, in which they provide their own ratings of a product's predefined usability aspects.

Existing literature reports several types of usability questionnaires administered after scenario-based user testing sessions: usability questionnaires for websites, mobile applications, and any information system in general. I report some of the common questionnaires typically used to determine perceived usability in healthcare.

Ryu and colleagues (2005; 2006; 2007_a; 2007_b) conducted a series of studies to develop a Mobile Phone Usability Questionnaire (MPUQ). Developed from existing relevant measurement instruments (Ryu & Smith-Jackson, 2005), the MPUQ was standardized using statistical analytical methods. MPUQ, however, comprises about 72 Likert scale items grouped into six dimensions, such as: ease of learning and use; helpfulness and problem solving capabilities; affective aspect and multimedia properties; commands and minimal memory load; control and efficiency, and; typical task for mobile phone (for further details, see Ryu and Smith-Jackson (2006)). Although MPUQ includes understanding different aspects of usability, it is very long and can cause users to feel frustrated while completing the questionnaire.

The PSSUQ (Post-Study System Usability Questionnaire) is a 19-item usability questionnaire that measures users' perceived satisfaction with a product or system (Lewis, 1992). The PSSUQ consists of three subscales: system usefulness, information quality, and interface quality. Each item is measured on a 7-point Likert scale. Responses range from 1 (strongly agree) to 7 (strongly disagree). Lower scores on the subscales indicate a higher overall user rating. However, one limitation of the Post-Study System

Usability Questionnaire is the broad scope of "interface quality," which is insufficient to reflect the complexity of a computational system's interface design.

The ASQ (After-Scenario Questionnaire) is a three-item questionnaire for assessing participant satisfaction after the completion of each scenario. The scale addresses three components of user satisfaction with system usability: ease of task completion, time on task, and adequacy of support information (such as documentation and help). Because the questionnaire is very short, it takes very little time for participants to complete. However, the questionnaire lacks more information on user's perception and ease of use.

IBM developed both PSSUQ and ASQ, aiming to serve two different purposes; whereas ASQ captures users' feelings toward performing scenario-based tasks on an information system, PSSUQ evaluates the users' overall satisfaction (Lewis, 1995), including system usefulness, information, and interface quality.

The Perceived Health Web Site Usability Questionnaire (PHWSUQ) is composed of 15 items with a 7-point Likert-type scale (1 being very unsatisfied and 7 being very satisfied) assessing the following four dimensions: satisfaction, ease of use, usefulness, and logic of organization. The PHWSUQ was derived and updated from existing questionnaires (Keinonen, 1997; Spool et al., 1999). Three experts, two with expertise in usability and one in gerontology, provided evidence of the face validity of the questionnaire.

The Health IT Usability Evaluation Scale (Health –ITUES) is a 20-item questionnaire that was developed to identify the usability of web-based Health IT systems. Existing literature points to preliminary evidence for factorial validity and internal consistency of Health-ITUES (Yen et al., 2010). However, this questionnaire was evaluated against only one system with one group of users, which can potentially limit broader applicability.

A commonly used questionnaire post scenario-based user testing is the System Usability Scale (SUS). The SUS is a short questionnaire (10 questions) developed by Brooke (1996) and aimed at quickly and reliably assessing the usability of information systems. Brooke suggested that the results of usability evaluations vary significantly according to the *context* where a system is used, such as within a selected user group, task scenarios, or social context. Therefore, instead of developing a lengthy questionnaire trying to cover every circumstance of usability, what practitioners truly needed was a simple, but reliable tool that could capture the essence of the usability of a system in a brief time period. Based on this idea, only 10 well-refined and extensively tested items were created for the SUS. As intended by Brooke, the SUS was more useful for practitioners who expected quick results than researchers who wanted to get a comprehensive view of system usability. An added bonus to using the SUS was that items 4 and 10 reliably measure the dimension of perceived “learnability” (Sauro & Lewis, 2012). Therefore, by measuring these items separately, it’s possible to gain an understanding of users’ perceived usability and learnability of the product or system under study.

Although SUS is applicable for evaluating any type of electronic product and does not comprise mobile-specific usability dimensions (such as navigation), it has been used to compare mobile systems, while obtaining a global view of subjective usability assessments (Beul et al., 2014; Eapen & Chapman, 2015). I chose SUS as a post-test psychometric tool for capturing user input for the following reasons: (1) its optimal length of 10 questions, (2) the need to identify the overall usability of the system, and (3) validity and reliability offered by prior research on the usage of SUS for evaluating mobile applications.

9.2.2 Measuring workload

The term workload, as summarized by Hoonakker et al. (2011) in their manuscript on measuring workload of ICU nurses, is a complex concept, comprising the operator who is performing a task as well as external, environmental, organizational, psychological, physical, or cognitive demands impacting the operator’s performance while completing the task. Typical approaches used to measure an operator’s workload include measuring the (1) objective physiological measures (such as heart rate, brain activity, etc.) and the (2) subjective report by the operator on their experience of workload. Overall, these techniques involve measuring the cognitive and physical resources required to perform a task.

Objective measurement of workload is often indirect, based on the assumption of a relationship between cognitive activity and autonomic activity (Tsang & Wilson, 1997). Subjective measurements, although operator-reported, are measured using instruments that have higher inter- and intra- reliability, are less-intrusive, can be quickly administered at the end of a task without interrupting task performance, do not require expensive equipment, and are inexpensive to administer and analyze (Tattersall & Foord, 1996; Yeh & Wickens, 1988). Further, subjective measures take into account individual differences in ability, state, and attitude—differences that may be obscured in objective measures of performance until breakdown makes them obvious (Muckler & Seven, 1992). Hence, for purposes of initial exploratory analysis, the design study administered a subjective instrument to measure workload. I report some of the most commonly administered subjective workload measurement instruments in the remainder of this section.

The Cooper-Harper Scale (Cooper & Harper, 1969) is a 10-item scale with a decision-tree that is used to measure mental workload, specifically while handling qualities of aircraft during flight test. This rating scale, however, comprises dichotomous questions, to which the operator responds while progressing through the decision-tree. The decisions made in response to the questions heavily depend on the words used in the questions. Wierwille and Casali (1983) devised a modified version of this scale, called the MCH scale. The MCH scale was devised for assessing workload in systems other than those where the human operator performs motor tasks; namely, where perceptual, mediational, and communications activities are present. There is contradictory evidence on the validity and sensitivity of this scale. Generally, the MCH was found to be a good estimator of overall mental workload (Casali, 1983; Wierwille, 1993). Conversely, Hill and colleagues (1992) found the MCH to be of little value. It was hard to complete, not accepted or liked, was not sensitive, and poorly described workload. Further, this scale only measures one dimension: mental workload.

The Subjective Workload Assessment Technique (SWAT) is a multidimensional test that uses three levels (low, medium, high) for time, mental, and physiological stress load measures (Hill et al., 1992). This test includes three steps to complete and analyze workload: (1) scale development, where the operator sorts cards into a ranking reflecting his/her perception of time, mental, and physiological stress load, (2) the operator rates the workload, and (3) the rated scores are converted into a 0-100 scale using the scale developed in step 1. Some studies indicate that the SWAT scale proves useful in estimating changes in mental workload (Colle & Reid, 1998; De Waard, 1996; Eggemeier, 1983; Wierwille, 1993). By contrast, Hill et al. (1992) report a 43% failure rate on the first attempt to perform the sorting step for the SWAT. Experienced operators encountered this high failure rate, suggesting that the failure rate would be much higher for inexperienced operators.

Instantaneous self-assessment (ISA) is a technique that was developed as a measure of workload that provides immediate subjective ratings of work demands during the performance of primary work tasks, such as air traffic control. ISA involves participants self-rating their workload during a task (normally every two minutes) on a scale of 1 (low) to 5 (high). Typically, the ISA scale is presented to the operators in the form of a color-coded keypad. The keypad flashes when a workload rating is required, and the operator simply pushes the button that corresponds to their perceived workload rating. Alternatively, the workload ratings can be requested and acquired verbally. This technique, can, however, impact the performance of the primary task, as reported by Tattersall and Foord (1996).

One of the widely used instruments to measure workload is the NASA task-load index (NASA TLX) scale, which is used to assess the overall subjective workload (Hart, 2006; Hart & Staveland, 1988). The NASA-TLX is a multi-dimensional instrument that consists of 6 subscales: Mental Demand (MD), Physical Demand (PD), Temporal Demand (TD), Frustration (FR), Effort (EF), and Performance (PE). Twenty-step bipolar scales are used to obtain ratings on these dimensions, resulting in a score between 0 and

100. The underlying assumption of the instrument is that the combination of these 6 dimensions is likely to represent “workload” experienced by operators (Hart, 2006). Overall workload (OW) is represented by a combination of the six dimensions. Several studies by researchers have modified the procedure for analyzing the score from the NASA-TLX scale. Originally weighted to develop a composite score tailored to individual workload, the technique has evolved to simply apply an aggregation (such as sum or average) on the individual scores to determine an estimate of overall workload (Hart, 2006). Previous research (Hill et al., 1992; Hart & Staveland, 1988; Rubio et al., 2004) shows that the NASA TLX is a more reliable and valid instrument than other subjective workload instruments. Furthermore, NASA TLX is easy to administer, especially when using the raw scores instead of the weighted scores (Hendy, Hamilton, & Landry, 1993; Nygren, 1991). Finally, NASA TLX is one of the few instruments that includes a measurement of physical workload.

Most studies to test reliability and validity of NASA TLX were conducted mainly in air traffic control, and civilian or military aviation. The NASA task load index is also a validated instrument for evaluating the burden of multiple tasks a user must perform in parallel. It is well suited for the use scenario of an application where the user is required to multitask. The NASA Task Load Index has been successfully applied in evaluating health care IT products in the past (Honnaker et al., 2011; Soz et al., 2010; Yuan et al., 2013). Given the above description, I chose to administer the NASA TLX instrument to measure the overall workload while testing the prototype.

9.2.3 Participants

Verbal protocol analyses of studies implementing think-aloud techniques produce rich data. Hence, it is often argued that large sample sizes are not necessary for such studies (Sen & Vinze, 1997; Todd & Benbasat, 1987; Vessey & Conger; 1993). Typically, a small group of users who are representative of the target population can yield important results. For this study, clinical participants included a convenience sample of 5 residents (R1-5) on their ICU rotation and 10 ICU nurses (N1-10). A list of potential volunteers was provided by one of the lead ICU physicians working in the medical ICU of Eskenazi Health Hospital in Indianapolis, IN. From this list, volunteers were invited to participate. The desired sample size was 8 to 12 participants. This number was based on previous research, determining that 80% of user-interface problems can be detected with this sample size (Kushniruk & Patel, 2004; Nielsen, 2000).

9.2.4 Study conditions

Prototypes of two design versions of the mobile application were developed using Axure, which helped populate the fields relevant to the scenarios on an iOS device (iPhone 4s). The two prototypes corresponded to two study conditions: (i) experimental (Design 1), with PANI's task management and communication functionality features derived from Studies 1, 2a, 2b, and 2c, and (ii) control (Design 2), with design features derived from software project management mobile applications (Murphy, 2015).

9.2.5 Study procedure

The prototypes were evaluated in a series of sessions. The sessions varied based on the role of the participant in the ICU.

9.2.5.1 Testing session for Residents

In each session, the participant was asked to complete four tasks (that were chosen to be representative of their real use) using the two design versions. Each task began with a relevant clinical scenario. Scenarios were based on real patient encounters, and were assessed for face validity by two ICU members.

Participants began each session by watching a 4-minute video explaining the concept of PANI. Following this, they completed a pre-test questionnaire comprising demographic questions and questions specific to mobile device usage and patient information management. The participants were then provided a priming session to familiarize themselves with (i) the fictitious patients referred to in the tasks and (ii) mobile application prototype. Following the priming session, participants proceeded to complete the tasks for each design.

Four tasks corresponding to four types of activities generally performed by doctors were tested

- Adding a new action-item -> creating task
- Forwarding an action-item -> disseminating task (team-based task management)
- Personal reminder -> personal task management
- Information sharing -> communicating or notifying patient-centered information

All participants evaluated both control and experimental design versions. All the tasks for a design version were evaluated before moving onto the next design version. Participants were asked to respond to a series of questions and to "think aloud" as they used each prototype, using the methodology described by Kushniruk & Patel (2004). The testing sessions were audio-recorded and the mobile device screen was video recorded.

Following the completion of each task, the participants completed the NASA TLX questionnaire. At the end of testing the four tasks for each design version, the participants completed the NASA TLX questionnaire and the System Usability Scale considering the overall design version. After testing both design versions and completing all the questionnaires, the participants responded to retrospective interview questions.

The order in which the participants tested the design version was randomized. In addition, while testing each design version, the order in which the tasks for each version were administered were randomized. This was done to prevent order and learning effects. Each session lasted approximately 30-40 minutes.

9.2.5.2 Testing session for nurses

Owing to the limited availability of nurses, the nurses were randomly split into two groups, with each group receiving a different design version of the technology probe. Overall, both groups of participants completed the same set of tasks and questionnaires, and responded to the same set of interview questions, with the only difference being the design of the prototype.

In each session, the participant was asked to complete two tasks (that were chosen to be representative of their real use) for one design version. Each task began with a relevant clinical scenario. Similar to those administered for residents, the scenarios were based on real patient encounters, and were assessed for face validity by two ICU members.

Further, similar to the testing session administered to residents, the participants began each session by watching a 4-minute video explaining the concept of PANI. Following this, they completed a pre-test questionnaire comprising demographic questions and questions specific to mobile device usage and patient information management. The participants were then provided a priming session to familiarize themselves with (i) the fictitious patients and (ii) the mobile application prototype. The participants then proceeded to completing the two tasks.

Two tasks corresponding to the two types of activities generally performed by nurses included

- Adding a new action-item -> requesting a resident to sign an order (also known as ‘verbal order’)
- Information sharing -> communicating or notifying patient-centered information

Participants were asked to respond to a series of questions and to “think aloud” as they used each prototype, using the methodology described by Kushniruk & Patel (2004). The testing sessions were audio-recorded and the mobile device screen was video recorded. Following the completion of each task, the participants completed the NASA TLX questionnaire. At the end of testing the two tasks for each design version, the participants completed the NASA TLX questionnaire and the System Usability Scale considering the overall design version. After completing the questionnaires, the participants responded to retrospective interview questions.

The order of completing the two tasks was randomized to prevent order effects. Each session lasted approximately 15-20 minutes.

9.2.6 Data collection and analysis

All the sessions were transcribed and the transcripts were pieced together with my observation notes. The audio portions of the test session (resulting from think aloud reports) were transcribed to a word processing file. The transcripts were later annotated and coded using verbal protocol analysis and included comments from the participants. The video portion of the session included records of participants' actions (taps, swipes etc.) and the screen that was used at each point.

To analyze the transcripts and video recordings, I used the coding scheme illustrated by Kushniruk & Patel (2004). This included a record on (1) participants' navigation, (2) mention about graphical user interface (color, images, resolution, etc.), (3) participants' comments on layout and organization, (4) understanding of error messages, (5) consistency of operations, (6) overall ease of use, (7) nature and speed of feedback provided by the prototype, and (8) visibility of system status.

SPSS (v.21) was used for quantitative statistical analysis of measures such as user performance, overall workload, and usability and user satisfaction. ATLAS.ti (v1.0.15) was used to perform content analysis of transcribed, qualitative data.

9.2.7 User performance

All the participants were tested for execution speed, i.e., time taken to complete each task (response times, RTs) in minutes. No time limits were imposed. The central tendencies and dispersions of RTs are reported using the mean, and statements of statistical inference are based on a significance level (α) of .05. To correct the positive skew, each recorded value of RT was replaced by its square root. By retaining the original unit of measurement (minutes elapsed), this transformation simplified interpretation of the data.

9.2.8 Success rate

User success rate was also recorded for all the participants. Success rate is defined as the percentage of tasks that users complete correctly. Success rate was computed as follows: (1) Success (S) if the participants successfully completed the task, (2) Partial (P) success if the participant was able to complete part of the task, but failed to complete other parts, and (3) Failure (F) if they failed to complete the task. Given the exploratory nature of the data collected and to get an overall general view of user success rate, one point was assigned for each success, a half point for each partial success, and zero points for each failure (Jakob, 2015).

9.2.9 NASA TLX Questionnaire

After each task, all the participants completed the NASA TLX questionnaire to self-evaluate the amount of cognitive and physical burden associated with using the prototype.

9.3 Results

9.3.1 Quantitative analysis

9.3.1.1 Residents

The distribution of RT became sufficiently normal after applying the square root transformation for both experimental (Shapiro Wilk D[20] = .961, p = .570) and control (Shapiro-Wilk D[20] = .952, p = .419) designs. Using a repeated measures ANOVA with a Greenhouse-Geisser correction showed an overall significant difference in square root-transformed RT (F(1,3) = 13.668, p = .034, η = .820). The post-hoc tests using Bonferroni correction are reported. Overall, participants took significantly less time (t[20] = -.288, p = .046) to complete all the tasks using design 1 (experimental group; M = 1.055 min) as compared with design 2 (M = 1.353 min).

In total, 20 tasks were observed for each design version. Of the 20 attempts using design 1 (experimental group), 16 were successful and 4 were partially successful. Using

50% credit assignment for each partial success, the success rate for all the participants completing tasks using design 1 was 87.5%. Similarly, of the 20 attempts while using design 2 (control group), 13 were successful, 6 were partially successful, and 1 attempt was not recorded. The overall success rate for all the participants completing all the tasks using design 2 was 84.2%. Although the difference in success rates provides a general picture of how each design supports task completion, the difference does not provide more information on which design is better, owing to the small number of observations and the rough estimate of partial success scores. However, exploring the observed attempts recorded for task 3, there was a 40% success rate using design 2, while there was 80% success rate with design 1. Similarly, of all the recorded attempts for task 4, there were 70% and 100% success rates while using designs 1 and 2 respectively. These results indicate that there are some design interactions in both the versions that support the participants and some that require improvement.

Using Friedman's test showed no significant difference in the overall workload when comparing both the design versions across all the tasks, $X^2(20) = .000$, $p = 1.000$. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in non-significant results overall and considering each type of workload. Using a paired samples t-test showed no significant difference in the overall reported SUS scores between design 1 (M = 80.5, SD = 12.57) and 2 (M = 81, SD = 6.75), t(4) = -.115, $p = .914$.

9.3.1.2 Nurses

The distribution of RT became sufficiently normal after applying the square root transformation for both design 1 (Shapiro Wilk D[10] = .933, $p = .478$) and design 2

(Shapiro-Wilk D[10] = .921, $p = .368$). A two-way ANOVA showed a significant main effect of design version on square-root transformed RT ($F(1,16) = 6.445$, $p = .022$). This study found that square-root transformed RT of participants while using design 2 (control group; M = 1.710 min, SD = .38) was significantly more than when using design 1 (experimental group; M = 1.330 min, SD = .26), $t(18) = 2.626$, $p = .017$.

In total, 10 tasks were observed for each design version. Of the 10 attempts using design 2, 6 were successful, 2 were partially successful, and 2 were failures. Using 50% credit assignment for each partial success, the success rate for all the participants completing tasks using design 2 was 70%. Similarly, of the 10 attempts while using design 1, 9 were successful and 1 was partially successful. The overall success rate for all the participants completing all the tasks using design 1 was 95%. On exploring the observed attempts recorded for task 2, there was a 90% success rate using design 1, while there was a 60% success rate using design 2. A Mann-Whitney test showed no significant difference in overall perceived workload between the design versions, $U = 73$, $p = .089$. No significant difference was noticed between the reported overall perceived workload between the day and night shift nurses, $U = 47.5$, $p = .970$. In sum, there was no difference in the overall perceived workload reported for either design.

Using an independent t-test showed no significant difference in the overall reported SUS scores between design 1 (M = 85, SD = 15.55) and 2 (M = 82.92, SD = 11.45), $t(8) = .246$, $p = .812$. Similarly, no significant difference in the overall reported SUS scores was identified between day shift (M = 79.17, SD = 13.29) and night shift (M = 90.63, SD = 8) nurses, $t(8) = -1.531$, $p = .164$.

9.3.2 Qualitative analysis

Overall, participants characterized PANI (design 1; experimental group) as a very useful tool for ICU rounding and overall clinical workflow. PANI's functionality that enables the creation and assignment of action-items among team members was positively noted. Positive concurrence was also mentioned regarding PANI's ability to notify members after receiving the results of a medical intervention:

> "I really like how I can assign an action-item to a nurse and notify her that it is important; along with hearing back from her before she/he leaves for the day. That way, I don't have to go looking for her/him in person or make a phone call." – R1.

> "With the current setup, I have to click through several screens on a computer at the nursing station for me to know what task was assigned to me. The orders are not arranged by patient details. As a result, I have to go through an entire list to find my patient and then go look at the corresponding order. Also, this device or application makes it so easy for me to notify the doctor when the results are ready. This is pretty cool." – N1.

The feature to setup personal reminder alerts as tactile "silent alarms" using FitBit was perceived as very useful. Directing attention when important or urgent information was communicated was also well received.

> "It is so much easier for me to setup an alarm using the digital application of PANI. Because I can forget about trying to remember, I can focus on other things. I like how the FitBit vibrates and I see a visual display on my phone. I think I should be able to recollect why I set this alarm even if my phone is in my pocket – and I don't necessarily need to look at it when the FitBit starts vibrating. Also, since there is no sound, I don't think I will be disturbing others around me." – R3.

> "I like how PANI does not depend on the vibrations of the phone. I can see myself putting my phone in my pocket. That is, sometimes I never notice if my phone is vibrating. This would usually mean I missed an important message or phone call. I prefer the first design I tested over the second one" – R5.

The color-coded notification feature (displaying information with action-item updates and results from the EMR as a completed action-item) was perceived as very useful:

> "The application is intuitive in letting me know that something colored red is urgent, orange, maybe normal, and yellow is of low priority. One of the designs, which used FitBit, was very interesting; when FitBit buzzes I know I have received something urgent. I can determine when the nurse completed a high priority action-item when I see the notification. For example, as with this session, I can detach my phone from the clipboard

and actually clip it to the top of my workstation when I am busy using the EMR. It is really nice that I can see a link to the radiology image of the patient. I see this feature helping me share the image with the family members next time I visit the patient." – R4

Finally, participants proposed the need for a corresponding desktop version of the mobile application. Participants suggested that they would prefer to begin a note or action-item on their mobile device as a placeholder, which can later be resumed using their workstation. They argued that the short notes that they create using PANI can be edited with ease, which they believed would reduce cognitive effort as well as serve as an external memory aid. Participants preferred retaining sheets of paper on the clipboard as opposed to having a stylus input on the phone to allow for quick note-making, especially during a phone conversation. However, they suggested having audio input to call out quick notes at instances other than during a phone conversation. They also preferred carrying rounding sheets with patient details for quick hands-on information, as opposed to having a digital tool that helped them navigate multiple screens to find the patient data of interest during rounding.

9.4 Discussion

Findings from Study 1 were used to ideate PANI's task management functionality. Study 1 proposed PANI as a clinical tool that integrates several components in one system to support the management of notes, action-items, and patient information. These components include (i) a mobile application, (ii) paper-based artifacts, and (iii) a wearable device (such as FitBit). Consequently, the initial ideation of

PANI comprised three components: (i) an easy-to-carry clipboard that fits in a doctor's pocket, allowing traditional paper sheets to be attached for facilitating quick note-taking, (2) the mobile device application that is accessed from a detatchable smartphone clipped to the clipboard, and (3) a wearable device, such as FitBit configured and paired with the mobile application to provide tactile "silent" notifications for personal reminder alerts. The components of PANI were envisioned to be detached and used separately or used together as a whole to integrate into the existing ICU workflow.

Based on the findings from the studies 2a, 2b, and 2c, I added a communication module to work together with PANI's task management functionality. This was done based on the understanding that patient-situation awareness is maintained in the ICU using both communication and task management work practices. Consequently, the mobile device application was refined to include stand-alone asynchronous communication or action-item dissemination as text messages, and FitBit was re-envisioned to include the delivery of tactile feedback while communicating urgent patient information. Following the design of PANI, a formal participatory design study (Study 2d) was conducted involving semi-structured interviews and discussions on its perceived usefulness and feasibility in ICU workflow.

The primary goal of PANI is to explore the inclusion of an ICU tool that combines different modalities: paper, digital functionality (for mobile and desktop use), and a wearable device. This includes an attempt to contextually situate everyone with respect to the progress of the patient. The form factor of PANI includes a module-based structure in which the paper and mobile digital artifacts can be assembled together or used separately. Thus, PANI is capable of providing affordances such as flexibility, portability, and accessibility, similar to paper-based artifacts by themselves (Harper et al., 1997). Findings from Study 2d identified ICU healthcare providers concurred on the concept of PANI as a tool that helps break down their original note-making practice based on the module of interest. For instance, healthcare providers can create and disseminate quick action-items with the team using the mobile application. They can continue to use paper-based artifacts for scribbling quick and immediate notes based on the urgency of the situation. Further, ICU healthcare providers can take advantage of a FitBit device to set up personal alerts (reminding them at appropriate times to perform an activity) or share urgent patient information.

9.5 Summary

This chapter discussed the process I followed to design and evaluate the task management with added communication functionalities (learned from Chapter 8) for PANI. This chapter concludes the description and discussion of Study 2.

Study 1 proposed a novel, mobile clinical tool named PANI (Patient-centered notes and information manager). The design recommendations derived in Study 1 were used to ideate the task management and communication functionalities of PANI. Study 2 included the design and evaluation of a novel, mobile task management and communication tool that can be used to enhance patient-situation awareness in the ICU. Studies 2a, 2b, and 2c were used to refine and evaluate the design for the communication functionality of PANI. Findings from these studies identified a novel patient-centric notification to support ICU communication with minimal interruptions to ongoing work. Study 2d evaluated the feasibility of PANI (in a controlled, simulated environment) in enhancing patient-situation awareness by combining task management with the novel patient-centric.

The next chapter brings together the findings from Study 1 and Study 2 and highlights how the Locales Framework afforded both understanding the situated nature of ICU work and designing a novel system to overcome some of the breakdowns and barriers for ICU healthcare providers maintaining patient-situation awareness.

Chapter 10. Conclusions and Future work

Prior research has identified healthcare providers' patient-situation awareness as critical to understanding and contributing to medical work (Green et al., 2016). Maintaining patient-situation awareness has been identified to include several supporting activities, such as information gathering, sharing, and interpretation of patients' condition over time (Nemeth, 2008; Endsley et al., 2003; Reader et al., 2009; Reddy et al., 2003). There is, however, little understanding of team members' practices in managing interruptions while seeking and sharing patient-centered information through collaboration and communication.

To examine this phenomenon, I conducted a field study in the medical intensive care unit of a major hospital. Chapters 5 and 6 described how medical work in the ICU shapes and influences the daily activities of physicians, nurses, and pharmacists—especially in terms of how they manage and support their work through communication and collaboration. Applying the different aspects of the Locales Framework focused my attention on note-making and technology-mediated communication at both individual and collective levels. Study 1 concluded that, while note-making helped collaborate and coordinate tasks at an individual level, it increased the tendency of healthcare providers to maintain patient-situation awareness at a collective level through technology-mediated interruptions (such as phone calls). To overcome this significant challenge of technology-mediated interruptions, I envisioned a tool named PANI. Chapters 7-9 described the process I adapted to co-design and evaluate PANI with the help of ICU healthcare providers. In this concluding chapter, I will close my dissertation by briefly recapping my major contributions and discussing future research work.

10.1 Study limitations

As with all research, this research had its limitations. My dissertation research focused heavily on healthcare providers, and hence involved observations and design suggestions without involving direct input from patients or family members (although the patient is at the core of the clinical workflow identified in my work). As I did not obtain formal ethical clearance to observe patients or their family members, the observation in Study 1 was limited to hallways, nursing stations, and conference rooms in the medical ICU. This also limited observation in other locations, e.g. the emergency room (ER), trauma/burn unit, operation theatre, and other places where transitions of care take place. Hence, there was often a break in the sequence of observational notes. I conducted ad hoc opportunistic interviews to fill in gaps, asking healthcare providers to recollect actions outside the ICU.

I acknowledge that the ICU practices at the study site can differ from other ICUs. The study site, however, is one of the leading health care providers in the Midwest US. I expect the findings reported in this dissertation to be representative of a typical ICU environment. Future studies at multiple ICU settings will enable wider generalizability of findings for ICUs.

Study 2 included only a subset of patient information, cognitive, and environmental situations. For example, I chose not to vary the time of the day or relationship between the interrupter and patient, aiming to gain more experimental control. Further, I chose specific options based on the understanding that they can be implemented in the ICU using existing technologies. For instance, the patient initials, room number, and vital signs can be automatically populated if the device is paired with the EMR; leaving the sender to only type in the actual message and choose the importance of the message with respect to his/her understanding of the patient's current condition. Another limitation is that Study 2 was laboratory-based. Consequently, how providers respond in a real-world setting can be affected by a variety of factors that we may be unaware of.

10.2 Study contributions

During a six-month period, I examined the work practices of healthcare providers such as nurses, physicians, and pharmacists in a highly collaborative and extremely busy ICU environment. Prior work in the ICU has focused on understanding collaborative information seeking and sharing while maintaining contextual awareness (Reddy et al., 2001). Prior work has also discussed the task- and goal-based approach to providing patient care (Green et al., 2016; Nemeth, 2008; Endsley et al., 2003;). However, as my fieldwork attests, ICU patients' condition are dynamically changing, and healthcare providers must constantly generate and maintain a shared understanding of patients' conditions to support both their individual and the overall teams' tasks or goals. Prior work has identified that healthcare providers often make notes on paper to support their tasks or goals (Chen, 2010). My fieldwork shows that, in addition to externalizing perceptions of patients' conditions, healthcare providers also make notes to support the completion of their tasks/goals. Although notes help externalize thoughts and offload cognitive effort, they increase the need for healthcare providers to communicate or share information, either face-face or with the help of technology tools such as phones, pagers, email, etc. My fieldwork also helped identify that, while communication increased the shared understanding of the care team members, it also led to increased waiting time involved with reaching out to a team member or disrupting a team member's ongoing activity with an unwanted interruption.

In chapter 1, I set out to answer two questions:

- What are the task management (in the context of paper note-making), dissemination and communication practices followed by healthcare providers to keep themselves up-to-date on dynamically changing patients' conditions?
- Can we overcome the pain-points in the identified task management and communication practices through design?

In the following section, I answer these two questions and describe my major contributions:

Expanding our understanding of the current task management and communication practices and the corresponding pain-points in generating and maintaining patient-situation awareness.

Team members must often re-align and re-orient their knowledge about the patient, tasks, and goals throughout the day in addition to general rounding practices every morning and evening. Consequently, the need for timely communication of patient information often results in team members interrupting and being interrupted more frequently.

Enhancing technology-mediated communication with the inclusion of patient-specific information as an additional context that both improves the shared understanding of the team members and supports the existing clinical workflow.

In general, providers use technology tools (such as mobile phones or pagers) to rapidly communicate information when they are not physically co-located. The information shared between providers include: lab/radiology results, patient's response to medication, procedure completion and corresponding patient's condition, and follow-up/consult with a specialist. Providers often seek and share additional patient-specific information that helps improve their shared understanding and decide on a next plan of action. For instance, providers often share patient's vital signs while interpreting and deciding on next steps.

10.2.1 Broader perspective on ICU clinical work in the context of paper note-making, patient goals, and clinical task dissemination and other communication practices that improve patient-situation awareness of healthcare providers

What are the task management (in the context of paper note-making), dissemination, and communication practices healthcare providers follow to keep themselves up-to-date on dynamically changing patients' conditions?

Healthcare providers often make notes to distribute/externalize patient information and offload cognitive effort required in remembering information. The process of creating note artifacts helps healthcare providers to think clear and ask/discuss with other team members. Providers often annotate their notes as the day progresses. Although some select information on the notes is verbally discussed, the written notes as such are not shared artifacts. The notes often co-exist in the artifact ecology already present in the ICU; that is, information from the notes is often transcribed to and from electronic and human information sources.

Findings from my fieldwork (Study 1) were unpacked by understanding the ICU environment as a social world comprised of a group of providers who use some means to communicate patient information, which is similar to the idea behind the Locales

Framework. That is, I viewed the situated nature of ICU work using the idea of dynamic social worlds, which helped me focus on the interaction or technology-mediated information exchange at hand. I chose to adapt the Locales Framework, since it is concerned with the principled design of CSCW systems, where the framework helps provide a coherent image of system requirements and informs their construction. Further, the Locales Framework has been validated in the past to understand existing collaborative work practices, and to motivate the design of new systems (Greenberg et al., 2000; Kaplan & Fitzpatrick, 1997; Scott & Alan, 2003).

The Locales Framework helped me understand and derive design guidelines to help overcome pain-points in technology-mediated communication with minimal interruptions. Although there are existing studies investigating interruptions in medical work and proposing technology interventions, there is a lack of design guidelines specific to the ICU environment. My dissertation proposed a set of design guidelines for effectively managing notification interruptions in the ICU, motivated through cognitive theories, models relating to attention and memory, and human factors principles for different modalities of notifications.

10.2.2 Designing to mediate task management and communication, in turn improving patient-situation awareness, with minimal interruptions to work

Can we overcome the pain-points in the identified task management and communication practices through design?

For the second part of my dissertation, I adapted the guidelines derived in Study 1 to design and evaluate a novel messaging application. Study 2 involved a co-design process, in which ICU providers and UX designers collaborated with me in adapting the guidelines to design a novel mobile application named PANI. This co-design process resulted in participants suggesting visual and tactile cues as means to support communication through asynchronous messages.

PANI was designed to include the lean Kanban approach from Toyota.[4] That is, ICU providers were envisioned to seek the right amount of information specific to their tasks or goals at the right time. PANI was designed to involve task management and communication through technology-mediated notifications (TMNs). Focus group and design sessions highlighted the importance of the patient-specific information involved in any communication between providers. Hence, the design process involved creating novel TMNs, such as patient-enhanced notifications, which contained additional information directly and indirectly obtained from the patient, along with the primary message. PANI's patient-enhanced notification comprised of: (i) visual cues delivered through color-coded "**previews"** on a mobile device screen; and (ii) tactile cues delivered through a wearable device; both indicating the content and urgency of communicated message. The co-design process concluded that the presence of visual and tactile cues may improve the receiver's understanding and awareness of the patient, eventually contributing to rapid decision-making about responding to the text message notifications.

Study 2 also comprised of user evaluations and interview sessions, which helped ascertain that patient vital signs, coupled with the text message, assisted receiving ICU providers in deciding when to respond to the TMN. Providers reported feeling less interrupted when receiving PANI's messages as compared with pager alert or phone calls, because visual and tactile cues helped providers perform cost-benefit evaluation for interrupting their ongoing activity to respond to the message.

[4] https://leankit.com/learn/kanban/what-is-kanban/

- As opposed to a callback number or callerID, PANI's visual cues, coupled with the message, helped direct their attention to the most relevant information. The visual message informed them about the patient's condition, in addition to, for instance, the patient's lab result.
- As opposed to a sound alert from pager or phone, tactile cues as silent vibrations from a wearable device, coupled with the delivery of a visual message, helped direct their attention to the message at the right time. Providers reported feeling less urgent or anxious in responding to a vibration that occurred momentarily and stopped after 5 seconds, as opposed to an alert that induced disturbance to the physical and social surroundings.

These contributions also pave the way for future research that needs to be done if we are to fully understand and design support for task management and communication with minimal interruptions in the ICU.

10.3 Future work

Healthcare providers organize their understanding of patients' conditions by not only talking with patients or their family members, but also by seeking and sharing patient information with the rest of the care team. The patient care team meets every morning to hand off information, ensuring they achieve shared patient-situation awareness. Rounding also helps the team devise and disseminate tasks and goals for all the members. Providers often support their workflow by generating personal, paper-based artifacts, such as paper notes. However, the patient's condition is dynamic and constantly changes during the day. Further, healthcare providers do not limit their activities specific to only their assigned patients. Hence, the personal paper notes and a team member's individual understanding of the patient's condition also change during the day. Providers often attempt to share dynamically changing patient-situation awareness through practices involving face-face or technology-mediated communication. This dissertation focused primarily on technology-mediated communication owing to the mobile nature of medical work, in which providers cannot always be physically co-present. Although communications through mobile phones help providers stay informed, they induce unwanted interruptions. This dissertation involved a design process comprising of focus group and user evaluation sessions, with ICU providers acting as co-designers of novel communication messages with visual and tactile cues. Although this dissertation has expanded our understanding and designed a solution to address the pain-points in maintaining patient-situation awareness, there is still much work to do.

The ICU is a busy and information-intensive environment, where providers have limited cognitive abilities and time. Human errors resulting in increased patient mortality in the ICU have been well documented, uncovering the need for technology tools that augment or support the limited computational abilities of ICU providers. Hence, there is a need to provide the right amount of information at the right time to help maintain shared patient-situation awareness among all the patient care team members. ICU providers are exceptional at providing patient care and learning from experience. While communicating about a specific lab result at the right time is useful, there is a need for a smart system that also communicates relevant information that can augment or support provider's understanding and decision-making process. For instance, a patient's lab result may be communicated along with current vital signs, the primary prognosis, or even a predictive model of what could be done next. Thus, similar to Reddy's (2004) cognition amplifiers and guardian angels, there is a need for an agent that:

- Anticipates what the provider wants to do
- Supports performing the activity with less effort, and
- Discovers and warns the provider about unanticipated, and possibly catastrophic, events that could impact patient safety

There is also a need to understand the difference between conversations focused on a single topic as opposed to conversations on multiple topics. For instance, a phone call may involve communication of multiple topics relevant to the same patient. Although the visual and tactile cues in PANI's messages help a receiving provider rapidly perceive and determine when to respond to a communication attempt, there is a need to support conversation of multiple topics.

To develop such systems, we need to further investigate ways to incorporate deep learning algorithms coupled with human intelligence into PANI's design.

10.4 Concluding Remarks

In this dissertation, I demonstrated that healthcare providers generate new paper-based artifacts that are used in conjunction with the ICU's existing artifact ecosystem to support clinical workflow. Providers verbally share only select, modified information from the paper notes, and annotate the notes as the patients' condition changes. Providers often communicate with one another using technology to improve their shared understanding of the patients' recovery process, in turn interrupting one another as they re-align and re-orient their knowledge. My work involved deriving design guidelines for a technology solution that will minimize interruptions and improve providers' patient-situation awareness with the right information at the right time.

The derived guidelines were then adapted for designing a technology solution named PANI. PANI's design evolved through a collaborative process with ICU providers and UX designers. Design implications for PANI were derived from user evaluation sessions in a simulated environment. The findings reported in this dissertation emerged from fieldwork, were empirically grounded, and were supported through theoretical frameworks. This work is an initial set of steps to better understanding and designing to overcome healthcare providers' pain points while maintaining patient-situation awareness in the ICU.

Appendix

Table A.1. Summary of key differences between both the design versions

Design Feature	Design 1	Design 2
Navigation and layout	• Faceted navigation of action-items list based on patient and clinician	• Emphasizes content over navigation. Provides relevant content for action-items list
Visibility	• Provides a visual bread crumb path • Provides visibility of priority and notification option settings	• Provides only the information of the last person modifying an action-item • No visibility of the priority and notification option settings
Affordances	• Offers natural signals and symbolic communication	• Uses the same labels as in design 1, but different icons
Feedback	• A new action-item is added to the corresponding facet. • Action-item dissemination and communication through text messages • Forwarding/assigning updates • A completed action-item remains in the list. A link to the result is attached to the completed action-item.	• A new action-item is added at the top of the list. • Does not include communication through text messages • Forwarding/assigning an action-item adds the visual information of the person who last modified the action-item. • Completed action-item is removed from the list.

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CURRICULUM VITAE

Preethi Srinivas

EDUCATION

PhD in Human-Computer Interaction, March 2017
Department of Human-Centered Computing, School of Informatics and Computing (SoIC), Indiana University, Indianapolis, IN

MS in Computer Science, July 2010
College of Engineering and Computing, Department of Computer Science Software Engineering, Miami University, Oxford, OH

BTech in Information Technology, July 2008
Jeppiaar Engineering College, Department of Information Technology, Anna University, Madras (Chennai), India

PUBLICATIONS AND PRESENTATIONS

Peer-Reviewed Journal Article

Srinivas, P., Cornet, V., & Holden, R. (2016). Human factors analysis, design, and evaluation of Engage, a consumer health IT application for geriatric heart failure self-care. *International Journal of Human–Computer Interaction*.

MacDorman, K. F., **Srinivas, P.**, & Patel, H. (2013). The uncanny valley does not interfere with level 1 visual perspective taking. Computers in Human Behavior, 29(4), 1671-1685.

Peer-Reviewed Conference Papers

Srinivas, P., Reddy, M., and Faiola, A. (2016). Better managing technology-mediated interruptions in the ICU: Examining the role of patient information for improving text message notifications, *American Medical Informatics Association, Annual Symposium,* November 12-16, 2016 (nominated for AMIA Distinguished Paper Award).

Srinivas, P., Faiola, A. and Mark, G. (2016). Designing guidelines for mobile health technology: Tools for managing notification interruptions in the ICU. *Proceedings of the SIGCHI conference, San Jose, USA, May 7-12 2016.*

Faiola, A., **Srinivas, P.**, and Duke, J. (2015). Supporting clinical cognition: a human-centered approach to a novel ICU information visualization dashboard, *American Medical Informatics Association, Annual Symposium*, November 14, 2015.

Srinivas, P., Faiola, A., & Khan, B. (2015). Supporting Information Management in ICU Rounding: A Novel Mobile System for Managing Patient-Centered Notes and Action-Items, *IEEE 17th International Conference on e-Health Networking, Applications and Services*, October 14, 2015.

Faiola, A., **Srinivas, P.**, & Doebbeling, B. (2015). A Ubiquitous Situation-Aware Data Visualization Dashboard to Reduce ICU Clinician Cognitive Load, *IEEE 17th International Conference on e-Health Networking, Applications and Services*, October 14, 2015.

Tunnell, H.D., Faiola, A., Haggstorm, D.A., & **Srinivas, P.** (2015). Clinicians as secondary users of patient-centered mobile technology in complex healthcare settings (HealthCom'15), *IEEE 17th International Conference on e-Health Networking, Applications and Services*, October 14, 2015.

Faiola, A., **Srinivas, P.** & Hillier, S. (2015). Improving patient safety: Integrating data visualization and communication into ICU workflow to reduce cognitive load. In *Human Factors and Ergonomics in Health Care'15*, Extended Abstracts on Improving Outcomes.

Faiola, A. and **Srinivas, P.** (2014). Extreme mediation: observing mental and physical health in everyday life. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing*: Adjunct Publication, pp. 47-50. ACM.

Srinivas, P., Haidan H., Pirzadeh A., Bolchini D. (2011). Clever Shopper: Supporting in-store decision making, *Pervasive Computing,* 2011, San Francisco, USA.

Archived Peer-Reviewed Workshop Papers

Srinivas, P., Bodke, K., Clark, D. (accepted). Deliver-UCD: Use of participatory and user-centered design to explore designing for older adults. In CHI'17 *Workshop on Designing Mobile Interactions for the Ageing Populations*.

Srinivas, P. and Faiola, A. (2014). Modeling daily rounds to support efficient task management in ICU workflow. In *Workshop on Interactive Systems in Healthcare*. AMIA.

Faiola, A., **Srinivas, P.**, and Karanam, Y. (2014) A novel approach to ICU data visualization and communication integration. In *Workshop on Interactive Systems in Healthcare*. AMIA.

Faiola, A., **Srinivas, P.**, Karanam, Y., Chartash, D., and Doebbeling, B. (2014). VizCom: A Novel Workflow Model for ICU Clinical Decision Support. In *CHI '14 Extended Abstracts*: Work-in-Progress, Toronto, Canada, April 2014. ACM Press, New York, NY.

Frikken, K., **Srinivas, P.** (2009). Key allocation schemes for private social networks, In *ACM Workshop on Privacy in the Electronic Society*. 978-1-60558-783-7/09/11.

Poster Presentations

Faiola, A. & **Srinivas, P.** (2015). Improving patient safety: Integrating data visualization and communication into ICU workflow to reduce cognitive load. In *Human Factors and Ergonomics in Health Care'15*, Extended Abstracts on Improving Outcomes.

Srinivas, P., & Faiola, A. (April 11, 2014). Smartphone dependency and consciousness: Observing flow in the everyday life. *Indiana University and Purdue University at Indianapolis (IUPUI) Research Day*.

Finch, R. J., **Srinivas, P.**, Karanam, Y., Koval, O., & Faiola, A. (April 11, 2014). Augmenting consciousness through invasive technologies: How do cochlear implant patients engage activity in the world? *Indiana University and Purdue University at Indianapolis (IUPUI) Research Day*.

Faiola, A., **Srinivas, P.**, Karanam, Y., & Koval, O. (April 11, 2014). Reducing diagnostic error in the ICU: A novel approach to clinical workflow -- visualization-communication integration. *Indiana University and Purdue University at Indianapolis (IUPUI) Research Day*.

Srinivas, P. Uncanny valley and motor empathy: Identifying movement synchronization with humanlike characters, In *GHC* 2013, Minneapolis, USA.

Srinivas, P., Patel, H., & MacDorman, K. F. (April 26, 2013). Uncanny valley and motor empathy: Studying movement synchronization with humanlike characters. *Indiana University and Purdue University at Indianapolis (IUPUI) Research Day*.

Srinivas, P., Patel, H., & MacDorman, K. F. (April 13, 2012). Uncanny valley and empathy: A study of the effects of human likeness and eeriness on empathetic associations during an image categorization task. *Indiana University and Purdue University at Indianapolis (IUPUI) Research Day*.

Srinivas, P., Patel, H., Ho, C.-C., & MacDorman, K. F. (April 8, 2011.) An uncanny valley of visual perspective taking: A study of the effect of character human likeness and eeriness on altercentric intrusions during a dot counting task. *Indiana University and Purdue University at Indianapolis (IUPUI) Research Day*.

Invited/Juried Presentation

Srinivas, P. (2017). When a phone call caused code blue. Invited to talk at the CHI'17 Stories Program.

Srinivas, P. & Jia, Y (2016). LookUp – Away from mobile for good. Invited to demo the mobile application at the final rounds of the 2016 Human Factors Ergonomics Society, San Diego.

Srinivas, P. (2015). Crit2Do - Mobile application to facilitate task management post the daily ICU rounds. Invited to demo the mobile application at the final rounds of the 2015 IIE Annual Conference in Nashville, Tennessee.

Srinivas, P. (2015). Modeling clinical workflow in daily ICU rounds to support task-based patient monitoring and care. Invited to Doctoral Consortium at CSCW'15, March 2015, Vancouver, Canada.

Faiola, A. & **Srinivas, P.** (2014). Reducing error in the intensive care unit: A novel approach to workflow modeling and distributed clinical intelligence. eHealth Initiative's Data & Analytics Council Webinar.

Srinivas, P. (2013). Measuring the effects of human likeness and eeriness on empathetic associations with a primed categorization task. In *CHI'13 Extended Abstracts on Human Factors in Computing Systems* (pp. 2761-2766). ACM.

Non-Archived Paper
Faiola, A., **Srinivas, P.**, Finch, R., & Wu, Z. (2014). Symbiont Consciousness: Sociocultural Embodied Augmentation of Humanity. *PhilPapers*.

HONORS AND AWARDS

Regenstrief Innovation Challenge (2017)
Received funding for my research proposal suggesting the design of behavioral interventions involving the use of everyday household materials and conductive circuits.

Runner Up, Dieter W. Jahns Student Practitioner Award (2016)
Awarded Certificate of Appreciation by Foundation for Professional Ergonomics for my work in understanding and designing communication with minimal interruptions in hospital intensive care unit.

Scholarship to attend the 4th Heidelberg Laureate Forum (2016)
I was one of the 200 invited young scientists to attend and present a poster on my research at the Heidelberg Laureate Forum. The award included coverage for travel, stay, and food.

First place, Mobile Health Applications for Consumers Design Competition (2016)
For an innovative mobile health application facing consumers at the 2016 International Symposium on Human Factors in and Ergonomics in Health Care

First place, JagStart IUPUI Student Idea Pitch competition (2016)
For innovative mobile solution for a social challenge

ACM Upsilon Pi Epsilon Scholarship (2016)
For excellence and professional commitment to the computing and information technology fields

First place, Mobile App Challenge (2015)
At the 2015 Annual Conference for Institute for Industrial Engineers, Computer and Information Systems Division

Elite 50 award (2015)
For achievement outside the classroom among 8,100 graduate and professional students

Doctoral Colloquium CSCW Award (2015)
Computer-Supported Cooperative Work and Social Computing (CSCW) 2015,
Funding for conference attendance, travel, and lodging

Graduate Student Assistantship (Full tuition scholarship, plus stipend)
Department of Human-Centered Computing, Indiana University School of Informatics and Computing – Indianapolis (2010 – 2015)

Conference Travel Award (2014)
Ubiquitous Computing / International Symposium on Wearable Computers (Ubicomp/ISWC) 2014, Seattle, WA

SOIC Conference Travel Award (2013)
Indiana University School of Informatics and Computing – Indianapolis (SOIC), to attend CHI 2013, Paris, France

Hayes Research Fund (2011)
Indiana University School of Informatics and Computing – Indianapolis

Graduate Student Assistantship (Full tuition scholarship, plus stipend) Miami University College of Engineering and Computing, Department of Computer Science, (2008 - 2010)

Medal of Honor, (2008)
Anna University, Jeppiaar Engineering College, Department of Information Technology
Ranked in top 30 students in the Department of Information Technology (of over 20,000 students from all colleges affiliated to the Anna University)

Gold Medal awarded for topping the class within the college for all the semesters cumulatively, (2008)
Jeppiar Engineering College, Department of Information Technology

Best Student of the Year, (2007)
Indian Society for Technical Education

SELECTED PROFESSIONAL EXPERIENCE

Senior User Experience Researcher/Designer (May 2016 – Present)
Regenstrief Institute, Indianapolis, USA

Graduate Technical Intern (Summer 2014)
Intel Corporation, Hillsboro, Oregon

User Experience Technology Intern (Spring 2008)
Microsoft Corporation, Bangalore, India

SELECTED TECHNICAL SKILLS

User Research	Prototyping & Design	Programming	Database	Web Technologies
User-centered design Ethnography (shadowing, observation) Interviewing and surveying Experience sampling Cognitive modeling	Axure RP Balsamiq Omnigraffle Moqup Gliffy JustInMind Vision Microsoft PowerPoint Adobe suite	C, C++ C#, Java ActionScript 3 Python Development environments: Visual Studio, Eclipse	MySQL Microsoft SQL Server Microsoft Access	HTML5 CSS Javascript jQuery XML, XSLT
Participatory design Focus groups	InVision Principle Sketch Marvel Origami Framer	Quantitative statistics: R, SPSS Qualitative tool: ATLAS.ti		

TEACHING

Teaching Assistant, Indiana University School of Informatics and Computing – Indianapolis (Summer 2015)
Course: INFO 270: Introduction to Human-Computer Interaction principles and practices
Topic: Fundamental principles and practices of human-computer interaction (HCI) and evaluation

Teaching Assistant, Indiana University School of Informatics and Computing – Indianapolis (Spring 2014, Spring 2015)
Course: INFO 501: Introduction to Informatics
Topic: Data management using mySQL and data analysis using R

Student Lecturer, Indiana University School of Informatics and Computing – Indianapolis (Spring 2014)

Course: INFO I308: Information Representation and Retrieval Topic: Relational database design, XML

Student Lecturer, Miami University Department of Computer Science (Spring 2010, Fall 2009, Spring 2009)
Course: CSA 148: Business Computing Topic: MS Excel, MS Access

MEMBERSHIPS

- Association for Computing Machinery (ACM)
- Institute for Electrical and Electronic Engineers (IEEE)
- American Medical Informatics Association (AMIA)
- Interaction Design Foundation (IDF)
- Golden Key International Honor Society
- Human Factors and Ergonomics Society (HFES)

PROFESSIONAL SERVICE

Committees

- President, Interaction Design Foundation, Indianapolis Chapter (2014 – present)
- Chair, ACM-W IUPUI Chapter (2015 – present)
- Vice Secretary, Women in Technology (WiT), IUPUI (2012)
- Department Representative, Graduate Student Association, Miami University (2009)
- Reviewer: Undergraduate Research Review Committee, Miami University (2009)
- Student Representative, Student Technical Advisory Committee (STAC), Miami University (2009)
- Developer, Benton Information Technology Services, Miami University (2009 – 2010)
- Microsoft Student Partner (2006 - 2008)
- Chief-Organizer, JET-VISTA, National Level Technical Symposium, Jeppiaar Engineering College, Anna University (2006)

Student Volunteer

- American Medical Informatics Association (2014)
- Ubicomp (2014)
- Pervasive Computing Conference (2011)

Peer Review

- CHI (2017) (peer-reviewed full papers and notes)
- CHI (2016) (peer-reviewed full papers and notes)
- Ubicomp (2015) (peer-reviewed demo and poster entries)
- AMIA (2015) (peer-reviewed full paper and panel entries)
- CHI (2015) (peer-reviewed full and short papers)
- Ubicomp (2014) (peer-reviewed poster entries)
- CHI (2013) (peer-reviewed work-in-progress submissions)
- IEEE International Conference on Development and Learning and on Epigenetic Robotics (2011, 2012) (peer-reviewed short papers)