A Mobile Voice Communication System in Medical Setting: Love it or Hate it?

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ABSTRACT

Hospital work coordination and collaboration often requires mobility for acquiring proper information and resources. In turn, the spatial distribution and the mobility of clinicians can curtail the opportunities for effective communications making collaboration difficult. In this situation, a mobile hands-free voice communication system, Vocera, was introduced to enhance communication. It supports quick and impromptu conversations among coworkers for work coordination and collaboration anytime and anywhere. We study this deployment and present our findings concerning the impact of this communication system on the information flow. Our information flow framework's communication strategies help contrast the information processes before and after the deployment of Vocera.

Author Keywords

Mobile, voice communication, Vocera, information flow, healthcare, observational study, communication strategy.

ACM Classification Keywords

H.m. Information Systems: Miscellaneous.

INTRODUCTION

A wealth of research has found that face-to-face communication facilitates collaborative work, e.g., [4,9,18]. However, given the increasing complexity of most hospitals, clinicians are often spatially separated, curtailing the opportunities for face-to-face communication. In fact, medical work is characterized by local mobility [3,4,10]. Clinicians often have to move around to access people and obtain information in order to have the resources necessary to carry out their work [3]. Gathering resources through clinician mobility entails substantial time cost, which can impact patient care delivery. Quick and frequent communication among clinicians is often needed for work coordination and collaboration in the time-critical hospital environment, motivating the adoption of mobile technology such as a PDA [11]. However, most handheld computers require two-hand manipulation such that the clinicians have to pause their task-at-hand during communications. Thus, a mobile communication device that allows clinicians to communicate with their collaborators while still being able to continue with their current task could greatly improve the quality of patient care.

This paper reports a study on the information flow in a local hospital ward as a result of the deployment of Vocera [17], which is a mobile voice communication system. This study is part of a longer-term research project aiming to investigate and to improve the communication and information flow as a means to facilitate patient care delivery. We start by motivating our study and outlining our framework for nurses' information flow as derived from our previous study [15]. Then, we describe our current study's findings in terms of our framework's communication strategies, and discuss some highlights and design implications.

BACKGROUND

The increasing specialization of modern medicine often entails multi-disciplinary collaboration when making a diagnosis and deciding on a treatment plan for a patient. This is because each specialty carries specific and often unique information relevant to a patient's illness. Therefore, healthcare practitioners must work together to seek, synthesize and disseminate information [13]. However, the distributed nature of medical setting makes the coordination necessary for collaborative work complex and difficult. Collaborators often have to locally move around to execute specific actions in order to accomplish work [3,4]. Thus, medical practitioners must deal with the continual challenge of achieving the right configuration of people, resources, knowledge for collaborative work. To achieve this, clinicians often have to spatially move in order to get in touch with their collaborators [3]. Thus mobile technology that provides a low-cost communication medium that dispersed collaborators can use to communicate frequently and spontaneously would be beneficial to support collaboration and coordination, and to reduce unnecessary mobility in medical work [3,9,10,11].

Previously, we conducted two field studies to investigate nursing communication on an acute medical teaching unit in a local hospital, paying particular attention to the time period during shift changes [15,16]. While shift change communication may occur in different formats, e.g., bed-side handover, much of the shift change communications in our study ward exhibited a high degree of active information seeking by incoming nurses. On arrival, incoming nurses had to move around to access a variety of distributed information sources to gather important medical information. They made use of and added to this information throughout their shift in preparation for the information dissemination at the end of their shift. Meanwhile, outgoing nurses continued providing patient care, interwoven with various communicative activities until the actual transfer of responsibility. Although our previous studies focused mainly on shift change communications, our observation sessions spanned across both regular shift work periods and shift changes. As such, we have become increasingly aware that nurses' shift change is only one crucial part of the continual information flow. We also found the communication strategies used for the information flow during shift changes and the totality of shift work highly similar. This motivated us to study how the deployment of Vocera impacted the communication and information flow. We expected nurses to take advantage of the hands-free system to receive updates from their outgoing coworkers without physically moving into face-to-face reporting as previously observed [15,16].

A FRAMEWORK FOR NURSES' INFORMATION FLOW
In this section, we outline our framework for nurses' information flow as developed from a previous study on shift change communications [15]. Its structure proved useful in analyzing the communication data from our current study. The framework consists of six components: information, personnel, artifacts, spatiality, temporality, and communication mode. These components are not stand-alone elements independently contributing to the information flow but are highly interrelated, exhibiting complex relationships. For example, the kind of information artifact used influences the timeliness with which information is communicated among clinicians.

The *information* is typically patient-specific and thus uniquely defined for each patient's illness trajectory. This information is important for planning nursing care for individual patients and for coordinating care plans for multiple patients. The *personnel* involved are particularly important when medical diagnosis and care information has not (yet) been fully documented, a common occurrence due to time pressure. Thus, clinicians are required to access different people in order to bring together the intellects and expertise that reside with individual clinicians. The *artifacts* are the physical devices that are used to communicate information for delivering nursing care. We study the roles of these artifacts in the information flow and how they hinder or facilitate their intended usage. The *spatiality*
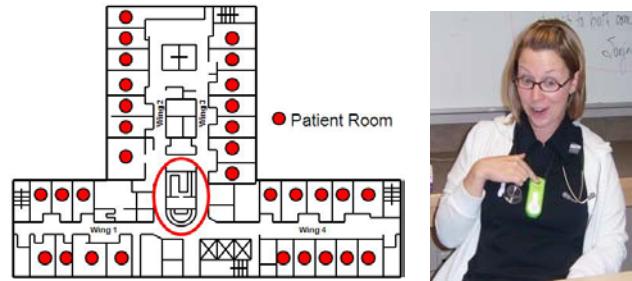
Figure 1. (Left) Ward layout, central nursing station as circled (Right) Pressing Vocera button to make a call

considers where communication takes place and how the locations hinder or facilitate information flow such as the mobility needed. We also look into the equipment setup in specific information centers for supporting information flow in similar ways described by Harrison and Dourish (1996). The *temporality* of information flow is the order and timeliness for accessing specific information sources and how this impacts the outcome of information flow, as well as the temporal patterns that may help locate collaborators [12]. Lastly, the *communication mode* is the style and media through which specific kinds of information are communicated. We also study if specific communication modes hinder or facilitate information flow. These six factors are useful in characterizing communication processes, but they are not exhaustive. Other factors like organizational mandate and social structure may also impact the communication process and should be considered. However, the six factors of our framework were particularly instrumental in our studies.

STUDYING THE DEPLOYMENT OF VOCERA
The research site is a 40-bed acute medical teaching unit in a local hospital. Patients admitted to this ward generally still require acute care as they are often transferred directly from ICU. However, the nurse-to-patient ratio ranges from 1:4 to 1:8 depending on work shifts as opposed to that in the ICU of 1:1 or 1:2. Thus, nurses working in this ward constantly face high stress and time pressure. Innovative research activities frequently take place on this ward so the nurses are generally open-minded towards technology. The ward consists of a centrally located nursing station and four radiating wings of patient rooms (Fig. 1, Left). Its layout makes it convenient to access information at the central information hub but difficult for nurses working in different wings to communicate and to maintain awareness.

Technology
The technology discussed in this paper is Vocera communication system [17]. It uses voice recognition and wearable communication badges running on a wifi network for making two-way conversations with coworkers using natural spoken commands. Vocera are compact, lightweight single button badges. They can be worn with a lanyard or clipped on a shirt collar. One must log on to the system. To place a call, one has to press the button and give a verbal

command to the automated operator (a.k.a. the genie) (Fig. 1, Right). The genie has to recognize the voice command, e.g., *"Call Mary"*, it then searches the database before connection is made for a two-way voice communication. No other physical manipulation is needed. Thus, once the voice link is established, the conversing parties can continue their task-at-hand. To terminate the connection, one party has to press the button. Vocera allows callers to leave a message, to broadcast to a specific group and to forward all the calls to a specific person. Also, built-in fun tunes will be played in response to specific commands, e.g., star-trek tunes played to "Beam me up!"

Method
Our study was conducted in the first week (first stage) and the fifth month (second stage) of Vocera's deployment. The first author conducted 8 and 12 observational sessions respectively, each lasted 2 to 4 hours. The observations took place during regular shift periods, shift changes, and meal breaks. Participants in the two stages were respectively 3/3 unit clerks, 9/7 nursing aids, 36/37 nurses, and 1/2 patient care managers (1 unit clerk, 4 nursing aids, 17 nurses, and 1 manager participated in both stages). Observations and interviews were used to find out how the participants used the system. Field notes were taken. The fact that this mobile voice communication system required minimal and subtle physical interactions from the participants made the field study complex and challenging as it was often unclear when they were communicating over Vocera. The distributed layout of the ward also made it difficult to observe two-way conversations. The first author primarily stayed around the central nursing station as many Vocera communications were initiated in response to incoming phone calls. With its central location, the researcher was then able to more easily locate the respondents who were often distributed in the ward wings. Because most conversations were brief, the contextual information was usually missing and could only be recollected from follow-up interviews with the participants. Thus, the data collection was based on observable events and subsequent informal interviews with the participants for the communication motives and details. The findings of the two stages are highly similar, with a few differences which are highlighted in the findings section.

We organized our findings using a fish-bone diagram [8] (Fig. 2), with the six factors of our framework contributing the structure. The fish-bone representation provided an overview visualization of Vocera deployment and helped to focus the analysis of the phenomena impacted by the framework factors (see the next section for more information). Color is used to facilitate reading, with negative or unexpected phenomena shown in darker backgrounds. The displayed data includes observed events and series of events showing causal relationships that are directly a result of Vocera deployment.

FINDINGS
From our observations, we identified many communication strategies, which resonate with some aspects of our framework. The six framework factors were all associated with a primary strategy for coordinating the communication on the ward as follows:

- Choosing appropriate *artifacts* for information flow;
- Choosing an appropriate *communication medium*;
- Identifying and locating *personnel* to communicate;
- Off-loading *information* to the intended recipient;
- Minimizing *spatial* movements;
- *Prioritizing* and *scheduling* activities.

Because of this association between our Vocera observations and the framework's communication strategies, we use the structure of the framework to report our findings. While our framework allows a thorough analysis by understanding the inter-relationship between the six factors, one drawback is that these inter-relations contain overlaps. However this helps ensure relevant phenomena were properly considered. To establish previous communication practices, we first describe the communications as occurring before deploying Vocera using the framework's communication strategies as the structure, and then we report the impact of Vocera technology on the information flow and communication strategies. This helps define the changes that arose with the use of Vocera.

Pre-Vocera Communication
Choosing appropriate artifacts for information flow
Communication artifacts available before Vocera was deployed were telephones and computers at the nursing station and along the ward wings, an intercom at the nursing station, and portable paper notes. Cell phone use was not allowed while on duty. Telephones in the ward could be used to make internal calls within the hospital and to the outside. Internal calls required only an extension code while all external calls required a prefix "9" followed by the phone number. The intercom allowed overhead broadcast of messages from the nursing station over the entire ward with the exception of patient rooms. This design was deliberate so as not to interfere with patients' rest. Patients could also communicate with the nursing station via the intercom from their room. An online text paging system was also available for contacting physicians.

Most communication from outside the ward came through telephones at the nursing station. When a phone call came in, a unit clerk would most likely use the intercom to broadcast for the attention of a specific clinician, if known, followed by the targeted clinician either calling the nursing station from his/her ward wing or spatially moving into face-to-face interaction at the nursing station. Personal paper notes were also pervasively used as an intermediary notepad by all the nurses and unit clerks in the course of their work for recording information (e.g., a patient's pain level) that needed to be relayed to specific clinicians or to
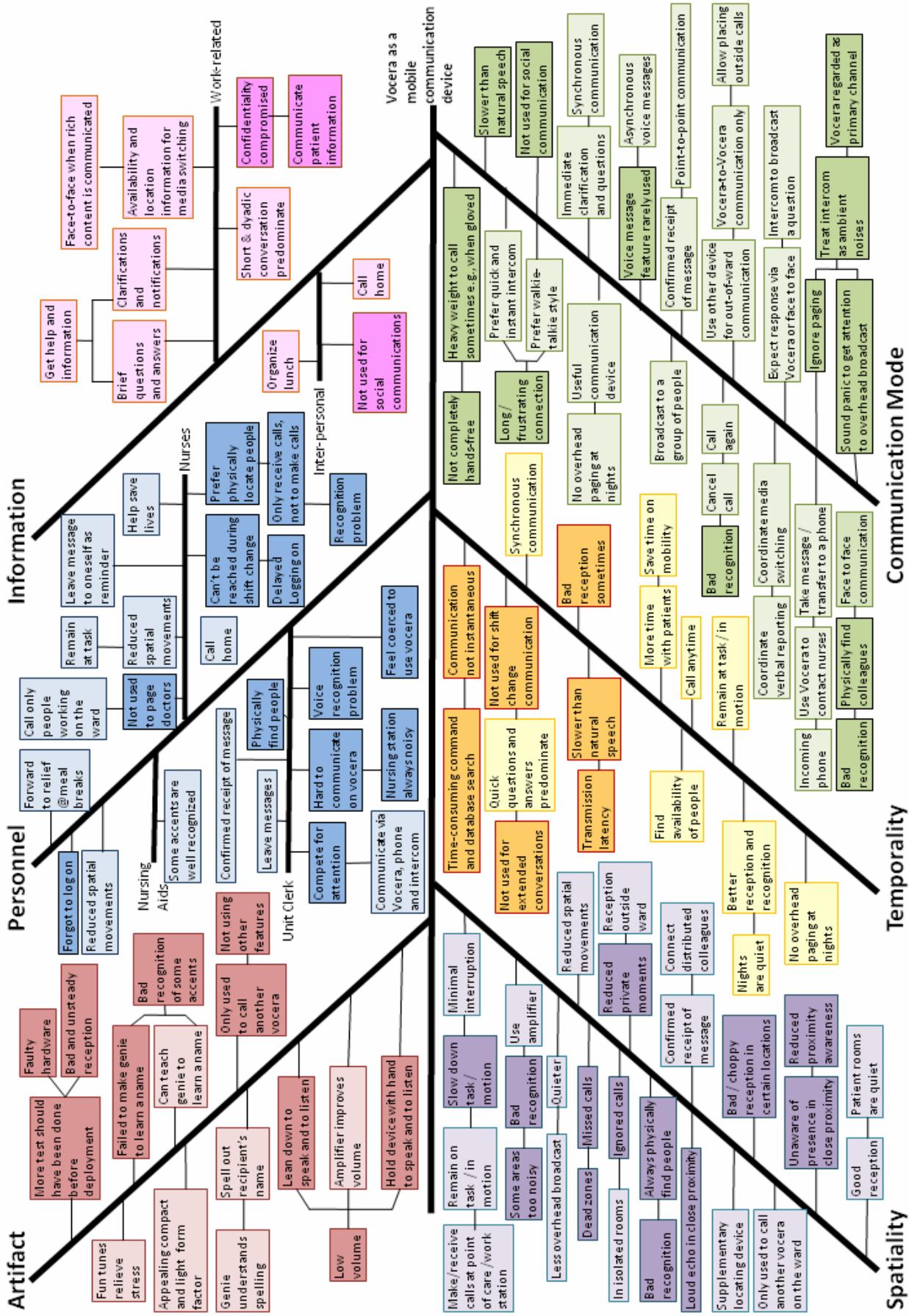
Figure 2: A fish bone diagram used for visualizing and analyzing the findings of the Vocera deployment (Negative or unexpected phenomena in darker backgrounds)

be documented later, and required communicative events, e.g., appointment scheduling.

Choosing an appropriate communication medium

Face-to face interactions, point-to-point closed telephone links, one-way broadcast over the intercom, and digital paging through texts for physicians were available in the ward. Unfortunately, the most effective face-to-face communication is not always possible due to the distributed nature of medical work. But telephone communication still allows collaborators to synchronously clarify, elaborate, and confirm information. With its point-to-point closed connection, a telephone is considered an appropriate medium to communicate private patient information. However, as nurses were always on their feet, they were mostly unavailable to converse over the phone. Therefore, broadcasting through the intercom provided convenience to initiate connection with clinicians. However, because of its lack of a feedback channel, clinicians could only respond through another medium, typically through telephone or by spatially moving into face-to-face communication. The effectiveness of this broadcast medium was also limited by the presence of "dead zones" inside patient rooms. Therefore the only way to ascertain proper receipt of the broadcast communication was to receive feedback from the intended recipient via another medium. Broadcasts were also interruptive to clinicians who were not the intended recipients as they would naturally slow down their task-at-hand to pay attention to the broadcast and only resume to normal pace after they realized that they were not the intended recipient. Such an interruptive work environment could impede one's work flow. The public nature of intercom broadcast also limits the kind of information that can be communicated. If the information would jeopardize a patient's privacy, the broadcast can only be an invitation for relevant clinician, leaving communication of the content for a more appropriate medium.

Nevertheless, the value of overhead broadcast was evident in emergency situations to coordinate rescue operations. When a patient became critically ill, the primary care nurse would immediately press the "Coding" button available in every patient room. In response, the hospital would issue a hospital-wide broadcast, "Code Blue, Unit 38." The Code Blue [Resuscitation] Team would then hear the broadcast and rush to the specific ward immediately.

Identifying and locating personnel to communicate

Multi-disciplinary collaboration is prevalent in modern medicine. Thus, the nursing station plays a crucial role as all incoming communications are first received there. The following vignette illustrates how incoming calls are typically handled.

Jane, the unit clerk on duty, received a phone call from the radiology department looking for the primary care nurse for the patient in room 3840. Jane looked up the large assignment board across the nursing station and identified that it was Carrie. She then put the phone call on hold, picked up the intercom receiver and made a broadcast with

a directed message, "Carrie, radiology is on the phone for 40 [room 3840]". Carrie was in her ward wing so she picked up the phone there to call Jane, "Can you transfer it to B [ward wing B]? She then hung up. The phone in the ward wing then rang. Carrie picked it up and talked to the radiologist. [However if Carrie was inside a patient room at the time, she would have missed the broadcast. Without getting a response from Carrie, Jane would either make another broadcast (same broadcast or to ask other people to relay the message) or to find Carrie herself.]

Sometimes, the unit clerk might not know right away who the phone call was for. For instance, a physician called, *"Someone paged me?"* Jane would then simply make an undirected broadcast to identify the concerned clinician, *"Who paged Dr. Smith? She's on the phone."*

As medical work is highly collaborative, nurses often require assistance from their colleagues in the ward. This type of connecting with colleagues is frequent. *"Carrie needed help, but she did not see any colleagues nearby. So she would either call or go to the nursing station to ask Jane to broadcast for assistance on her behalf. Alternatively Carrie could go to find her colleagues in person. But this usually took longer time and more effort."* Thus, to identify and to locate collaborators often required the use of multiple communication channels or spatial movements with the existing technologies.

Off-loading information to intended recipient

The centrally located nursing station serves as the reception desk and the information hub of the ward. The "gatekeeper" function, discharged by unit clerks, plays an important role to ensure communication is properly received and routed so that patient care is carried out efficiently. For example, the unit clerk receiving a phone call from the pharmacy regarding a patient's newly prescribed medication may take the message and then relay it to the primary care nurse, or broadcast for the primary care nurse to ask for routing directions. Such information off-loading is a common and frequent practice in the flow of information.

Although each nurse was assigned with a specific number of patients in each shift, nurses at the ward are highly collaborative. We observed many instances where a nurse noticed another nurse's patient needing assistance or attention. S/he would then go to find the colleague to relay the information. In situations where the nurse was too busy at the time, she would make use of technologies, e.g., to phone the nursing station to off-load the information.

Minimizing spatial movements

Technology-mediated communications are widely used to connect distributed collaborators without spatial movement. Broadcasts on the intercom allow simultaneous communication to a large audience, thus reducing the need to spatially move to look for intended recipient(s) of information. Responses could also be made through telephone although sometimes face-to-face communication was necessary. However, when no response was received

for the broadcast, mobility was likely required to physically look for the intended recipient, which would be more costly in time and effort.

Though nurses often need to move around to look for information and resources, when possible they found work-arounds to reduce their mobility. When the situation was not time critical, they would postpone their information seeking and dissemination activities until several demands made the trip worthwhile. Such poly-motivated mobility practice [1] can considerably save nurses' time. The use of paper notes as a reminder helped facilitate this practice of grouping tasks which is indeed an integral part of organized and efficient nursing practice.

Prioritizing and scheduling activities
Nursing care involves many planned as well as spontaneous activities relevant to multiple patients' diagnosis, treatment, and nursing. These activities include actual care procedures and communication events that must be temporally coordinated, synchronized, and prioritized. Fluctuations in a patient's illness require nurses to dynamically change their care plan activities, which in turn must also be communicated to relevant clinicians who would then have to adjust their work plan. Intercom broadcasts and face-to-face communication were frequently used to coordinate clinicians working on the ward whereas off-ward clinicians were typically contacted through telephones.

Communication with Vocera system
Vocera system was deployed among unit clerks, nursing staff, and a small number of off-site clinicians. For brevity, we use *members* to refer to the people in this Vocera community. As the majority of communications within the ward occurred between the nurses, unit clerks, and nursing aids, our study focused on their communication practices. In fact, we found communications on Vocera system only took place between members working on the ward as they were unaware which off-site clinicians were also members. The deployment of this wireless mobile communication system was adopted with mixed responses, ranging from *"I love it!"* to *"This is the crappiest thing!"*

Choosing appropriate communication artifacts
Vocera provided additional communication resource that is portable and can be used anytime and anywhere while the old technologies continued to be in use. However, the voice recognition was found to be suboptimal and presented a non-trivial problem that all members had to deal with at varying difficulties. The genie frequently did not understand the spoken command. This voice recognition problem was not limited to non-native members speaking with an accent. Native English speakers also found this problem occurred too frequently and caused much mental stress and frustration. When the genie misinterpreted the spoken command, the caller could repeat the command but most members would just terminate the call and restart another one. They said it was faster than waiting for genie's instructions to repeat the command. Most members would

Figure 3: Holding Vocera badge for better reception

try 2 to 3 times before they gave up and looked for alternatives to communicate, as illustrated in the following.

Jenny used her Vocera to call Patrick. "Call Patrick." "I'm sorry, I don't understand." Jenny terminated the call and restarted another one. "Call Patrick, Unit 38." "You want to call dietitian in Unit 38?" She then stopped the call and told us, "How can Patrick be even close to dietitian?" She then decided to find another way to reach Patrick. She did not know where Patrick was so she used the intercom at the nursing station. "Pat, can you please call Jenny?" Patrick got the message so he called Jenny on his Vocera. The connection was uneventful so the two talked on the voice link. [In situations where if Jenny knew where Patrick was, she typically just went to find him to talk face-to-face].

We received a wide range of affective responses towards the system, from loving it to hating it. The dramatic differences in the feedback largely hinged on their experiences with the voice recognition at connection. A few members found this connection experience so frustrating that they opted against using it for calling. But they still wore it so that other members could reach them. They also preferred the old technologies and would personally go to find their coworkers. But several said they felt coerced to have to visibly use Vocera and to express positive experience with it when it was not in reality.

Although Vocera could be used to broadcast to all the members or a designated subgroup, e.g., the nursing aids, the intercom was still preferred because it was easy to use. Moreover, as Vocera was not truly hands-free, members often had to first take off their gloves which are necessary in many clinical procedures before pressing the button on their badge to start a connection. Thus, some nurses found it tedious and complicated to call on Vocera while they were working.

The ambient noise was also relevant when deciding which communication artifact to use. Voice recognition got worse in noisy areas and the volume of Vocera voice link was generally low. Thus members always had to either lean their head towards the badge or hold the badge up close to their mouth to speak or their ear to listen (Fig. 3). A nurse stated, *"The volume is too low! When I'm working with a patient, I can't hear it and I can't hold it up to listen…"*

In the early stage, we found members appreciated the playful moments when built-in fun tunes were played. They

found the tunes helped ease their stress. But we did not see any members play these fun tunes in the fifth month of its deployment. We were not too surprised as this is quite typical when the novelty of a technology faded away.

Choosing an appropriate communication medium
Vocera offered several communication media to the members in addition to those available through the old technologies. Communications conducted via Vocera were open such that people around could also hear the conversations. It allows open point-to-point communications between distributed members and broadcasting to the entire group or to a designated sub-group. It can be used to leave messages for a member who could then retrieve the messages through their Vocera badge. It can also be used to call to regular landlines and cell phones, with voice commands. At meal breaks, members can forward their calls to the relief's Vocera.

Calls made on Vocera are not instantaneous as the genie must first understand the voice command before making the connection. But members generally perceived it as a more efficient way to reach their coworkers than having to physically moving into conversations. Therefore members frequently used Vocera to connect with their colleagues. However, observable latency impeded the actual voice communications so they had to talk slower than normal, making it difficult to communicate detailed information. This is likely why we did not see any reporting activities taken place using Vocera during shift changes. A nurse said, *"It's too slow... Unless you're sick and can't get up, then you'll use a Vocera to do that [shift reporting]!"* Also, although nurses could continue with their current task while using the technology, they had to somewhat slow it down.

The open voice link that can be overheard by people around was also detrimental for communicating private information. Thus, when detailed or private information was needed, members only used Vocera to coordinate switching to another medium to continue the conversation. We frequently saw nurses use Vocera to negotiate when and where to meet for face-to-face shift reporting.

Members preferred broadcasting on the intercom rather than using Vocera as the former was easy to use. But Vocera would be used when the intercom was not an option such as during night shifts. Intercom use was forbidden at nights so as not to wake patients up because doors might be open even though intercom broadcast basically could not be heard inside the rooms. With its broadcasting utility, Vocera was used in a real situation making a life-and-death difference, as told by the nurse who initiated the operation.

"The incident occurred during night shift, a time when the staff is busy and scattered throughout the floor. A seriously ill and confused patient disconnected himself from his IV and searched for an exit. Security was called, as he was a risk to himself and others. The patient went out an exit and down to the next floor, where the door was locked, and proceeded to collapse. Vocera was used to communicate

with and coordinate the staff, to bring oxygen and an O2 saturation monitor to the patient, obtain supplies for the IV site which was bleeding, obtain a wheelchair to take the patient from the second floor to the third floor and keep the Code 66 [an emergency code] team, who had been called when the patient collapsed, apprised of the movements. Vocera offered communication and coordination that would not have been possible without the Vocera."

Despite such encouraging usefulness of the system, some members were still entirely disappointed with it. For example, *"It [Vocera] is the worst thing ever happened. It [the genie] just doesn't understand. The noises here are too loud that they never work properly."*

Vocera supports asynchronous communication through voice messages but only unit clerks were seen to leave messages for other members. This is understandable as unit clerks had to handle continual incoming calls among clerical duties, and leaving a message is an easy and direct way to off-load information to intended recipient(s). However, we saw a nurse leaving messages for herself regarding patients' medical conditions. She said it was too time-consuming to write the details down but it was easy to press a button and leave a message. For example, she could just talk to Vocera about the size, color, shape and amount of fluid coming out of the wound while she was changing the dressing for a patient. Another nurse also said that "leaving messages for oneself" would be very useful when they were inside isolated rooms where they had to be gowned up and could not write anything down. But she could still press the button to record a message.

Vocera was rarely used to make phone calls as spoken commands must be first recognized by the genie to make the connection. Thus it is much easier to call on a phone. We only saw a few nurses calling their families on Vocera to briefly exchange affections.

We were also told an interesting phenomenon as a result of the members being used to Vocera communications. Many members now treated the intercom medium as ambient noises. Many times when unit clerks used the intercom to broadcast a message, the members disregarded it. The unit clerk then had to sound panicked over the intercom for urgent matters in order to draw their attention.

Identifying and locating personnel to communicate
With Vocera, a member did not need to know where the other members were when establishing a voice link. The following vignette illustrates how the unit clerk handled incoming phone calls differently with Vocera.

Jane received a phone call from the radiology department looking for the primary care nurse for the patient in room 3840. Jane then looked up the board across the nursing station and found that it was Carrie. She put the phone call on hold, used her Vocera to call Carrie and asked how she would like to take the phone call. Carrie then asked her to transfer it to the phone in her ward wing. When the phone rang, Carrie picked it up and talked to the radiologist.

As opposed to broadcasting over the intercom and waiting for Carrie's response via another medium, Jane was able to connect with Carrie directly and negotiate in the same communication medium. Even if Carrie was inside a patient room at the time, she would not have missed the call on her Vocera. Thus, Vocera offered clear benefits in locating people. However, when communication via Vocera broke down, members would have to use the old communication technologies. Vocera breakdown would delay the communication process as people would usually have tried it several times before they gave up and reverted. Incoming phone calls can also be transferred to a member's Vocera. However, we did not see anyone using this feature in our study. Most nurses were not aware of this feature; those who knew did not use it as they found it too complicated.

Nevertheless, many nurses considered the benefit of using Vocera to connect with their coworkers without physically finding them outweighed the frustrations experienced with the voice recognition at connection. Thus using Vocera to locate and check the availability of members represented a large fraction of Vocera use.

Off-loading information to intended recipient
The poly-motivated mobility pattern exhibited before the deployment of Vocera has transformed into many frequent and instantaneous off-loading of brief information through the synchronous voice link. Most conversations conducted over Vocera were short and dyadic. These conversations typically involved quick work-related questions, clarifications and notifications, location and availability information of a coworker so that further actions could be arranged. For example:
 "Mary, can you go to 23 [Room 3823] to help Sara?" "Ok, I'll be there in 5 minutes."
"Where are you, Joe?" "I'm in [ward wing] A" "Can I come to give you a verbal [report]?" "Yeah!"
Members used Vocera to spontaneously seek information when necessary and they could also be certain that the information has been properly relayed and received through the synchronous communication. However, we did not see people using the system to converse over rich information content. Rather, for longer and complex information exchange, they used Vocera to obtain location and availability information to determine if, when and where a more detailed conversation (e.g., face-to-face) could occur.

Vocera is operated over an open voice link making it inappropriate for communicating private or confidential information. Before, unit clerks always relayed private patient information to other clinicians through telephone or face-to-face interactions. But Vocera conversations were also perceived as similar to the telephony. The fact that callers were usually unaware of their colleague's location would sometimes have unknowingly compromised the patients' privacy by sharing private information over the open voice link when other people were around the other end of the link. We were told of an incidence where a member used Vocera to inform a nurse that her patient's

critical lab results had come back, not knowing that the nurse was in conversation with the patient's family. The nurse immediately saw an increased anxiety of the family. Thus she would prefer that such information not be communicated through the open voice link. Many nurses also reported situations when they were talking on Vocera with a colleague, the patient and their family mistook that the nurse was talking to them, thus causing confusion.

Minimizing spatial movements
Before using Vocera, one way to minimize spatial movements was by making poly-motivated communication trips. But the convenience offered by Vocera to reach their coworkers without spatially moving to find them allowed members to frequently and spontaneously connect with their coworkers while they were on their feet, accessing information or providing care. For instance, a nurse used it to call her outgoing colleague for clarifying a patient's treatment progress while reading the patient's chart at the nursing station. Thus, members perceived a substantial decrease of distances they had to cover. One member stated: *"This device is so useful! It saves me a lot of walking and searching. Once I heard a beeping sound from an IV [infusion pump] in a patient room and the nurse was not around. I just used it [Vocera] to let the nurse know right away!"* In fact, preliminary measurements showed that Vocera reduced a nurse's mobility in an 8-hour shift from about 6680 to 3360 steps. Vocera was also useful when it was not safe to leave a patient while seeking help.

With Vocera, not only could members make and receive calls inside patient rooms, the reception was also reportedly better as patient rooms are generally quieter. With less overhead broadcast on the intercom, the ward has also become quieter in general. More importantly, the synchronous voice link provided instantaneous confirmation of receipt of information without making extra effort, e.g., going in person, to find out.

Vocera also reduced the trouble of "people hunt" that often occurred before when a person did not find the intended collaborator in the location where he/she was expected to be. The hunt would then continue on to the next expected location until the collaborator was correctly located. Instead, Vocera allowed members to first locate the intended collaborator before making any spatial movement for further communication.
"Before, I sometimes would go to a wing to find a nurse who was actually somewhere else, so I would have to keep searching…wasting so much time!"
"A lot of times, we walk all the way over to the other side of the ward to just see if somebody can come to help…"
However, a number of locations in the ward have been reported to be dead zones for Vocera. Members working there would then have to communicate in the old ways and use the old technologies. This also caused frustrations to other members who tried to use Vocera to reach the members working in these areas.

We also observed an undesirable phenomenon as a result of the convenience of using Vocera to connect with another member. Many members have become less alert towards their physical surroundings. We found that members have become less watchful about their close proximity for the presence of coworkers they wanted to communicate with. They seemed to have subconsciously regarded Vocera as the first choice for communication. We observed many incidences where the intended collaborator was just nearby, e.g., a few steps away, but the member made a Vocera call without first checking the surrounding for the presence of their colleague. This made the communication unnecessarily dependent and worse still, the more effective face-to-face interaction has become secondary to the technology-mediated communication.

Prioritizing and scheduling activities
Vocera allows impromptu conversation while members were working on a task or moving around the ward. Although the connection on Vocera was not truly instantaneous, due to the need for voice command recognition, information could basically be communicated as soon as it was acquired. Thus members no longer had to postpone their information seeking or dissemination activities. Such ubiquitous communications also appeared to improve the timeliness of information flow for meeting the dynamic needs of patient care.

Despite the frequent trouble of voice recognition, many members concurred that the time saved by using Vocera to locate and negotiate with people outweighed the slight connection latency. As a result, participants had more time to spend with their patients. *"It makes a huge difference! I can spend more time getting my work done now coz I don't need to go find people anymore…"*

DISCUSSION
Our findings indicated mixed responses, although in general the Vocera technology was well-received.

Positive Impact. With Vocera, members could communicate with each other anytime and anywhere, supporting the time-critical and mobile nature of medical work. It basically allowed the members to continue their task-at-hand and reduce unnecessary mobility to locate and connect with their collaborators who were always on their feet [3]. Our study revealed more time for patient care with the savings in time searching for collaborators; previous literature indicated that such time saving led to improved medical safety [6]. Members also used Vocera to manage the conversational progress and negotiate availability for deciding when to switch media, typically to face-to-face communication [4]. The synchronous voice channel was frequently used for spontaneous quick questions, clarifications, and coordinating work, replacing the poly-motivated mobility practices [2]. Thus, information was made available in a timely manner. Meanwhile, the instantaneous off-loading of information helped reduce memory load, which will likely decrease medical errors.

Vocera also largely replaced the use of overhead broadcast which was interruptive and noisy. Thus Vocera brought about a more pleasant work environment which has been found to help improve work quality and workload [6].

Life-and-death difference. Vocera's role in making a life-and-death difference as demonstrated in the paper showed that this communication technology has great value in medical work. Currently, Vocera is only deployed among the nursing staff in a single ward. The technology will likely benefit the prevalent multidisciplinary collaborations once it is widely adopted.

Unintended consequences. Vocera was perceived by most members as the primary communication mode between distributed collaborators. Thus they became less alert to overhead broadcast and the presence of collaborators nearby. These unintended consequences may have negative impact on the information flow [1]. Thus, the intercom system may be designed to integrate with Vocera so that they compliment with each other and at the same time serve as a backup should the other fails. Besides, contextual information of coworkers would be valuable for estimating their availability as well as their proximity before initiating communications. On the other hand, the unanticipated use of Vocera to leave messages for oneself indicated its potential to include an easy-to-use and retrievable recording feature that effectively supports dynamic work.

Unrealized expectations. Members did not use Vocera for casual interactions with their coworkers in the first week of its deployment. But we expected that social interaction would more frequently take place through Vocera when they became more familiar with the technology. We also predicted that the informal interaction would help improve the social awareness among the distributed members. However, social communications on Vocera did not occur as we had expected in its fifth month of use because the nurses were usually busy and did not have time for social interactions at work. They only caught up with their colleagues during shift changes and meal breaks. The nurses also did not conduct their shift reporting on Vocera because of the inferior reception quality. Instead, nurses mostly used Vocera to negotiate availability and to switch to another communication medium for the reporting.

Primary technology problem. Communications on Vocera helped improve information flow in our study ward. Yet, the biggest hurdle was to make the connection. This led to some members' hostility towards its adoption and their opting to only use the technology as a receiver. To them, the technology was more a hindrance than a benefit [10].

Since Vocera offers clear benefits and has great potential in supporting the time-critical and dynamic medical work, we propose several *design guidelines* to influence the (re)design process for this type of technology to better support information flow among the members.

Design for easy connection. Vocera was designed for ubiquitous communication across distance. Therefore, it is

vital that connection can be made with ease and confidence. Since the current state of voice recognition technology is still limited, we suggest providing an alternative command input to ensure reliable connection. Examples include providing an address book of all members and speed dials for frequently called members such as the nursing station.

Design for heterogeneous adopters. The current Vocera system provides a homogeneous product to a group of heterogeneous members whose job nature and mobility patterns are quite different. Knowing and designing technologies for the differences in their interactions, activities and use is important so that everyone benefits directly [5]. A communication device is ideally compact and simple to use for mobile workers. But working primarily at the stationary information hub mainly to properly route incoming communications to intended recipients, unit clerks could use a different device which allow them to easily connect with other member's Vocera without facing the voice recognition problem. Being able to connect reliably would greatly facilitate the information flow through the central hub while maintaining the benefits of Vocera use. This is particularly important when Vocera is to be deployed among other groups of clinicians whose job and mobility characteristics may be different.

Design for contextual awareness. An up-to-the-moment awareness of coworkers' activities and locations would help coordinate communication and be valuable when interruptions could be detrimental or unwelcome, e.g., when providing comfort to a terminally-ill patient [11].

CONCLUSIONS
The motivation behind this study was to evaluate how the novel technology impacts communication and information flow. We found that the technology was adopted with varied responses, from loving it to hating it. The negative responses were mainly a result of their dissatisfaction towards the connection experience whereas the positive adoption was due to the convenience of connecting with other coworkers without having to resort physically moving to locate them. The findings from this study will inform the overall technology design to support the nurses' information flow in the study ward, as well as serving as a guide to Vocera deployment in other wards.

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