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# *InfoFlow Framework for Evaluating Information Flow and New Health Care Technologies*

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This article presents a framework of 6 distinct yet interrelated factors for describing information flow that arose from a combination of field studies in a hospital ward and a review of literature. These studies investigated the dynamics of nurses' information flow, focusing on shift change. The InfoFlow Framework's 6 interrelated factors that affect the information flow are information, personnel, artifacts, spatiality, temporality, and communication mode. The framework is presented as a tool for evaluating new health care technologies. The 6 factors and their interrelationships are described first. Next, this structure is applied as a tool to aid in the analysis of the data generated in a study that assesses technology in use. Then the use of the framework is illustrated by structuring it as a set of questions that can be used as a guide for other researchers to generate coherent descriptions of the information flow and to evaluate technology deployments. Finally, there is a discussion of areas where the InfoFlow framework may be applied to allow an evaluation of the extent to which the framework may be generalized to other settings.

## *1. INTRODUCTION*

This article presents the InfoFlow Framework and an application of the framework in the evaluation of a communication technology deployed in a hospital ward. The InfoFlow Framework is composed of six factors that provide structure for the description and evaluation of nurses' information flow in a hospital ward. We formulated this framework based on field studies that spanned across both regular shift periods and shift changes to investigate the dynamics of nurses' information flow and a distillation of past literature (e.g., Bardram & Bossen, 2005b; Reddy, Dourish, & Pratt, 2006, Solet, Norvell, Rutan, & Frankel, 2005,

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Strauss, Fagerhaugh, Suczek, & Wiener, 1985; Xiao, 2005). The field study that motivated the development of the InfoFlow Framework was, in fact, the first in a series of studies that we conducted to investigate information flow in the medical domain. We have subsequently used this framework to guide the data analysis in a study that investigated the impact of a newly deployed communication technology on information flow. Although the InfoFlow Framework can also be used for generating technology designs, this article focuses on the development of the framework and its evaluative role for aiding in the assessment of new health care technologies.

In medical settings, communication and information flow are ubiquitous and account for a substantial part of healthcare practitioners' daily routines, encompassing interactions in varying contexts and information sharing across temporal and spatial dimensions (Bardram & Bossen 2005b; Bossen, 2002, Schmidt & Bannon, 1992; Solet et al., 2005). In fact, communication failure was found to be the most frequently cited root cause of adverse events, 65 to 70%, by the Joint Commission on Accreditation of Healthcare Organizations (JCAHO; 2007). Furthermore, handover communication, which consists of the processes of passing patient-specific information from one caregiver to another, from one team of caregivers to another team, or from one healthcare organization to another, was identified as being a high-risk event with respect to patient safety (JCAHO, 2007).

Our research investigates nurses' information flow in a medical setting. Imagine a nurse who comes on shift having no knowledge of what has happened on the ward or to her patients in the last 24 hr. She would then have to update herself with the necessary information and knowledge within the brief handshake of shift change in order to be able to continue patient care. In situations where the nurse has been away for an extended period and has just returned to her first shift of work, she would then likely have to gather considerably more information for building a "picture of the current state of the operation" than if she had only been away for 24 hr. Thus, information acquired during shift change or handoff plays a fundamental role in the subsequent information flow that takes place during the shift work.

Our purpose is to create a framework that can help guide the design, development, and evaluation of technological support for information flow within health care settings. Such a framework would facilitate comparative studies, identification of potential problem areas, and targeted interventions. Specifically, our framework consists of six essential components of the information flow process. These are information, personnel, artifact, spatiality, temporality, and communication mode. In this article, we focus on describing how the InfoFlow Framework can be used for evaluating new technologies in health care. Many technologies being introduced within the hospital environment are concerned with issues of information flow, such as electronic patient records (e.g., Ellingsen & Monterio, 2001; Fitzpatrick, 2000; Ventres et al., 2006), large displays (e.g., Bardram, Hansen, & Soegaard, 2006), mobile devices (e.g., Cisco 2007; Houston, Ray, Crawford, Giddens, & Berner, 2003; Turner, Milne, Kubitscheck, Penman, & Turner, 2005), and tools to support handover (e.g., Baldwin & McGinnis, 1994; Hewitt, 1997; Van Eaton, Horvath, Lober, Rossini, & Pellegrini, 2005). Although a number of studies in human–computer interaction and computer-supported cooperative work have explored the impact of these technologies on information flow, largely through qualitative data collection (e.g., Ventres et al., 2006; Wilson, Galliers, & Fone, 2006), we consider that our framework could guide data collection and analysis for evaluation while also supporting the comparison of systems across settings.

To provide context for this work, we present a brief review of previous research into nurses' information flow. The related work section is kept brief because previous research is cited as appropriate throughout the description of the framework that follows. Next, we present summarized findings of our study that informed the development of the InfoFlow Framework. We then present an application of the framework in evaluating the impact of a mobile voice communication technology on nurses' information flow. We also tabulate a set of questions associated with the factors of the framework to serve as a guide for evaluating technologies to support information flow in medical settings. Last, we briefly discuss several areas where the InfoFlow Framework may be applied for studying information flow. These could allow us to assess the extent to which the InfoFlow Framework can be generalized to other settings.



## 2. BACKGROUND

Although evaluation has been core to the human–computer interaction community, most evaluation in human–computer interaction has focused on technology use within specific task scenarios such as those investigated in usability studies (Neale, Carroll, & Rosson, 2004). However, as health care computing applications have become increasingly pervasive, additional challenges to evaluation arise (Randell, Fitzpatrick, Wilson, Mamykina, & Tang, 2009). In particular, the distributed and dynamic nature of medical work makes it ever more important to investigate the information flow and supporting technologies over periods of extended use as behaviours often change over time.

Several frameworks have been developed in a variety of work domains for evaluating information flow. Grusenmeyer (1995) presented a framework to study information flow during shift change in a paper mill plant. She differentiated four phases of the information flow: the end of a work shift, the arrival of the incoming operator, the meeting of the operators, and the taking up of post by the incoming operator. Although her framework was derived from observing dyadic communication among operators at shift change in an industrial context, her framework helps guide the general study of information flow across settings, because the phases she identified exist universally.

Subsequently, Behara et al. (2005) proposed a conceptual framework for studying information flow during patient transitions in the emergency room. This framework addresses four attributes of the information flow: the type of process in which it occurs (e.g., degree of standardization, production volume level and nature of the process), the primary content, the structural issues (e.g., nature of participants) and the dynamic issues (e.g., degree of structuredness and degree of interactions required). It can be used to understand the fundamental properties of information flow in a specific setting and to categorize and compare different settings for redesigning the work processes.

Patterson, Roth, Woods, Chow, and Orlando (2004) identified 21 strategies for handoffs from studying four settings with high consequences for failure: a space shuttle mission control center, two nuclear power generation plants, a railroad dispatch center, and an ambulance dispatch center, These strategies aimed to provide for effective coordination and communication during face-to-face verbal handoffs and have since been widely cited in studies on other handoffs. Although these strategies were developed from studying various settings, most of the strategies appear to be most applicable to information flow during shift change in space shuttle mission control environments as the data collected in the other settings were not originally collected for this purpose.

Hardey, Payne, and Coleman (2000) proposed an information flow model that focused on the roles of "scraps" in mediating formal documentation, information flow at shift change, and the delivery of nursing care. Scraps, which are analogous to the nurses' self-prepared paper "personal notes" in our study ward (Tang & Carpendale, 2007), are created in response to perceived inadequacies of existing information systems. However this model presents the information flow process only in terms of the use of the informal, temporary information artifacts without taking other important aspects of the information flow into consideration.

In contrast, our proposed framework addresses six important factors of nurses' information flow in medical settings and allows researchers to flexibly reconfigure the factors for studying information flow and identifying areas for improvement and, thus, is designed to be more comprehensive and pragmatic.

A hospital is an information-rich environment characterized by varying levels of coordination between colocated and distributed clinicians through a multitude of information artifacts and channels to accomplish collaborative work. Giving and receiving information forms a substantial part of a clinician's everyday routine (Solet et al., 2005), thus plays an indispensible role in the continuity of patient care in round-the-clock hospital work contexts.

Previous studies of information flow in medical settings have mostly focused on particular aspects of the communication process, for example, mobility issues (Bardram & Bossen, 2003, 2005a), temporal aspects (Bardram, 2000; Reddy & Dourish, 2002; Reddy et al., 2006), coordinating artifacts (Bardram & Bossen, 2005b; Bardram et al., 2006; Cabitza, Sarini, Simone, & Telaro, 2005), communication channels (Coiera & Tombs, 1998; Gurses & Xiao, 2006; Patterson et al., 2004), and information content (Baldwin & McGinnis, 1994; Bates & Gawande, 2003; Currie, 2002; Kerr, 2002). From these studies, we have gained considerable insight into the processes of and challenges for effective information flow. However, from the perspective of evaluating health care technologies for supporting the information flow process, we felt it would be useful to have this wealth of knowledge formulated as a framework that could be used to aid in the assessment of new healthcare technologies, in a similar manner to Nielsen's (1994) usability heuristics and Gutwin and Greenberg's (1999) Awareness Framework. Next, we briefly describe our study, which, together with a distillation of previous work, led to the development of the InfoFlow Framework.

## 3. DEVELOPMENT OF THE INFOFLOW FRAMEWORK

The InfoFlow Framework arose from the findings of a field study integrated with findings from the literature. For ease of reading we include a summary of this field study (see Tang & Carpendale, 2007, for a full description). Our field study was conducted in a teaching ward of a large urban hospital. Information flow during nursing work, focusing on shift change, was observed for approximately 3 months in 2006.

### 3.1. Research Site and Methodology

Our study ward was an acute medical teaching unit. Patients admitted to this ward are often transferred directly from the Intensive Care Unit (ICU). Therefore, the patients generally still require acute care for a vast array of, often multisystem, illnesses. However, the nurse-to-patient ratio ranges from 1:4 to 1:8 depending on work shifts, as opposed to the drastically lower ratio of 1:1 or 1:2 in the ICU. Therefore, nurses working at this ward constantly face high stress and time pressure. Yet these nurses are recognized for their enthusiasm toward their work and the strong dynamic team environment that they have built in such a high-stress and time-critical hospital ward. In addition, innovative research activities frequently take place on this ward as a test bed before technologies are deployed in other hospital wards. Therefore, nurses working on the ward are generally open-minded toward technology.

Figure 1a shows the layout of the 40-bed ward. The ward is configured in a star design with a centrally located nursing station (Figure 1b and Figure 2a) and four radiating ward wings of patient rooms (see also Figure 2b). The layout makes it convenient to access information at the central information hub but makes it hard for nurses working in different wings to communicate and to maintain awareness.

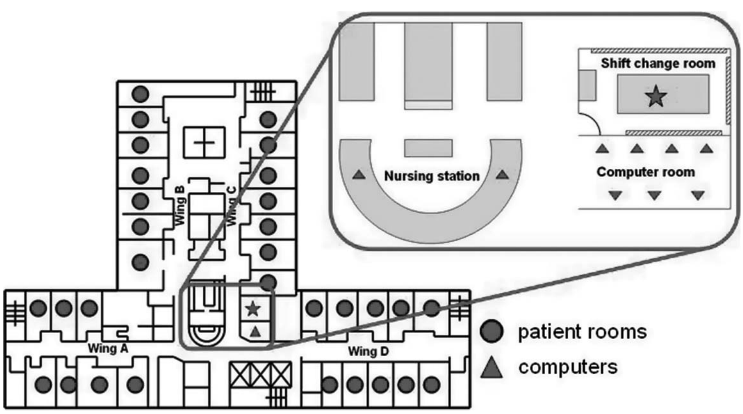


**FIGURE 1** (a) Floor plan of the study ward (bottom left), and (b) layout of the nursing station, shift change room and computer room (top right).


a b

**FIGURE 2** (a) Nursing station (b) nurses communicating in a ward wing.



Participants in our study were 2 patient care managers, 37 registered nurses, and 3 undergraduate nursing students, all of whom were working on the ward at the time of the study. Nurses are assigned to specific patients for the duration of their shift.

We employed a naturalistic approach to perform an observational study in the field study site to acquire a better understanding of the current practices of nurses' information flow. We used minimally intrusive direct observations, semistructured interviews, examination of formal and informal documents (e.g., annotated patient care summaries and personal notes), and informal discussions with nurses. We also used a digital camera to capture snapshots of nurses' activities and the documents.

Twenty-five observations, each spanning at least 45 min before and 45 min after the shift change period, were conducted during all nursing shifts. Handwritten field notes were taken during observations and were transcribed soon after each observation. Interviews were conducted on-site whenever possible, primarily for clarification and elaboration of the participants' actions. Interviews were also conducted outside the ward to gather detailed information that could not be obtained through observations. Data collected during the observations and write-ups of observations were validated with the participants.

### 3.2. Nurses' Information Flow at the Ward

Nurses' information flow during shift change in our study ward was found to be composed of a pair of parallel processes, information assembly, and information disassembly, taking place during the brief handshake of shift change (Tang & Carpendale, 2007). We define *information assembly* as a process of actively seeking information from a variety of information sources that may be spatially distributed. The process of information assembly arises from a need to fill the information gap between one's knowledge about a task and the perceived requirements of the task (De Haan, 2000). *Information disassembly* is analogous to the reversal of information assembly: activities undertaken at the end of a shift to disseminate information gathered during work to a variety of information repositories that were initially information sources at the start of the shift. It may also include directly handing information over to the incoming nurses.

Figure 3 summarizes the information flow process as observed in our study ward. Part of the nurses' activities involved exchanging information with other clinicians such as physicians and ancillary professionals (e.g., physiotherapists and social workers) as well as nurses on the next shift. Most of this information flow takes place in asynchronous colocated modes by means of coordinating artifacts such as patient charts.

Thus, correct interpretation of information placed in the coordinating artifacts is crucial for the information flow. Moreover, information is distributed over verbal, paper, displayed and digital media (Figure 3, top). The multimedia information sources entail varying modes of communication necessary for the information flow, whereas their spatial distribution necessitates mobility for information access. Furthermore, information acquired at the beginning of a shift is typically externalized in a coordinating personal artifact which is then used as a work plan and bedside information source during shift work (Figure 3, center). The personal artifacts are also used as an opportune notepad for newly emergent information during the shift and as an information source for reporting at the end of a shift (Tang & Carpendale, 2008). Thus, examination of these personal artifacts allowed us to identify a set of information content and function types

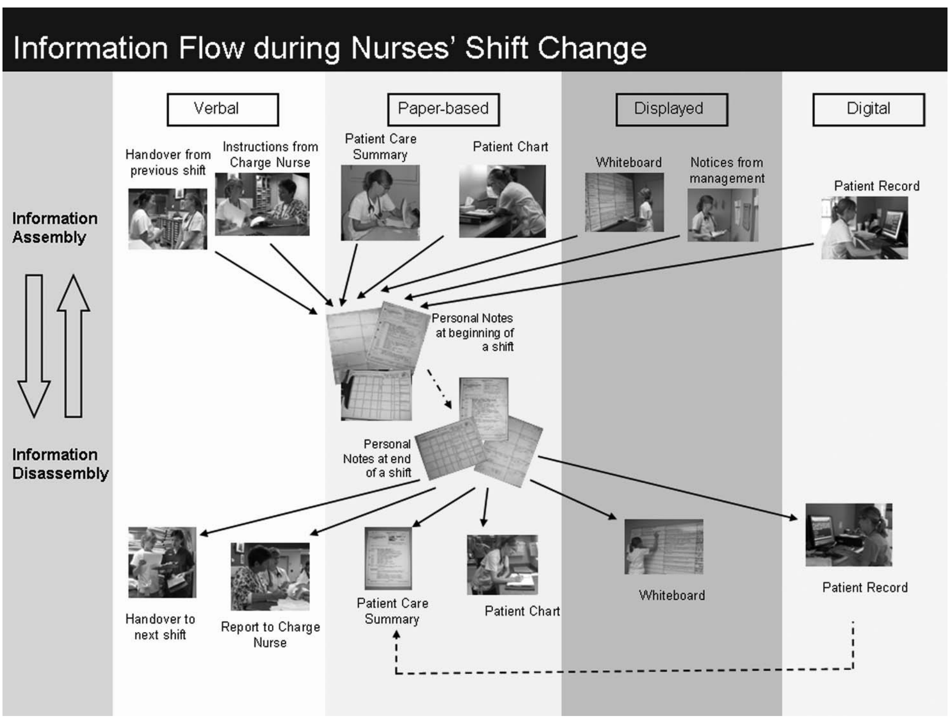


**FIGURE 3** An overview of the information flow during nurses' shift change.

communicated during shift change. From observations spanning across both regular shift work periods and shift changes, we found the communication strategies used for information flow during shift change and those used during shift work to be very similar.

### 4. INFOFLOW FRAMEWORK

Our InfoFlow Framework has six factors: information, personnel, artifacts, spatiality, temporality, and communication mode. These factors are not stand-alone elements independently contributing to the information flow process but are highly interrelated (Figure 4). All of these factors impact upon and are impacted by all the other factors. For example, the kind of information artifacts used influences the timeliness with which information is communicated among clinicians. In addition to their importance in our own studies, the importance of each of these factors has been reported in other studies conducted across various domain settings (e.g., Bardram & Bossen, 2005a, 2005b; Forsythe, Buchanan, Osheroff, & Miller, 1992; Harrison & Dourish, 1996; Luff & Heath, 1998; Reddy et al., 2006).

The remainder of this section describes each factor of the framework in detail. Though it is possible to describe this framework starting from any one of the factors, we start from the information factor, at least in part because effective transfer of information has so frequently been noted as the primary objective during shift change (Kerr, 2002; Sexton et al., 2004; Wilson, Galliers, & Fone, 2005). The framework discussion then moves to personnel and artifacts, describing the relationships between these factors. Last, the spatiality, temporality and communication mode factors of the information flow process are discussed in association with the previous factors. We draw on our own study and experiences reported in the literature to illustrate the roles played by the factors in the information flow.

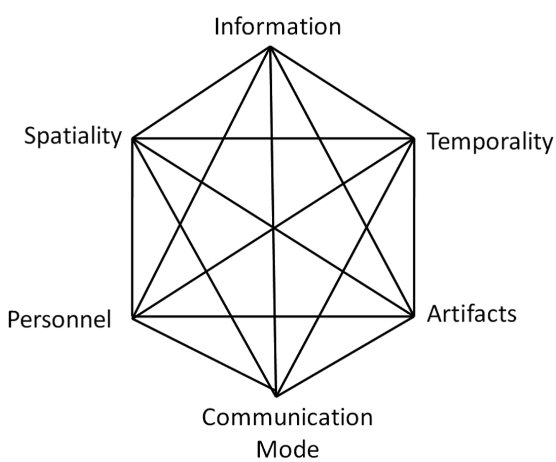


**FIGURE 4** A framework for information flow during shift change consisting of interrelated factors.

Although each of these individual factors justifies focused research, our framework's contribution is to provide a holistic view of the information flow process so that it can be studied in a systematic manner using existing knowledge and concepts to investigate its complex processes.

### *4.1. Information*

Information is the essence of communication and is central to all collaborative work. In fact, medical work is regarded as information work because information is key to task accomplishment when delivering patient care (Strauss et al., 1985). Specifically, communication of task-pertinent information across shifts has also been repeatedly found to be essential to continuity of operation regardless of the complexity of the information flow process (Grusenmeyer, 1995; Lardner, 1996; Wilson et al., 2005). Hence, information communicated at shift change directly influences the quality of health care. For our purposes, information includes facts, knowledge, assessments, instructions, graphical representations, perceptions, and meanings received and interpreted.

In the process of achieving medical work, two kinds of information are often communicated: work-related and interpersonal information. Although interpersonal information is important for group cohesiveness and team morale, our framework primarily addresses the communication of work-related information. The work-related information in this case is typically patient-specific and thus uniquely defined for each patient's illness trajectory. Such information is important for planning nursing care for individual patients and temporally coordinating and executing the care plans for multiple patients. Thus, the Joint Commission (2007) has set a National Patient Safety Goal to "implement a standardized approach to "hand off" communications." Accreditation Canada (2008) also identified improving "the effectiveness and coordination of communication among care/service providers . . . across the continuum" as a patient safety goal (Muskat & Yang, 2008, p. 28).

Communication breakdowns in the medical setting often have deleterious consequences on patients (Vidyarthi, 2004). In particular, communication during shift change has been identified to be highly vulnerable. Thus, miscommunication between the incoming and the outgoing nurses during shift change has resulted in, or contributed to, a number of documented adverse events that have taken place in medical settings. For example, the extreme case of the amputation of the wrong leg of a patient was found to have been caused by the outgoing nurse having forgotten to communicate to the incoming nurse during shift change about a clerical error that the incorrect leg to be amputated was put in the surgery schedule (Patterson, Roth, & Render, 2005). Such an unfortunate event could have been prevented if a standard set of information to be communicated was enforced during the handover. Thus, many studies, including our own, have attempted to identify a set of information that must be communicated during shift change.

Without standard guidelines as to what information must be communicated, the informational contents of handover have been found to exhibit a high degree of variability in both quality and quantity (Solet et al., 2005). For example, Currie

(2002) identified patient's admission diagnosis, treatment received, demographics, present restrictions, care plan, and medical history as being the most important types of information for discussion during shift change. Baldwin and McGinnis (1994) listed a set of specific information that is crucial in shift reports: vital signs, activity, diet, labs, tests, IVs, and so on. In addition, previous studies have found that the types and the amount of information required for the continuity of patient care varies across settings and services (Solet et al., 2005). For example, an acute oncology ward generally requires more time to prepare and execute the information flow that emphasizes the treatment plan and the patient's illness trajectory, whereas a general medical ward, where patients are less seriously ill, may find the social support available to the patient to be a crucial piece of information. Therefore, the set of information required for shift change should also reflect the nature of care in the particular setting. Thus, instead of making another list of specific information content, we have previously proposed several categories of information in terms of their roles in nursing work. These are reminders and to-dos, alerts, prompts, scheduling, reporting, and verification information (Tang & Carpendale, 2007). These functional information types are typically action oriented and so can help the clinicians build a mental model of their work plan to guide their shift work.

Although a predetermined set of information helps ensure that necessary information is communicated, it is difficult to know if incorrect information has been communicated or incidental information has been missed. Unfortunately, the identification of such incorrect or missing information is often a result of hindsight investigations into adverse events. Nevertheless, a standardized protocol for the shift change information set should help improve the quality of the information flow.

Given a specific set of information, the next question is where the information can be found. Information does not exist in a vacuum; instead, it typically resides in a person's head or is inscribed in an object.

### 4.2. Personnel

With increasing specialization in medicine, multidisciplinary care is now common such that clinicians all carry information specific to their work duties and their expertise (Gulmans, Vollenbroek-Hutten, & Van Gemert-Pijnen, 2007; Gurses & Xiao, 2006; Kane & Luz, 2006). It is therefore important to identify the people who carry and/or require information that is necessary for the continuity of patient care, as well as the kind of information they each carry/need. We regard these personnel as *information participants*.

For instance, information participants in a typical nursing shift change are nurses of the same discipline. But they may also include nursing aids, the charge nurse, specialty nurses (e.g., a prick nurse), unit clerks, physicians of different specialties (e.g., general practitioners, cardiologists, and surgeons), or ancillary professionals (e.g., physiotherapists, social workers, occupational therapists and laboratory technicians), largely depending on the patients' needs.

In our study ward, patients' treatment and care plans are updated frequently because of its acute care and teaching nature. Thus, physicians are occasionally seen to instruct incoming nurses or to confirm they understand how to carry out the most current treatment and care plan during shift change. Besides, as information is often entangled with the context of its production, incoming nurses would actively connect with relevant clinicians for interpretation and clarification, if necessary, of the information they had acquired (Berg & Goorman, 1999). In fact, clinicians such as physicians were often found to seek answers to clinical questions by contacting their colleagues rather than looking up literature (Covell, Uman, & Manning, 1985; Gorman & Helfand, 1995). Clinicians' credibility could influence the integrity of their information and thus may impact the flow of information when (re)verification of information is deemed necessary (Berg & Goorman, 1999; Cicourel, 1990).

Questions and clarifications are generally encouraged at shift change to ensure that correct information is being understood across shifts. However, perceived differences in social status and hierarchical authorities (e.g., senior doctors can override the diagnosis by junior doctors) have been found to be a barrier to effective handoffs, as junior clinicians are sometimes too intimidated to ask questions making them unable to fully understand the current operation (Solet et al., 2005). Manias and Street (2000) also reported that hostility and competition may be present at shift change and that, if so, they are likely to hamper team morale. Thus, it is likely beneficial to be able to identify such vulnerability in the information flow in order to improve it.



### 4.3. Artifacts

Artifacts are extensively used to coordinate collaborative work (Bardram & Bossen, 2005b; Xiao, 2005); as organizational memory (Gurses & Xiao, 2006); and for aiding, enhancing, or improving cognition (Norman, 1991). In medical settings, a wide range of information artifacts are used to coordinate the delivery of patient care. Examples include large whiteboards, patient charts, work schedules, desktop computers, personal digital assistants, and disposable paper note sheets. These artifacts may also include informal, temporary "bundles" using any available media such as paper towels, sticky notes, latex gloves, or tissue boxes for quickly scribbling information to support the performance of specific tasks in particular contexts (Ash et al., 2001). These information artifacts possess varying characteristics in their form factors, interactivity, mobility, and life span contributing to their affordances for specific roles and functions played in the collaborative work.

Although digital solutions have been replacing paper medical records to provide more consistent, integrated, distributed, and timely sharing of information (Harper, O'Hara, Sellen, & Duthie, 1997; Sellen & Harper, 2002), they do not provide the same kind of affordances as paper-based artifacts in supporting work. For example, they do not afford the "elbow room" needed for initial, exploratory, and provisional information, such as when information is tentatively scribbled in pencil, in the course of decision making such as when making a difficult diagnosis (Fitzpatrick, 2004; Hardstone et al., 2004). Therefore, the handling of medical information often still involves a mixture of multimedia artifacts including paper, displayed, and digital records.

An artifact's material characteristics could also impact the type of information that it may carry (Bardram & Bossen, 2005b). Alternatively, an artifact may only be designated for use by specific personnel only. Therefore, one single artifact would rarely carry all the information necessary for a patient's diagnosis, treatment, and care. In practice, information is accumulated from multiple artifacts. Although information may be overlapping in the artifacts, a certain level of data redundancy has been found to be beneficial in reducing the risk of erroneous communication, which can in turn help forestall adverse events (Cabitza et al., 2005; Lardner, 1996; Munkvold, Ellinsen, & Koksvik, 2006; Vidyarthi, 2004).

In fact, reviewing documentation in various forms of artifacts can help incoming nurses to understand the tasks that have been performed, the current status, and the likely projection of future plans (Patterson & Woods, 2001) and thus will be useful for the continuity of operation. In our study ward, such shared artifacts are large whiteboards containing shift-specific nursing care information, electronic health records, and patient charts containing high-level multidisciplinary treatment and care information. Together, they provide a rich set of past, current, and future plans and a trajectory for continuing patient care. Although maintaining data consistency among multiple information artifacts, particularly those of different media types, is no trivial task, similar activities are also found in other settings. For instance, incoming flight controllers are required to assemble information from a variety of artifacts offering descriptions of different aspects of the operation (Durso, Crutchfield, & Harvey, 2007; Patterson & Woods, 2001). This practice of gathering information from a variety of complementary information artifacts is in fact a recommended strategy for effective information flow at handoff (Patterson et al., 2004).

Organizational protocols and culture may also determine the kind of information an artifact contains and who has access to the artifact. Some artifacts are kept permanently as official and legal documents. Others may only exist ephemerally for mediating the work process and will be disposed of afterwards. Of special interest, personal notes have been found to be pervasively used by individual clinicians and play a vital role in coordinating medical work (Hardey et al., 2000; Sexton et al., 2004; Tang & Carpendale, 2007). They are often used to bridge the distributed information sources by providing information at points of care.

### *4.4. Spatiality*

As medical settings are comprised of a collection of spatially distributed "work centers" (e.g., operating rooms, emergency department, ICU), personnel (e.g., patients, clinicians, nonclinical staff), and artifacts (e.g., clinical equipment and information documents), mobility is indispensable for accomplishing work. Bardram and Bossen (2005a, p. 136) regarded medical work as *mobility work* because mobility is often required to bring together "the right configuration of people, resources, knowledge and place in order to carry out tasks." Mobility itself does not usually accomplish any concrete tasks. But without mobility, many tasks cannot be fulfilled. For instance, in another setting workers had to be constantly moving around a waste water plant to gather the constantly changing and location-dependent information for assessing the quality of the water treatment, a mobility practice referred to as "zooming with the feet" (Bertelsen & Bodker, 2001). Similarly in the medical setting, mobility is not only necessary for achieving work during actual patient care but also vital for accessing distributed information participants and artifacts.

These days, many medical organizations are replacing their physical records with electronic health records for remote information access and entry. This switch drastically changes the notion of information availability such that mobility does not always constitute part of the information seeking and retrieval process. Nevertheless, most organizations still retain a certain amount of physical documentation so that certain collaborative work is mediated through physical artifacts that are not linked to a computer system (Xiao, Schenkel, Faraj, Mackenzie, & Moss, 2007). Hence, mobility is often necessary to access these physical artifacts.

To study information flow, our framework focuses on four aspects of spatiality. First, it is necessary to locate *where* the required information is. This entails the need to find out the locations of pertinent information participants and information artifacts. However, as clinicians are always on their feet, locating them is a challenge. Fortunately, with the use of technology-mediated communication systems such as traditional paging systems or more advanced ubiquitous communication systems, clinicians can now be more easily located. Without these communication tools, locating a clinician can be time-consuming and frustrating.

In practice, information is often located in places where it is needed the most (Harrison & Dourish, 1996). As such, the placement of an artifact often determines who has access to it (Xiao et al., 2007). For example, patient charts in our study ward are located in the central nursing station where clinicians always meet to discuss the "cases" and the patient charts are therefore at their fingertips. Also in the space shuttle control room, all relevant artifacts such as flight logs, radar display, and flight strips are in close proximity to the specific flight controllers participating in the shift change so that information necessary for shift change is readily available (Patterson & Woods, 2001). However, when shared artifacts are removed from their designated location, extra effort such as further mobility is required to locate them (Bardram & Bossen, 2003). In our own study, we have observed many incidences where nurses had to spatially move around the ward to look for patient charts that had been removed from the designated cabinet.

Second, the spatial *distance* that must be covered in order to access information should be evaluated. In this regard, knowing where relevant personnel and information artifacts are can help minimize the spatial distance that one has to cover when acquiring or handing over information.

Third, the *physical setting* of information centers impacts how effective information flow takes place. In fact, how we manage the spatial arrangement of objects around us is integral to the way we think, plan and behave (Kirsh, 1995). Further, a specific predefined spatial organization of artifacts in the workplace has been found to facilitate clinical work flow (Baeng & Timpka, 2003). For example, the shift change room in our study ward, equipped with whiteboards for shift reports and a large table where nurses could sit together during shift change, provided an inviting environment for incoming nurses to prepare for their shift work and to interact socially with each other. Conversely, when shift change takes place in public hallways, nurses are often interrupted by patients and their families, as observed in our study ward (Tang & Carpendale, 2008) as well as in the literature (Mei$\beta$ner et al., 2007; Reason, 2000). Such distractions are detrimental to the quality of information flow (Patterson et al., 2004). Therefore, physical settings for conducting handoffs should be private to protect patient confidentiality, reasonably quiet, away from interruptions and background noise, with appropriate lighting and ample writing space to take notes (Solet et al., 2005). Moreover, because medical work is constantly intense and time-pressured, clinicians such as nurses rarely find time to interact socially with their colleagues during their shift. Thus a physical setting that allows for casual communication during the brief duration of shift change is valuable, as was evident in our studies (Tang & Carpendale, 2007, 2008). A setting that allows clinicians to adjust the positioning of the computer monitor on which a patient's medical record is displayed during consultations was also found to improve the dynamics of encounters such that the patients become more engaged when they could see their own medical records on the monitor (Ventres et al., 2006).

Fourth, the *spatial arrangement of information* on artifacts also plays a role in the efficiency of information flow. To enhance information sharing, the organization of information in an artifact should also be studied. A well-structured template offering clear organization of information can facilitate information retrieval (Baeng & Timpka, 2003). Conversely, shared artifacts that do not follow an agreed-upon structure may render it difficult to retrieve information. Patient charts in our study ward used color-coded pages for different clinical disciplines. But sometimes clinicians do not follow the convention, making it difficult for others to find required information. In fact, a familiar layout of information has been shown to serve as important external memory that can facilitate information retrieval, which is especially valuable in time-critical situations, for example, to rescue a coding patient (Hardey et al., 2000; Tang & Carpendale, 2007). Similarly, a spatially encoded sequence of actions has also been reported to aid clinicians in carrying out their work (Baeng & Timpka, 2003).

### 4.5. Temporality

Timely information is crucial for making a diagnosis, treatment, and care plan. The progression of a patient's illness over time, together with the actions taken by people in different places such as in a medical ward and in an operating room, constitutes a patient's illness trajectory (Bardram, 2000; Reddy et al., 2006; Strauss et al., 1985). This trajectory information is particularly important to nurses who are assigned to patients on a shift basis. They must find out the patient's medical history and illness trajectory to be able to undertake appropriate patient care. Nurses must also take into consideration both the patient's temporal trajectory and their own time plan so that patient care can be delivered in a timely and efficient manner (Reddy et al. 2006).

To do this, nurses often mentally plan and schedule their work at the beginning of a shift, based on the temporal constraints and flexibility of their patients as well as their own. They make schedules to minimize temporal ambiguity by arranging tasks in proper temporal order, synchronizing tasks for conflicting temporal activities and allocating temporal resources to overcome the problem of scarcity (McGrath, 1990). In practice, however, scheduling and rescheduling takes place constantly in medical work due to unexpected changes in the patient's condition.

Shift change occurs in the overlapping period across consecutive shifts. Time assigned for the shift change process varies between settings. But shift change is often time-consuming, resulting in excessive overtime and inability to meet patients' needs during the process (McKenna, 1997). Nurses' shift change takes 10 to 61 min to complete, depending on the setting (Lamond, 2000; Sexton et al., 2004; Tang & Carpendale, 2007) and costs about £1.5 million per year in the United Kingdom (Hewitt, 1997). Therefore the assigned and the actual time taken for shift change should be evaluated to achieve a healthy balance between the quality of information flow and the cost.

Clinicians work in different shift cycles, making them temporally separated. Therefore artifacts that allow them to asynchronously communicate with their colleagues are widely used. Patient charts are a typical example of such artifacts used to coordinate collaborative work among multidisciplinary clinicians. These charts provide incoming nurses with up-to-date treatment plans and progress reports written by other clinicians (e.g., physicians) so that they can carry out appropriate nursing care. In some settings, these coordinating artifacts not only provide a means for asynchronous communication between collaborators, they also serve as a permanent record for later review when needed, for example, in a legal investigation.

The sequence of information access is sometimes important for achieving the best outcome from the information flow. Patterson's study of the space shuttle mission control shift change revealed that incoming flight controllers first gathered information from the data screens, flight log, and other documentation before being updated by the outgoing controller. With this sequence, they were able to build a good mental model of the current status, which helped them formulate their questions in the verbal handover (Patterson & Woods, 2001). Similarly, Grusenmeyer (1995) found that if the incoming operator met with the outgoing operator before familiarizing himself with the operation activities from inspecting the machinery and the written documents, then the verbal exchanges would be less favorable to the needs of the incoming operator than to the information the outgoing operator considered necessary to hand over.

Information flow activities may also exhibit some characteristic patterns at a collective level—temporal rhythms—that potentially allow others to orient and coordinate their activities for accomplishing tasks (Reddy & Dourish, 2002). For example, incoming nurses in our study ward often started inside the shift change room to acquire information necessary for their upcoming shift, and we have observed a nursing administrator taking advantage of this knowledge to move into face-to-face communication with all the incoming nurses simultaneously so that she did not have to look for individual nurses in their ward wings once their shift started. In addition, individual clinicians may also exhibit specific temporal patterns of information seeking activity that may help other people to locate them more easily (Reddy & Dourish, 2002; Reddy et al., 2006).

### 4.6. Communication Mode

Effective information flow is achieved through the coordination of spatial and temporal contexts of the work setting to allow information flows through specific personnel and artifacts in a timely and effective manner. Thus workgroups use a variety of communication modes to facilitate group interactions and collaborations (Orlikowski & Yates, 1998).

Face-to-face communication undoubtedly offers the best quality of communication (Kraut, Egido, & Galegher, 1988; Orlikowski & Yates, 1998; Solet et al., 2005; Vidyarthi, 2004). It offers a full range of communication modes—facial expression, posture, gestures, smell, eye contact, and proximity to help information participants to interpret and to make sense of the information being communicated (Solet et al., 2005). Yet the mobile and dynamic nature of medical work often makes it difficult for collaborators to interact in this rich medium. Instead, technologies are often deployed to bridge spatial and/or temporal separation. Despite being concise, the traditional same/different time/place computer-supported cooperative work model (Johansen, 1988) provides an easy way to understand how technologies may be used to connect collaborators across time and place. In fact, the inherent characteristics of various technologies afford different modes of communication for accomplishing work tasks (as illustrated in Figure 3, top row). For example, an open voice link allowed the space shuttle mission controllers who were spatially distributed to listen to updates and make corrections as necessary through discussions and negotiation as a team (Patterson & Woods, 2001). Paper artifacts placed in designated locations are often used to mediate communication between temporally distributed collaborators through textual and free form annotations. However, such asynchronous communication could result in ambiguities and unanswered questions that cannot be easily pursued without making extra effort (Solet et al., 2005).

The life span of information is tightly coupled with the mode used for communication. For instance, verbal communication is generally ephemeral unless it is audio-taped for future use. Information inscribed in official artifacts, both physical and digital, tends to be kept as permanent records. Therefore, a mismatch between them could lead to serious consequences. For example, when a patient's treatment information is not properly kept in a permanent record, the lack of information for review could lead to accountability problems in situations like legal proceedings.

In the medical setting, information confidentiality is of paramount concern such that a patient's personal information is strictly bound by ethical and organizational guidelines as to how and where such information should be communicated and recorded, as well as who has access to the information. Thus an appropriate communication mode should be chosen for the specific kind of information.

On the other hand, Behara et al. (2005) found that the choice of communication modes plays an important role in the co-construction of a mental model for a task. Yet, McKenna (1997) did not find any particular communication mode superior than the others. Instead, the appropriateness of a particular communication style depends on the information required, the people involved and the artifacts available, as well as their spatial and temporal constraints.

With modern medicine increasingly shifting to the use of computer-based medical records for improving the quality, storage, and use of medical data, allowing distributed clinicians to access centrally archived patients' information in real time, the quality of medical data is considerably improved over the paper system. However, the design of digital information systems has mainly focused on improving the data quality while neglecting the actual communication processes. For example, clinicians create or modify cognitive artifacts to deal with cognitively demanding tasks and for supporting teamwork such as spatially arranging physical patient charts in a particular order to indicate the status of patients (Baeng & Timpka, 2003). Yet, current information systems often fail to recognize and support these kinds of subtle but crucial information processing properties of the complex socio-technical systems in medical settings. Meanwhile, mouse and keyboard input for interacting with current digital information systems has been found to be suboptimal as compared to the familiar and flexible pen-and-paper interaction. Besides, many information systems are not integrated with other information artifacts, such as paper documents or other digital systems. This poses difficulty in maintaining data synchronization across varying information artifacts (Ellingsen & Monterio, 2003). Therefore the design of computer-based information systems should not only take into account the importance of sustaining the quality of data but also be planned for integrated, efficient, and effective communications.

## *5. USING INFOFLOW FRAMEWORK TO EVALUATE A NEWLY DEPLOYED TECHNOLOGY*

In this section, we present a case study that applies the InfoFlow Framework to an assessment of the data generated from a study that evaluated the impact of the deployment of a mobile voice communication system on our study ward.

The InfoFlow Framework was built upon a review of literature and our field study that investigated the information flow during nursing shifts. Our observational sessions spanned across both regular shift work periods and shift changes. We found the communication strategies used for the information flow during shift change and those used during regular shift work to be highly similar. Therefore, in this section we report the application of the InfoFlow Framework in the analysis of the data collected during a field study on the deployment of a mobile voice communication system, Vocera. We highlight the findings of this study in this section; more details can be found in Tang and Carpendale (2009).

We used a set of communication strategies associated with the InfoFlow Framework to structure the findings. These communication strategies were found to be widely used by nurses in our study ward when carrying out their work. The deployment of Vocera thus allowed us to conduct a third-party study to evaluate how this mobile communication technology impacted the nurses' communication and information flow in the study ward where the nurses are often spatially distributed over different ward wings. We expected that they would take advantage of the hands-free voice communication system to receive updates from their outgoing coworkers without physically moving into face-to-face reporting as previously observed (Tang & Carpendale, 2007, 2008).


**FIGURE 5** (left) A Vocera badge (http://www.vocera.com). (right) Pressing the Vocera button to place a call.



### 5.1. Vocera Communication Technology

The deployed technology was the Vocera® communication system (http://www.vocera.com/). It uses voice recognition and wearable communication badges running on a wi-fi network (Figure 5). Group members of the system can hold two-way conversations with other members using natural spoken commands. The wearable device is typically worn with a lanyard or clipped on a shirt collar. To make a call, one just has to press the button and give a verbal command to the automated operator.

### 5.2. Data Collection and Analysis

This study was conducted in the 1st week (first stage) and the 5th month (second stage) of Vocera's deployment. Eight and 12 observational sessions were conducted, respectively; each lasted 2 to 4 hr. The observations took place during regular shift periods, shift changes, and meal breaks. Participants included 3/1 unit clerks, 9/7 nursing aids, 36/37 nurses, and 1/2 patient care managers in the first and the second stages, respectively. One unit clerk, 4 nursing aids, 17 nurses, and 1 manager participated in both stages. All the participants carried a Vocera badge during their shift.

Observations and interviews were used to find out how the participants used the system. Field notes were taken with pen and paper. 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. Observations primarily took place around the central nursing station as many Vocera communications were initiated in response to incoming phone calls. With its central location, it was easier to locate the respondents who were often distributed in the ward wings. Because most conversations were brief, contextual information was usually missing and could only be collected 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.

We first used open coding to analyze the collected data, based on an initial set of codes. New codes were created when the initial codes did not fit the observed events. Some examples of the codes are [BAD VOICE RECOGNITION], [CHECK AVAILABILITY], and [MAKE CALLS AT POINT OF CARE]. The codes were then grouped under relevant communication strategies, each associated with a factor of the InfoFlow Framework. The communication strategies are listed in the next subsection. The codes that were grouped for each communication strategy were inspected for causal relationships or sequential occurrence of the events. The ordered event codes and the standalone ones were then organized using a fishbone diagram (Ishikawa, 1960) as shown in Figure 6, with the six factors of the InfoFlow Framework, each representing a communication strategy, contributing the structure.

Color is used in the fishbone diagram to differentiate positive and negative or unexpected phenomena. The negative or unexpected phenomena are shown in darker backgrounds. Because the displayed data includes observed events and series of events showing causal relationships that are a result of Vocera deployment, sequential events are to be read from the outer end toward the main fishbone for each framework factor. To illustrate, in the Communication Mode fishbone in the bottom right of Figure 6, observed behavior related to participants' use of Vocera as their primary communication channel is shown: The data revealed that intercom broadcasts were treated as ambient noise, which in turn led to two outcomes: nurses working on the floor ignored the intercom paging and unit clerks had to sound panic to draw attention from their colleagues. Similarly, on the left side of the Temporality fishbone, nurses had to speak slower than their natural speech due to transmission latency. Therefore with the causal and ordered relationships of the displayed events, together with the use of color and color shades, the fishbone representation provided an overview visualization of Vocera deployment as to why Vocera was or was not adopted as a mobile voice communication device (right end of the main fishbone). The visualization also helped to focus the analysis of the phenomena impacted by each framework factor.

### *5.3. Summary of Findings*

From our observations, we found the communication strategies that we identified resonate with some aspects of our framework. The six framework factors were all associated with a primary strategy for coordinating the communication

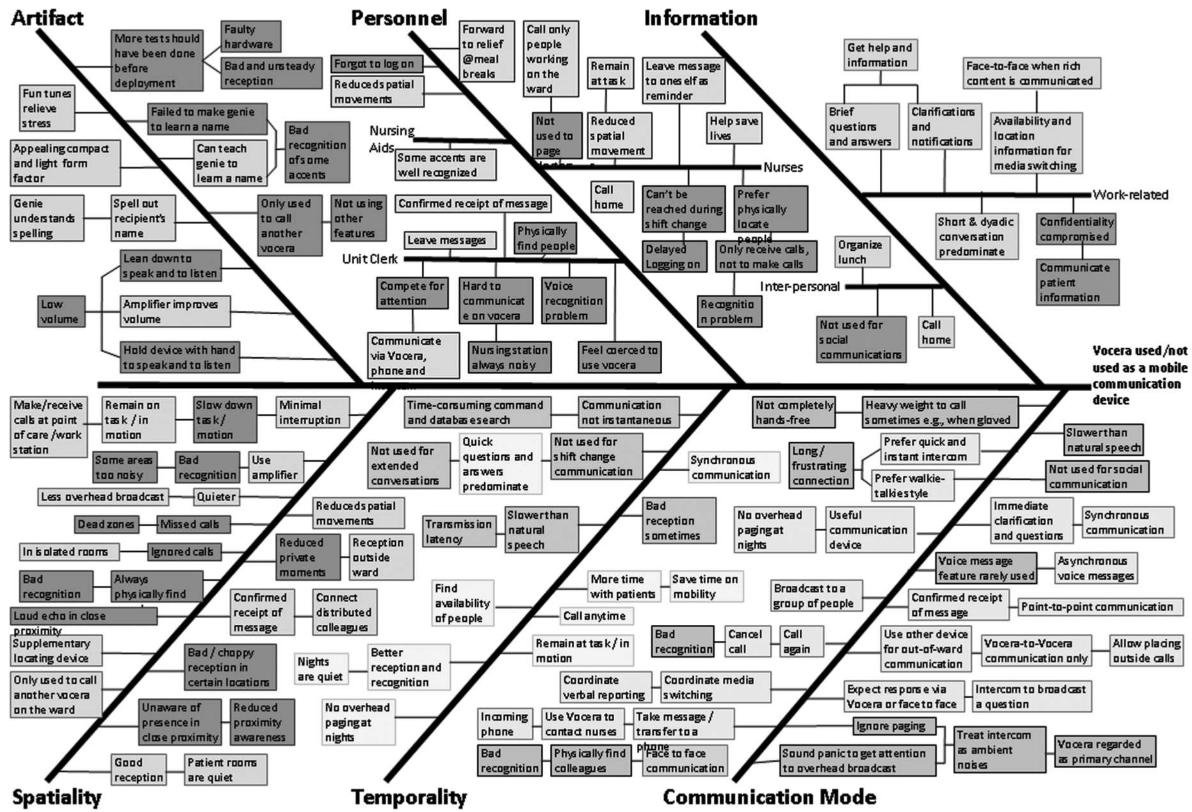


**FIGURE 6** A fishbone diagram used for visualizing and analyzing the findings of the Vocera deployment. (Negative or unexpected phenomena in darker backgrounds.)

on the ward as follows. The associated framework factor is italicized in each communication strategy:

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

On the surface, these communication strategies are independent of each other. But they are indeed interrelated as consideration of the other factors is inherent with the use of the strategies. For example, when deciding on what artifact to use, the information at stake, the intended recipient, the location of the recipient, and the desired communication mode at that moment were all reflected. Thus, the use of the InfoFlow Framework in our analysis allowed us to identify strengths and weaknesses of the technology in supporting communication in the ward. It also allowed us to focus on individual factors as well as on the interrelationship of multiple factors.

Despite problems encountered with the voice recognition capability of Vocera Communication System at connection, this technology has positively contributed to more frequent and timely communication among the spatially distributed clinicians without leaving their task at hand. Thus, the reduction in unnecessary mobility has allowed clinicians to regain time for actual patient care. Our study also recorded a life-and-death incident in which Vocera played a determining role in the coordination of a rescue operation. Nevertheless, the technology failed to realize some of its expected uses such as using Vocera for verbal reporting during shift change. Instead, nurses used it only to make arrangements to meet in person for the reporting due to the observed latency in transmission that meant they had to talk more slowly than their normal speech. In addition, several unintended consequences were observed, for example, nurses became oblivious to overhead broadcast announcements and to the presence of nearby collaborators, which could have a negative impact on patient care. Therefore, the study pointed to several (re)design directions for similar technologies, as follows:

- To allow easy and reliable connection for use in time-critical hospital settings as frequent communication among clinicians is vital to work coordination and accomplishment.
- To offer different setup and connection mechanisms to benefit heterogeneous members. For example, nurses who are constantly on their feet and unit clerks who are stationary at the nursing station and are responsible for routing communications can be provided with different devices and connection set-ups to meet their respective needs.
- To provide contextual information about collaborators to facilitate communication and to avoid interruption at inappropriate times.

The framework has thus allowed us to effectively guide the analysis in evaluating the impact of technology deployment on information flow.

## 6. AN EXAMPLE GUIDE FOR USING THE INFOFLOW FRAMEWORK

In general, frameworks are deemed useful if they can be informative in providing full descriptions, be useful in assessing and analyzing similar situations, and/or be helpful in generating new directions (Shields & Tajalli, 2006). Our InfoFlow Framework arose out of a descriptive aid created during the analysis of our field study data. Integration with existing literature further confirmed and strengthened it.

To increase the usability of the InfoFlow Framework to better allow researchers to flexibly reconfigure the factors for evaluating the impact of new technologies in their specific setting, we concisely summarise the six framework factors in a chart (Table 1), in which we pose a fundamental question for each framework factor. From this question, subquestions arise. These questions can act as a guide



**Table 1: A Proposed Question set for Evaluating the Impact of New Technologies on Information Flow in Hospital Settings**

Information
What information is important for the continuity of patient care?

- How many different kinds of information?
- How does each kind contribute to patient care?
- Is the set of information specific to the nature of care?
- Is there a way to know if and what information may be missing?

Personnel
Who has what information for the information flow?

- Who are the information participants?
- Who is/are the incoming information participant(s)?
- Who is/are the outgoing information participant(s)?
- What information is required of each participant?
- Who will be handing over the information?
- What expertise, authority or credibility do the people have?
- How do their position, authority and credibility influence the information flow?
- How do individual's customization practices influence information flow?
- Is the information flow process an opportunity for social interaction?
- How can interpersonal communication be supported?
- Is the information flow process an opportunity for educational purpose?
- Do the participants collaborate or compete during information flow?

Artifact
Which artifact has what information for the information flow?

- Which are the information artifacts?
- What information is carried by each artifact?
- Who uses the artifacts for information flow?

*(continued)*

**Table 1: (Continued)**

- Are the artifacts shared by multiple information participants?
- Do the artifacts carry public or private information?
- Do the artifacts carry permanent or ephemeral information?
- How do the artifacts' form factor and material characteristics influence their role in information flow?
- Do the artifacts carry complementary or overlapping information?

Spatiality
Where is the information (i.e. the information participants and artifacts) for the information flow?

- Which artifact carries what information in each place?
- Who carries what information in each place?
- What information is present in each place?
- Are the information participants stationary or mobile?
- Where are the information participants and the information artifacts?
- How to locate the information participants?
- Are the artifacts stationary or mobile?
- How does their mobility/portability influence information flow?
- How to locate the artifacts and how accessible are they?
- What characterizes each place?
- How much mobility is necessary to access the places?
- Does the place (including its setup) support information flow?
- How do information in different places relate?
- Are the artifacts designed with a spatial template of information to support the information flow?

Temporality
When is information (i.e. information participants and artifacts) available for the information flow?

- What are the information participants' shift cycles?
- How long is the information flow process officially provided for?
- How long does the information flow actually last?
- Does the information need to be acquired in a specific order?
- How timely information is available?
- Does the information require immediate attention or action?
- Are the information participants available for the information flow at specific times only?
- Are the artifacts available at specific times only?
- Are the places for the information flow only available at specific times?
- Does and how information flow differs for different processes (e.g., day/evening and evening/night shift changes)?
- What are the temporal characteristics of the information communicated during the information flow: outdated, current or for future use?
- Does the information flow process exhibit individual or collective temporal patterns?
- Are the information flow temporally flexible?

Communication mode
How information is communicated?

- What choices of communication are available?
- How information flow is conducted?

*(continued)*

**Table 1: (Continued)**

- What are the strengths and weaknesses of the method(s)?
- What information is communicated via the method(s)?
- Who uses the communication mode(s)?
- Is there a preferred communication mode by individual participant?
- Does the participants' expertise, authority or credibility influence the choice of communication mode?
- What artifacts are used for the communication mode(s)?
- Is the communication mode spatially constrained or spatially flexible?
- Is the communication mode temporally constrained or temporally flexible?



for data collection when evaluating new technologies that aim to improve information flow. By posing and answering these questions in a given situation, a relatively complete information flow description can be generated. This can be done both before and following the introduction of the new technology, enabling an understanding of the impact of the technology on information flow within the setting.

We chose to tabulate the questions as unranked lists as the framework can be used by starting from any one of the factors depending on the problem in question. For example, we started from the *artifact* factor in the evaluation case study described in the previous section as the goal was to evaluate the impact of the newly deployed communication artifact on the information flow. Table 1 thus provides a rich and flexible list of questions for studying information flow in medical settings.

However, we do note that although these framework factors are useful for characterizing the information flow process and for evaluating new technologies, they are not exhaustive. Other factors such as organizational mandate, culture, and social structure may also impact the information flow.

## *7. CONCLUSION*

The InfoFlow Framework presented in this article was built upon our understanding of the dynamics of information flow acquired in our own investigations of nurses' collaborative work as well as from past research. This framework can guide the evaluation of the elements and their interrelationship during information flow, which will facilitate comparative studies, identification of potential problem areas, and targeted interventions. The framework specifies six essential components of information flow. These are information, personnel, artifact, spatiality, temporality, and communication mode. We have applied the InfoFlow Framework as a tool to aid in the analysis of data generated in a study that assesses a newly deployed technology. However, the results may not be generalizable to other settings.

We then illustrated the use of the framework by structuring it as a set of questions for generating coherent descriptions and for guiding the assessment of new technologies. We anticipate that this framework will provide the community with a systematic means to study information flow and evaluate technologies in the medical setting, particularly in nursing work.

For future work, there are two possible research directions. First, exploring the use of the framework to evaluate new technologies for supporting information flow in other hospital settings could prove rewarding. For example, information flow is also important across multidisciplinary teams, and this may share factors with the nurse-focused InfoFlow Framework. Second, investigating to what extent the framework could be applied to nonhospital settings including other high-reliability domains such as air traffic control, would also be interesting. These research directions would allow us to examine to what extent the InfoFlow Framework is generalizable.

## REFERENCES

Accrediation Canada (2008). 2008 Canadian Health Accreditation Report – Based on analysis from surveys conducted in 2007. Available at: http://www.accreditation.ca (accessed Nov. 19, 2009)

Ash, J., Gorman, P., Lavelle, M., Lyman, J., Delcambre, L., Maier, D., et al. (2001). Bundles: Meeting clinical information needs. *Bulletin Medicine Library Association*, *89*(3), 294–297.

Baeng, M., & Timpka, T. (2003). Cognitive tools in medical teamwork: The spatial arrangement of patient records. *Methods of Information in Medicine*, *42*, 331–336.

Baldwin, L., & McGinnis, C. (1994). A computer-generated shift report. *Nursing Management*, *25*(9), 61–64.

Bardram, J. (2000). Temporal coordination: On time and coordination of collaborative activities at a surgical department. *Journal of CSCW*, *9*(2), 157–187.

Bardram, J., & Bossen, C. (2003). Moving to get aHead: Local mobility and collaborative work. *Proceedings of the Eighth Conference on European Conference on Computer Supported Cooperative Work*, 355–374.

Bardram, J., & Bossen, C. (2005a). Mobility work: The spatial dimension of collaboration at a hospital. *Journal of Computer Supported Cooperative Work*, *14*(2), 131–160.

Bardram, J., & Bossen, C. (2005b). A web of coordinative artefacts: Collaborative work at a hospital ward. *Proceedings of the 2005 International ACM SIGGROUP Conference on Supporting Group Work*, 168–176.

Bardram, J., Hansen, T., & Soegaard, M. (2006). Large interactive displays in hospitals—Motivation, examples, and challenges. *Proceedings of the CHI 2006 Workshop on "Information Visualization and Interaction Techniques for Collaboration Across Multiple Displays*.

Bates, D., & Gawande, A. (2003). Improving safety with information technology. *New England Journal of Medicine*, *348*(25), 2526–2534.

Behara, R., Wears, R., Perry, S., Eisenberg, E., Murphy, L., Vanderhoef, M., et al. (2005). A conceptual framework for studying the safety of transitions in emergency care. *Advances in Patient Safety*, *2*, 309–321.

Berg, M., & Goorman, E. (1999). The contextual nature of medical information. *International Journal of Medical Informatics*, *56*, 51–60.

Bertelsen, O., & Bodker, S. (2001). Cooperation in massively distributed information spaces. In W. Prinz, M. Jarke, Y. Rogers, K. Schmidt, & V. Wulf (Eds.), *Proceedings of the Seventh Conference on European Conference on Computer Supported Cooperative Work*, 1–17.

Bossen, C. (2002). The parameters of common information spaces: The heterogeneity of cooperative work at a hospital ward. *Proceedings of the 2002 ACM Conference on Computer Supported Cooperative Work*, 176–185.

Cabitza, F., Sarini, M., Simone, C., & Telaro, M. (2005). When once is not enough: The role of redundancy in a hospital ward setting. *Proceedings of the 2005 International ACM SIGGROUP Conference on Supporting Group Work 2005*, 158–167.

Cicourel, A. (1990). The integration of distributed knowledge in collaborative medical diagnosis. In J. Galegher, R. Kraut, & C. Edigo (Eds.), *Intellectual teamwork: Social and technological foundation of cooperative work* (pp. 221–241). Hillsdale, NJ: Erlbaum.

Cisco. (2007). *Improved patient care with mobile technology at the children's hospital at Westmead*. Retrieved from http://newsroom.cisco.com/dlls/global/asiapac/news/2007/pr_03-09.html Coiera, E., & Tombs, V. (1998). Communication behaviours in a hospital setting—An observational study. *British Medical Journal, 316,* 673–677.

Covell, D. G., Uman, G. C., & Manning, P. R. (1985). Information needs in office practice: Are they being met? *Annals of Internal Medicine*, *103*, 596–599.

Currie, J. (2002). Improving the efficiency of patient handover. *Emergency Nurse*, *10*(3), 24–27.

De Haan, G. (2000). Presenting spoken advice: Information pull or push? [Interactive poster]. *CHI '00 Extended Abstracts on Human Factors in Computing Systems*, 139–140.

Durso, F., Crutchfield, J., & Harvey, C. (2007). The cooperative shift change: An illustration using air traffic control. *Theoretical Issues in Ergonomics Science*, *8*, 213–232.

Ellingsen, G., & Monterio, E. (2001, August). A patchwork planet: The heterogeneity of electronic patient record systems in hospitals. *Proceedings of the Information Systems Research Seminar in Scandinavia (IRIS) 2000*. pp. 71–95.

Ellingsen, G., & Monterio, E. (2003). A patchwork planet: Integration and cooperation in hospitals. *Journal of Computer Supported Cooperative Work*, *12*(1), 71–95.

Fitzpatrick, G. (2000). Understanding the paper health record in practice: Implications for EHRs. *Proceedings of Health Informatics Conference (HIC 2000).* pp. 323–331.

Fitzpatrick, G. (2004). Integrated Care and the Working Record. *Health Informatics Journal*, 10(4), pp. 291–302.

Forsythe, D., Buchanan, B., Osheroff, J., & Miller, R. (1992). Expanding the concept of medical information: An observational study of physicians' information needs. *Computers and Biomedical Research*, *25*, 181–200.

Gorman, P. N., & Helfand, M. (1995). Information seeking in primary care: How physicians choose which clinical questions to pursue and which to leave unanswered. *Medical Decision Making*, *15*(2), 113–119.

Grusenmeyer, C. (1995). Shared functional representation in cooperative tasks—The examples of shift changeover. *International Journal of Human Factors in Manufacturing*, *5*(2), 163–176.

Gulmans, J., Vollenbroek-Hutten, M., & Van Gemert-Pijnen, J. (2007). Evaluating quality of patient care communication in integrated care settings: A mixed method approach. *International Journal for Quality of Health Care*, *19*, 281–288.

Gurses, A., & Xiao, Y. (2006). A systematic review of the literature on multidisciplinary rounds to design information technology. *Journal of the American Medical Informatics Association*, *13*, 267–276.

Gutwin, C., & Greenberg, S. (1999). A framework of awareness for small groups in shared-workspace groupware (Technical Report 99-1). Saskatchewan, Canada: Department of Computer Science, University of Saskatchewan.

Hardey, M., Payne, S., & Coleman, P. (2000). "Scraps": Hidden nursing information and its influence on the delivery of care. *Journal of Advanced Nursing*, *32*(1), 208–214.

Hardstone, G., Hartswood, M. and Rees, G. (2004). Supporting Informality: Team Working and Integrated Care Records. *Proceedings of Computer Supported Cooperative Work*, ACM Press, pp. 142–151.

Harper, R., O'Hara, K., Sellen, A., & Duthie, D. (1997). Toward the paperless hospital? *British Journal of Anaesthesia*, *78*, 762–767.

Harrison, S., & Dourish, P. (1996). Re-placing space: The roles of place and space in collaborative systems. *Proceedings of the 1996 ACM Conference on Computer Supported Cooperative Work*, 67–76.

Hewitt, B. (1997). Evaluating social interactions on the introduction of a telephone based system for nursing handovers. *SIGGROUP Bulletin*, *18*(1), 26–27.

Houston, T. K., Ray, M. N., Crawford, M. A., Giddens, T., & Berner, E. S. (2003). Patient Perceptions of physician use of handheld computers. *Proceedings of American Medical Informatics Association (AMIA) Symposium*, 299–303.

Ishikawa K. (1960s). *Ishikawa diagram*. Retrieved from http://en.wikipedia.org/wiki/Ishikawa_diagram on September 15, 2009.

Johansen, R. (1988). *Groupware: Computer support for business teams*. New York: The Free Press.

Joint Commission on Accreditation of Healthcare Organizations. (2007). *National patient safety goals*. Retrieved from http://www.jointcommission.org/PatientSafety/NationalPatientSafetyGoals/07_hap_cah_npsgs.htm

Kane, B., & Luz, S. (2006). Multidisciplinary medical team meetings: An analysis of collaborative working with special attention to timing and teleconferencing. *Journal of Computer Supported Cooperative Work*, *15*, 501–535.

Kerr, M. (2002). A qualitative study of shift handover practice and function from a sociotechnical perspective. *Journal of Advanced Nursing*, *37*(2), 125–134.

Kirsh, D. (1995). The intelligent use of space. *Artificial Intelligence*, *73*(1-2), 31–68.

Kraut, R., Egido, C., & Galegher, J. (1988). Patterns of contact and communication in scientific research collaboration. *Proceedings of the 1988 ACM Conference on Computer Supported Cooperative Work*, 1–12.

Lamond, D. (2000). The Information Content of the Nurse Change of Shift Report: a comparative study. Journal of Advanced Nursing, 31(4):94–804.

Lardner, R. (1996). *Effective shift handover* – A literature review. Offshore Technology Report, OTO 96 003, Health and safety Executive, 1996.

Luff, P., & Heath, C. (1998). Mobility in collaboration. *Proceedings of the 1998 ACM Conference on Computer Supported Cooperative Work*, 305–314.

Manias, E., & Street, A. (2000). The handover: Uncovering the hidden practices of nurses. *Intensive and Critical Care Nursing*, *16*, 373–383.

McGrath, J. (1990). Time matters in groups. In J. Galegher, R. Kraut, & C. Edigo (Eds.), *Intellectual teamwork: Social and technological foundation of cooperative work* (pp. 23–61). Hillsdale, NJ: Erlbaum.

McKenna, L. (1997). Improving the nursing handover report. *Professional Nurse*, *12*, 637–639.

Mei*β*ner, A., Hasselhorn, H., Estryn-Behar, M., Nezet, O., Pokorski, J., & Gould, D. (2007). Nurses' perception of shift handovers in Europe—Results from the European Nurses' Early Exit Study. *Journal of Advanced Nursing*, *57*(5), 535–542.

Munkvold, G., Ellingsen, G., & Koksvik, H. (2006). Formalizing work—Reallocating redundancy. *Proceedings of the 2006 ACM Conference on Computer Supported Cooperative Work*, 59–68.

Muskat, C., & Yang, L. (2008). Effective communication: A key ingredient for patient safety. *Qmentum Quarterly*, *1*, 26–29.

Neale, D., Carroll, J., & Rosson, M. B. (2004). Evaluating computer-supported cooperative work: models and frameworks. *Proceedings of the 2004 ACM Conference on Computer Supported Cooperative Work*, 112–121.

Nielsen, J. (1994). Heuristic evaluation. In J. Nielsen & R. L. Mack (Eds.), *Usability inspection methods*. New York: Wiley and Sons. pp. 25–62.

Norman, D. (1991). Cognitive artifacts. In J. M. Carroll (Ed.), *Designing interaction: Psychology at the human-computer interface* (pp. 17–38). Cambridge, UK: Cambridge University Press.

Orlikowski, W., & Yates, J. (1998). *Genre systems: Structuring interaction through communicative norms, 1998.* Retrieved from http://ccs.mit.edu/papers/CCSWP205/

Patterson, E., Roth, E., & Render, M. (2005). Handoffs during nursing shift changes in acute care. *Proceedings of the Human Factors and Ergonomics Society 49th Annual Meeting*. pp. 1057–1061.

Patterson, E., Roth, E., Woods, D., Chow, R., & Orlando, J. (2004). Handoff strategies in setting with high consequences for failure: Lessons for health care operations. *International Journal for Quality in Health Care*, *16*(2), 125–132.

Patterson, E., & Woods, D. (2001). Shift changes, updates, and the on-call architecture in space shuttle mission control. *Journal of Computer Supported Cooperative Work*, *10*, 317–346.

Randell, R., Fitzpatrick, G., Wilson, S., Mamykina, L., & Tang, C. (2009). Evaluating New interactions in healthcare: Challenges and approaches. *Proceedings of the 27th International Conference Extended Abstracts on Human Factors in Computing Systems*, 4771–4773.

Reason, J. (2000). Human error: Models and management. *British Medical Journal*, *320*, 768–770.

Reddy, M., & Dourish, P. (2002). A finger on the pulse: Temporal rhythms and information seeking in medical work. *Proceedings of the 2002 ACM Conference on Computer Supported Cooperative Work*, 344–353.

Reddy, M. Dourish, P., & Pratt, W. (2006). Temporality in medical work: Time also matters. *Journal of Computer Supported Cooperative Work*, *15*(1), 29–53.

Schmidt, K., & Bannon, L. (1992). Taking CSCW seriously: Supporting articulation work. *Journal of Computer Supported Cooperative Work*, *1*(1), 7–40.

Sellen, A., & Harper, R. (2002). *The myth of the paperless office*. Cambridge, MA: The MIT Press.

Sexton, A., Chan, C., Elliott, M., Stuart, J., Jayasuriya, R., & Crookes, P. (2004). Nursing handovers: Do we really need them? *Journal of Nursing Management*, *12*, 37–42.

Shields, P., & Tajalli, J. (2006). *Intermediate theory: The missing link to successful student scholarship*. Department of Political Science, Texas State University, San Marcose, Texas. Retrieved from http://ecommons.txstate.edu/polsfacp/39

Solet, D. J., Norvell, J. M., Rutan, G. H., & Frankel, R. M. (2005). Lost in translation: Challenges and opportunities in physician-to-physician communication during patient handoffs. *Academic Medicine*, *80*(12), 1094–1099.

Strauss, A., Fagerhaugh, S., Suczek, B., & Wiener, C. (1985). *Social organization of medical work*. Chicago: The University of Chicago Press.

Tang, C. (2009). *Studying nurses information flow to inform technology design*. Unpublished doctoral thesis, University of Calgary, Canada.

Tang, C., & Carpendale, S. (2007). An observational study on information flow during nurses' shift change. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 219–228.

Tang, C., & Carpendale, S. (2008). Evaluating the deployment of a mobile technology in a hospital ward. *Proceedings of the 2008 ACM Conference on Computer Supported Cooperative Work*, 205–214.

Tang, C. and Carpendale, S. (2009). A mobile voice communication system in medical setting: Love it or hate it? *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2041–2050.

Turner, P., Milne, G., Kubitscheck, M., Penman, I., & Turner, S. (2005). Implementing a wireless network of PDAs in a hospital setting. *Personal and Ubiquitous Computing*, *9*, 209–217.

Van Eaton, E., Horvath, K., Lober, W., Rossini, A., & Pellegrini, C. (2005). A randomized, controlled trial evaluating the impact of a computerized rounding and sign-out system on continuity of care and resident work hours. *American College of Surgeons*, *200*, 538–545.

Ventres, W., Kooienga, S., Vuckovic, N., Marlin, R., Nygren, P., & Stewart, V. (2006). Physicians, patients, and the electronic health record: An ethnographic analysis. *Annals of Family Medicine*, *4*, 124–131.

Vidyarthi, A. (2004). *A fumbled handoff: Missed communication between teams*. Agency for Healthcare Research and Quality. Retrieved from http://www.webmm.ahrq.gov/case.aspx?caseID=55

Wilson, S., Galliers, J., & Fone, J. (2005). Medical handover: A study and implications for information technology. *Proceedings of Healthcare Systems, Ergonomics and Patient Safety (HEPS).* pp. 337–341.

Wilson, S., Galliers, J., & Fone, J. (2006). Not all sharing is equal: The impact of a large display on small group collaborative work. *Proceedings of the 2006 ACM Conference on Computer Supported Cooperative Work*, 25–28.

Xiao Y. (2005). Artefacts and collaborative work in healthcare: Methodological, theoretical, and technological implications of the tangible. *Journal of Biomedical Informatics*, *38*, 26–33.

Xiao, Y., Schenkel, S., Faraj, S., Mackenzie, C. F., & Moss, J. A. (2007). What whiteboards in a trauma center operating suite can teach us about emergency department communication. *Annals of Emergency Medicine*, *50*, 387–395.