Can DiCoT Improve Infection Control? A Distributed Cognition Study of Information Flow in Intensive Care

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Abstract

Poor information flow in Intensive Care Units (ICUs) can degrade patient wellbeing and expose hospital staff to hazardous conditions. To identify areas for improvement, we applied the Distributed Cognition for Teamwork (DiCoT) methodology and representational framework in a large hospital in the Southeastern US. We conducted ethnographic observations and interviews for 4 months, discovering systemic information flow barriers. This paper focuses on patient isolation status, which is put into place when a communicable disease is discovered, and how status propagation is sometimes delayed, increasing risk of Hospital-Acquired Infection (HAI). We use DiCoT to navigate the solution space, and propose introducing digital signs. Our main contribution is describing how DiCoT principles quickly led us to solutions to improving information flow in critical care. In future work, we will conduct further investigation, with additional design iterations.

Author Keywords

Healthcare; information flow; distributed cognition; infection control; intensive care; internet of things.

ACM Classification Keywords

D.3.1 [Requirements/Specifications]: Elicitation methods; J.3 [Life/Medical Sciences]: Medical information systems; H.5.3 [Group/Organization Interfaces]: Theory and models

Introduction

Information propagation problems are a leading source of preventable clinical errors [24]. In hospital ICUs, a work environment that is complex, dynamic, and unpredictable [16, 5], the wellbeing and safety of patients and staff alike are dependent on effective coordination and information flow among hospital staff and physicians [27], as well as between human and technological actors [1].

One important factor that leads to increased mortality in ICUs are Hospital-Acquired Infections (HAIs). In 2002, the Center for Disease Control and Prevention (CDC) estimated that HAIs were linked to 99,000 deaths [12]. While patient isolation procedures are in place to prevent HAIs [21], their success depends on effective information flow. In this paper, we study patient isolation procedures, and discuss alternative solutions to improving information flow, based on an analysis of the ICU *system,* using a Distributed Cognition (DCog) approach [11, 10]. Our main contribution is to outline how DiCoT [3, 6], a particular DCog technique, leads us to design new solutions to improve information flow in the ICU. In order to describe this case in sufficient depth, we leave comparison to alternative design approaches to future work.

The Intensive Care Unit

A hospital ICU is usually staffed by physicians, pharmacists, respiratory therapists, nurses, Patient Care Assistants (PCAs), a Charge Nurse, and the Unit Manager. A nurse is usually assigned to one or two patients, but they often share work. Experienced nurses supervise novices. A nurse on the Critical Care Assessment Team identifies patients elsewhere in the hospital in need of intensive care. Pharmacists manage medications. PCAs manage many artifacts, including isolation signs. Physicians visit patients daily, while nurses provide continuous care.

Information Flow

Most ICU patients come from the Emergency Department (ED). Nurses work in one unit, so patients are handed off from ED to ICU nurses. The ED nurse typically briefs the ICU nurse in advance via phone. In an emergency, briefing may occur in-person, upon patient arrival.

Since team members, especially physicians, are often in another unit or office (or another clinic), face-to-face, colocated information exchange is not always possible. However, several artifacts support information flow by other means. Phones support synchronous, non-colocated conversation. Pagers and Electronic Health Records (EHRs) support asynchronous, non-colocated information exchange.

Distributed Cognition in the ICU

Patient care is highly collaborative work, and we therefore believe that the theory of Distributed Cognition [11], which views cognition as being distributed among actors, artifacts, space, and time [10], is well-suited to understand the use of information technology in this context [9].

For much of its history, DCog methods and principles have remained largely tacit and opaque [8]. Distributed Cognition for Teamwork (DiCoT) is an effort to bring DCog to a broader audience through formalization. We have chosen to apply DiCoT in order to advance this broader effort.

DiCoT is a methodology and representational system that draws upon Contextual Design and Claims Analysis [3]. It is a means of applying DCog theory toward development of new solutions [22, 17]. It has been applied, for example, to understand infusion administration in the ICU [17] and mobile healthcare systems [15].

DiCoT principles express cause-effect relationships between system design and resulting problems. We seek to

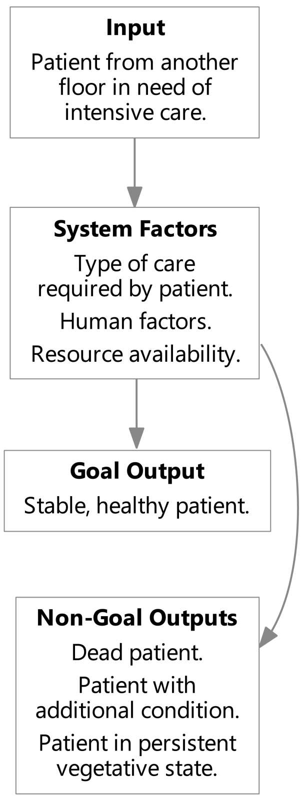

Figure 1: The High-Level Input Output Model.

improve DiCoT's predictive ability by applying its principles, measuring results, and modifying principles as needed.

Although DiCoT is promising, to the best of our knowledge, only one DiCoT study has been conducted in the ICU so far [17]. Additionally, while several DCog field studies have focused on trauma units (e.g., [14, 20, 18, 19]), no known DCog analyses have studied patient isolation in the ICU. In fact, we found only one study that approaches isolation from an ergonomics point of view [26] focusing on barriers to hygienic compliance. Our work, instead, investigates the distribution of cognition, revealing the problems that lead to Cohen's [5] observations of inconsistent isolation documentation. This paper seeks to fill this gap by using DiCoT to identify and mitigate the harmful effects of information flow bottlenecks in the ICU. We expect that the proposed framework will help identify how to reduce errors, and as a consequence, improve quality of care.

Design Ethnography

In order to understand the information flow structure within the clinical care context, we conducted ethnographic observations and interviews in an 18-bed intensive care unit of a large, non-teaching hospital, located in a medium-sized metropolitan area in the Southeastern United States. We made 10 visits to the ICU, over the course of four months, totaling 16 hours of detailed observations. We followed a weekend afternoon cohort with whom we had established a congenial relationship; observer-participant rapport is necessary to obtain valid, truthful results [7].

Approach

To gather the in-depth information necessary to perform a DiCoT analysis, we conducted Contextual Inquiry [2] with consenting care providers for a period of time ranging from 20 minutes to 2 hours. We ended observation early if a participant engaged in unrelated work, such as hygienic activities, or if a participant became too busy to verbalize their actions; the specialized knowledge of medical practice makes it difficult for an outsider to infer the intents of actions.

Because it is possible that problems arise when participants are under such strain that they cannot verbalize their actions, we conducted individual and group retrospective interviews to uncover situations that we would not have been able to directly observe. This type of mixed-methods approach is common in medical HCI research (e.g., [23, 7]). We ended an interview session when participants felt that the questions were fully answered.

We recorded observations by hand, as per Institutional Review Board (IRB) requirement. Other researchers have faced resistance to video recording in hospitals, due to medico-legal concerns [7]; this hospital was no different. We transcribed answers to interview questions, as well as discernible utterances, relevant body movements/positions, and emotions that participants expressed. We sketched the artifacts and the physical environment that we encountered.

Participants

Six nurses, the unit manager, 3 PCAs, 2 pharmacists, 1 respiratory therapist, and 2 physicians participated in our study. Due to the nature of emergencies in the ICU, participants came and left during group interviews, resulting in a variable number of participants, between 2 and 7, attending these sessions.

DiCoT Analysis

We followed Rajkomar and Blandford's work [17] and categorized the data to construct the six main DiCoT models: *Input/Output*, *Physical Layout*, *Information Flow*, *Artifact*, *Social Structure*, and *System Activity*. Together, these models helped us to understand the basic mechanics of the system. However, we focus primarily on the results revealed by the Information Flow and Cognitive Artifact models, as they are most relevant to patient isolation status propagation. Next, we briefly apply DiCoT principles to propose possible solutions.

While the complete set of DiCoT principles is listed by Blandford and Furniss [3], in the context of this work we only highlight the most relevant principles to our analysis:

Naturalness Principle. The form of a representation should match the form of what it represents. [1]

Horizon of Observation. Perceptual availability often determines situational awareness.

Create Scaffolding. Create external representations to alleviate long-term memory demands. For example, we may use a bookmark to track where we left off.

Information Movement. Information flows in many ways: screen displays; shouts; facial expressions. The medium of conveyance determines how information may be processed.

Buffering. Incoming information can interfere with ongoing tasks, degrading performance, or it can become lost if ignored. Less important information should be queued, rather than interrupting an important task.

Behavioral Trigger Factors. Local factors can trigger behaviors, reducing the need for an overall plan.

[1] It is worth noting that, in Media Naturalness Theory, the term *Naturalness* refers to the similarity of a medium to face-to-face interaction [13]. This is known in DiCoT as the *Communication Bandwidth* principle.

Expert Coupling. The more experience one has in an environment, the better they perform in it. The expert is "coupled" with the environment.

Error Checking. Error checking should be a shared responsibility. Separate information channels to ensure that decisions are independent.

In order to construct our DiCOT models, we searched for and coded all mentions of isolation in our field notes and interview transcriptions. We had asked several nurses about the process for isolation procedures, so extracting the commonalities in their responses revealed a collectively understood ideal process. We had also asked nurses to recall and reflect on non-ideal instances that may have exposed them or other patients to communicable diseases. In this case independently corroborated responses revealed systemic shortcomings.

Observational data revealed tacitly understood details, such as role-to-task mappings, and situations in which information overload could lead to propagation failure. Those outside the cognitive science domain tend to overestimate their cognitive limits; medical personnel are no exception [7].

Delayed Propagation of Contagion Risk

It is common for patients in the ICU to carry a contagious disease, and it is therefore important to prevent transmission to staff, other patients, or visitors. However, we discovered that this key operation is impaired by several important barriers that prevent effective patient isolation. We explain them in this section.

Cognitive Artifact: Isolation Signs

When a patient is "on isolation," signs act as a *Trigger Factor,* cuing staff to don the appropriate gear. Signs are fixed to the doorway for visibility *(Horizon of Observation)*.

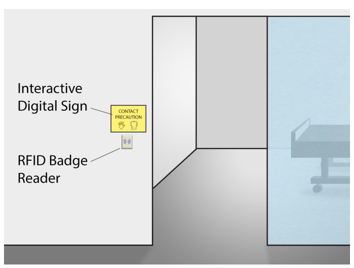

Figure 2: Our proposed interactive digital sign and badge reader. Staff members may use the device to display or remove an isolation sign interactively. The device is a contextually-situated representation of the isolation status in the EHR. Interactions with the sign are also interactions with the EHR.

In **Contact** isolation, nurses must avoid direct physical contact, wearing gloves and gowns while visiting the patient in-unit. Under hospital policy, however, they are *not* worn during transport. If a patient has **C. Diff.**, nurses are additionally required to wash their hands.

In **Droplet** and **Airborne** isolation, the contagion spreads via mucus and respiration, respectively. These require different masks for staff. Patients wear masks in transport.

Neutropenic isolation protects patients with compromised immune systems. Patients wear a mask during transport.

Combination. Isolations may be combined if a patient has multiple conditions; *Droplet/Contact* is the most common. For uncommon combinations, staff hang multiple signs.

Information Flow: Hanging the Signs

Isolation may seem simple at first glance. However, how the ICU team performs this selection, and the way that isolation propagates within and between units, is complex.

Our observations revealed that patient isolation status and type can be inferred from external *Scaffolding.* If a new patient wears a mask, they are on *Droplet, Combined, Neutropenic,* or *Airborne* isolation. The type of mask may indicate which sign to hang. If the team suspects another contagion, they draw a specimen, send it to the lab for testing, and tentatively hang a sign. If the test is negative, they remove the sign. Additionally, if one notices that the EHR indicates patient isolation, they hang a sign.

Staff may enter patient isolation into the EHR manually, but the EHR also triggers it automatically in two common situations: (1) a user places an order to the lab for a specimen to be tested for a suspected contagion, or (2) the patient has a history of harboring a particular contagion.

Barriers to Contact Isolation Status Propagation

Although the mask is the primary artifact that conveys isolation, in the case of *Contact* isolation, it is absent. Isolation status is still available to PCAs on a central workstation computer screen that lists the isolation status of all ICU patients, and it is available to nurses in the banner of the patient's EHR chart. However, both of these displays are relatively non-salient. Especially during an emergency, when the team must attend to higher-priority diagnostic information – e.g., lab analyses or chest x-ray results – the staff may be exposed to a contagion for a long time before discovering the isolation status. A nurse estimated that, in one instance, an hour elapsed before a PCA discovered Contact Isolation in the EHR. While it is fortunate that this was eventually discovered, contact isolation goes without any EHR documentation 18% of the time [4]. In these cases, isolation cannot be discovered in the EHR at all!

Patients Not Isolated During Transport

Contact-isolated patients do not wear gowns during transport, inconsistent with CDC guidelines [21]. In an interview, a participant speculated that the intent of this policy may be to preserve the hospital's image as a place of patient health. Exposure risks to visitors and nurses aside, this contributes to the lack of isolation-communicating cues noted in the previous section.

Multitasking and Information Flow

Multitasking also impacts isolation status propagation. In one instance, we observed a PCA conversing with an off-unit nurse via phone. During this conversation, a nurse approached the PCA, asked them to hang an isolation sign, and then walked away without confirming that their request was understood. After the PCA hung up the phone, they shouted to the nurse, asking them to repeat the request. The nurse did so, and the PCA rushed to hang the sign.

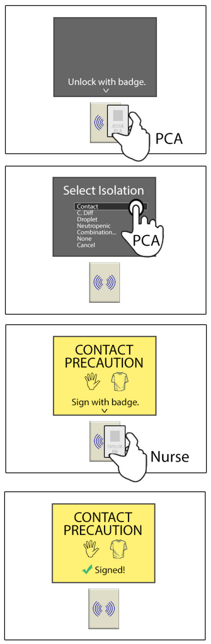

Figure 3: The design concept features a touchscreen and badge reader. We observed that PCAs hang signs, while nurses "sign" isolation orders. This solution preserves that role-to-task mapping. A PCA badges in and selects the status. When a nurse "signs" the isolation order with their badge, the device records the signature in the EHR. Unlike a paper sign, the device is resistant to visitor tampering, since it is unlocked with a badge.

We investigated how common these situations were. According to the PCA, they are often interrupted while on the phone. Applying the DiCoT principle of *Buffering*, we realized that the incoming request could have been lost in this scenario, reducing the availability of isolation status in the *Horizon of Observation*, and therefore increasing HAI risk.

Outcomes and DiCoT Design Considerations

By applying DiCoT, we discovered and described several information flow issues. We now apply DiCoT to propose the design of a cost-feasible solution based on digital signage – touchscreen computers are currently available for under $100 USD. Initial feedback from 6 nurses and 1 team leader led to an early design revision.

Interactive Digital Display

We propose deploying a digital sign next to each patient room, within the *Horizon of Observation*, to replace the paper isolation signs (see Fig. 2). The display resembles the original artifact, including its drawings of isolation gear, implementing the *Naturalness Principle.*

Admission. The ED records isolation in the EHR, so the device can display it automatically when a patient arrives in the ICU. Isolation is mentioned during briefing, so this redundant information channel provides *Error Checking.*

ICU Stay. If a contagion is discovered during the patient's ICU stay, staff may hang the sign and simultaneously record it in the EHR, as shown in Fig 3, increasing the likelihood of documentation, thus improving on the important issue of poor documentation compliance noted by Cohen [4].

Discharge. When the patient is discharged to a less intensive floor, their isolation status follows them, because it has been recorded via the device.

Contact Precautions

In conjunction with our device, we propose enhancing existing cues to provide independent *Error Checking.* Because mask presence signals non-contact isolation, similar *Scaffolding* could convey contact isolation. Contact-isolated patients could wear gowns, or their nurses could wear gloves, during transport. Also, masks could be color-coded by isolation status, in order to reduce the likelihood of selecting the wrong mask to use during transport.

Conclusion

In this study, we used a design ethnography approach to gain an in-depth understanding of current information flow problems in the ICU. By framing our observation in the context of Distributed Cognition and using DiCoT as an exploration tool, we found that poor information flow and limited scaffolding expose hospital staff to contagions. We hypothesize that appropriate use of digital signs next to patient room doorways may mitigate these problems, while improving documentation compliance. Several DiCoT principles corroborate our proposed solution.

In future work, we will conduct additional design iterations, as well as controlled studies, to strengthen DiCoT's predictive capability, and to avoid negative consequences often associated with replacing paper artifacts [25]. DiCoT provided a vocabulary to express the problems we discovered, and its principles quickly led us to a non-obvious solution. We recommend its use in future studies. While this paper focused on one particular application of DiCoT, it will be worthwhile to compare DiCoT to alternative design approaches in future work.

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