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Cognitive Properties of a Whiteboard: A Case Study in a Trauma Centre

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Abstract. Distributed cognition as an approach to collaborative work holds that a work unit is cognitive system in which cognitive activities are carried out jointly by workers with the use of tools. This approach has several direct implications to the study of collaborative work. In this paper, we analysed staff interactions with a large display board in a Level I trauma centre operating room unit. Coordination needs are exacerbated by the unpredictability of incoming emergency surgery patients admitted to the trauma centre as well as other contingencies (such as changes in scheduled surgery cases or staffing). The public display board has evolved into a key component for supporting collaborative work. The physical and perceptual properties of the board are exploited by the clinicians to support rapid paced, highly dynamic work. The canvas-like appearances of the display board, combined with magnetic objects attached to the board, afford its users to taylor the board as an effective coordinative tool and to invent new ways of representing information. Based on the concept of display-based cognition, our analysis illustrates the role of public displays in facilitating negotiation of scheduling, joint planning, and augmenting inter-personal communication.

Introduction

The field of computer supported cooperative work has brought into focus the importance of studying work activities in their natural context (Bannon & Schmidt, 1991). Detailed studies of the interaction with the physical environment and collaborative work can lead to insights into how we work together (Suchman, 1987; Hutchins, 1995a). As reported by those researchers who have paid attention to the work environment and to the way in which people exploit and inventively use the physical and perceptual properties of the work environment (e g. Hutchins, 1995b; Segal, 1994; Berg, 1999; Bardram, 2000), much can be learnt still about collaborative work. An equally compelling reason for studying artefacts in collaborative work is to inform design. Increasingly human collaborative activities are mediated by tools with computing and telecommunication capabilities. With rapid advances in technology, ever more powerful tools are being built to support collaborative work. One useful source of insight into how collaborative tools should be designed comes from observing ways in which non-computerised artefacts are exploited for supporting collaboration. Studies of computer systems (e.g. Bardram, 1997) have shown that these systems failed because of an inadequate understanding of existing work practices. Paper-based forms, for example, perform functions beyond simply conveying information. Ignoring these other functions may have detrimental effects on the usability of computer systems (e.g. Bardram, 1997)

In this article, we present an ethnographic study of a public display board in an operating room (OR) unit in a Level I trauma centre. Coordination needs are exacerbated by the unpredictability of incoming emergency surgery patients admitted to the trauma centre as well as other contingencies (such as changes in scheduled surgery cases or staffing). The board has evolved into a key component for supporting collaborative work.

After describing the study setting and methods, we will present the visual and physical properties of the display board. We will then present the cognitive properties of public displays through the analysis of the observed interactions between the staff and the display board. Discussions will follow the presentation of findings in each of the three areas: display-based cognition, distributed cognition, and articulation work. We will conclude with implications of our study for future research on public display boards and for design of such boards driven by computers.

Large public display boards have previously been studied by researchers (e.g Bardram, 2000; Garbis and Waern, 1999; Whittaker & Schwarz, 1999). With the advance of technology, more and more such boards will be based on computer displays (Stefik et al, 1987; Mynatt, 2000; Berkowicz et al, 1999). It is also the aim of the current paper to help researchers to better understand existing public display boards in use, so that the development of technology can be guided and driven by our understanding of the role of public displays in supporting collaborative work.

Coordinating schedules in operating rooms

Setting

The six operating room (OR) unit is part of a busy, urban trauma centre with over 6,000 admissions per year. Trauma patients are brought directly from incident scenes and are first evaluated in the trauma resuscitation unit (TRU). Emergency surgery may be performed in the OR unit for those patients who need immediate life-saving surgery within a few hours of their admission to the TRU. The OR unit is separated by a door from the TRU. When surgery is over, the patient is transferred to the post-anaesthesia care unit (PACU), which is also nearby on the same floor (Fig.1).

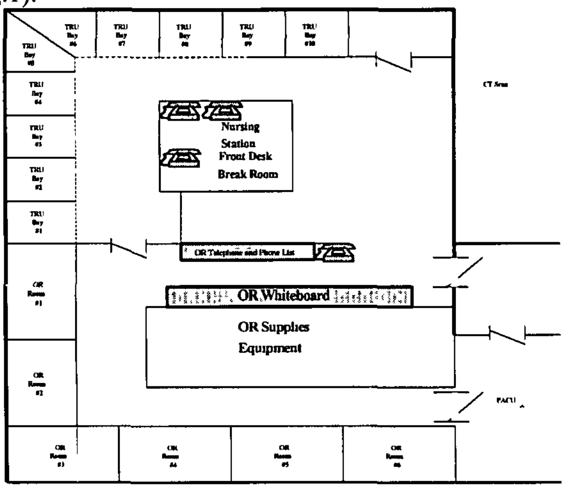


Fig. 1 Layout of the Trauma Resuscitation and Operating Room Units

The majority of the OR surgeries are, however, non-emergency in nature. Non-emergency patients, either previously admitted to the TRU or referred through doctor's offices and clinics, are scheduled for surgery the day before. The OR unit is open around the clock. The number of operating rooms open fluctuates over the course of the day. Generally, more operating rooms are open during the day and weekdays than other times; most of surgery cases occur between the hours of 7.30am and 3:00pm.

OR staff members work a combination of eight and twelve hour shifts. Staff members on an eight-hour shifts are usually relieved for lunch earlier and subsequently complete their shift earlier (3:00pm) than those working twelve-hour shifts (7:00pm).

A list of surgical cases is scheduled ("posted") the day before and distributed to the OR unit by a print-out. The list of cases posted is almost never the list of cases performed the next day. As with many other highly complex and dynamic work environments, uncertainty arises from various sources when changes are frequently introduced. In the study setting, change is constant and unpredictable Examples of changes affecting the planned surgery schedule include cancelled surgeries, unexpected additional surgeries (which result from both newly admitted cases as well as deterioration of previous patient cases necessitating re-visits to the operating room), multi-patient trauma situations in which demand exceeds resource supply, and any external variables impacting OR operational status (unavailable or malfunctioning equipment, lack of supplies, and changes in staffing patterns).

The charge nurse's primary duty is, to paraphrase one of the charge nurses we observed, "to make the ORs work." The charge nurse takes requests for surgery and translates them into a schedule of specific times and sequences in each of the individual operating rooms (one of six) If a case is not scheduled as the first case, its starting time cannot be scheduled The order of the case is then scheduled "to follow" another case. The charge nurse does not have clinical duties ordinarily, although all three charge nurses we observed had extensive clinical experience as OR nurses. Charge nurses work in a corridor connecting the TRU and the OR unit, although they are scrubbed and attired to work in the ORs. For the sake of description, we will use "the charge nurse" as a representative of all three charge nurses observed.

Methods

As part of a larger study of coordination through the trauma care process, access was gained to conduct an ethnographic study of the OR scheduling board used by staff Data were gathered by direct observation, interviewing, and photographing. Due to the sensitive nature of the work observed, most of the data were in the form of notes and photographs but not transcriptions of audio-taped verbal communications.

Most of the intensive coordination activities for the OR unit occur early in the morning. Researcher observations started 6:30am when the day shift charge nurse began shift for the ORs. All three charge nurses were observed. Over a six month period, three researchers (two were registered nurses) observed in the OR board area on eight days. Short interviews were conducted with nurses, physicians, anaesthesia providers in front of the OR board for explanation on its use.

Notes were taken about the people who came to the board and their interactions with the board as well as with other people at the board. When opportunities allowed, the research team conducted brief interviews about board users' purposes and views on the board. Still images were taken

Visual and physical properties of the OR board

Layout and size

The OR board measures 365x122cm (12 feet by 4 feet) and holds magnetic materials which themselves can serve as surfaces for writing. The board is partitioned into three major areas (Fig. 2a). The left-most area is for displaying which patients are scheduled for surgery in which operating rooms. The second section of the OR board is used to hold those surgical cases that are not planned ("add-ons") and are not assigned a start time nor a sequence for surgery. The far right section of the board is used to hold magnetic nametags for all OR staff (Fig. 2b) as well as a variety of indicator magnets. Across the top of the board are various other messages to announce important items. Additional messages may be posted in paper format held in place by magnets or annotated via erasable marker directly on the board.

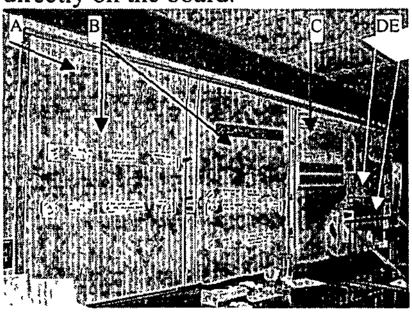


Fig. 2a Overview of the OR board (A. General staff information/announcements, B magnetic case strips for all six ORs in the unit, C Holding place for case strips, especially unscheduled add-on cases; D· Magnetic staff name tags for off-duty staff, E Magnetic staff name tags for on-duty staff)

Fig. 2b A close-up view of the right side of the OR board The top portion holds name tags of all nursing and supporting staff assigned to the unit The name tags of those who were currently on duty for the day were arranged on the bottom according to their assigned shift

Location

The OR board is located at the intersection of the OR unit and TRU (Fig. 1). The area is accessible to ORs, TRU, and ancillary personnel such as housekeeping, supply, patient transport, and administrative staff. Further, the area is supported by other communication and collaboration tools such as telephones and bulletin boards annotating surgical and anaesthesia staff, pager numbers, and announcements.

Schedule representation

Magnetic strips are used to indicate surgery cases (one strip per patient). Three types of strips are used· a white strip indicates a scheduled surgical case (Fig. 3a);

a blue strip indicates an "add-on" case (those that are not scheduled the day before and are not emergency status); and a white strip with red tape at both ends (Fig 3b) indicates an emergency case (also not placed on the surgical schedule the day prior). With all cases (scheduled, add-on, and emergency), the strip contains essential information about the surgical case. The information is hand-written onto the strip based on written and verbal surgery requests. From left to right, the following information items are usually written: expected surgery start time if the case is the first in a particular OR, current patient location (before the surgery) within the facility, patient name, name of planned surgical procedure, responsible surgeon, specialised equipment/supplies, and expected duration of the procedure (see Figure 3a).

Fig. 3a Left. Surgical case strip (in white) for scheduled operative procedure. The patient and surgeon names were blurred to protect privacy On the strip are (left to right) case starting time, location of the patient in facility before surgery, patient name, name of the surgical procedure(s), surgeon's name, special instrument requirements, and estimated length of the case

Fig. 3b Right Case strip for emergency surgery (in white) The ends of the strip are marked with red tape

For scheduled cases, the strips are usually prepared by the night shift charge nurse. For the add-on cases, the strips are prepared as requests come in Scheduled, add-on, and emergency cases are placed on the board under a number corresponding to a specific OR or in the holding area. Instead of a fixed table on the display board in which each OR has a cell, the number tags indicating individual ORs are magnets themselves and can be moved; therefore, display space for an OR can be changed by merely moving the OR number tag

Indicator magnets include a green smiley face (Fig. 4), which when placed next to a patient name alerts the staff that the patient requires isolation precautions (due to a communicable disease) and may require additional staffing.

A small piece of paper is sometimes placed under a magnetic strip (Fig 5). This paper ("Patient Call Slip") is prepared by the charge nurse to include the date, time, patient's name, current location within the facility, assigned operating room, whether or not the current unit has been contacted, isolation status, and any transfer considerations and equipment that will be necessary while moving the patient to the operating room (e.g. oxygen, monitors, medication pumps, patient weight, and need for escort by anaesthesia services) Patient call slips are used by OR technicians who transport patients from their wards to the operating rooms This messaging device ensures the correct patient is collected and transported to the appropriate OR.

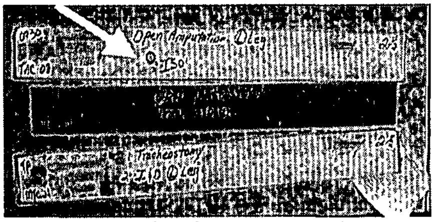


Fig. 4 A green dot (the top case strip) indicating the patient was on special isolation precautions for a communicable disease There are three strips for three cases here, representing the order in which the cases are to be carried out within one OR The middle strip is in blue, indicating an unscheduled case Note the paper slip placed under the bottom strip

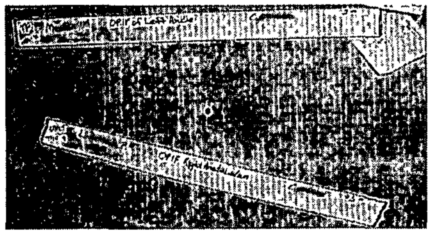


Fig. 5. Patient Call Slip placed behind the top surgical case strip The paper slip contains information for technicians to transport the patient from the ward to the operating room A slanted case strip (bottom) indicating that the patient is still in the room but that the surgical case is almost complete and staff can begin to prepare for the next patient

Staffing representation

Magnetic name tags for all staff members are located in the farthest right section of the board. The name tags are placed to the right of the operating room number (Fig. 6) to represent the staffing assignments. At least two staff members are assigned to each room: one circulating nurse and one OR technician. More staff may be assigned based on the acuity of the patient and the complexity of the procedure.

Those staff members working eight-hour shifts have an indicator magnet with either a star and sunglasses or a cat face next their name (Fig. 7).

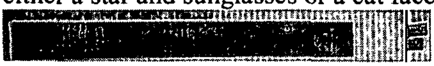
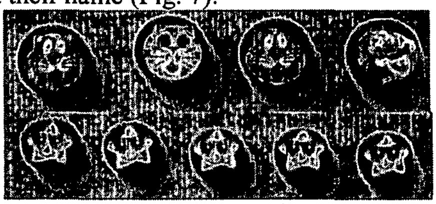


Fig. 6 Nursing staff assignment "displayed" on the right side of the case strip using name tags On the left is the case strip, to which the nurses are assigned



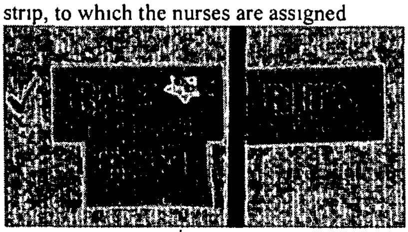
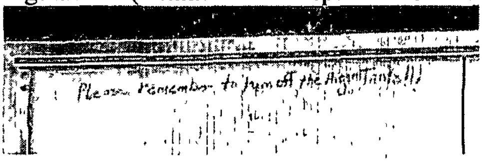


Fig. 7 Above A name tag withan indicator magnet showing a "sunglasses" or "cat face" logo identifies that the nurseis working an eight-hour shift Left The name tag next to it on the right (RITA) indicates the person who is scheduled to relieve the person on the left (RAMON) for the meal break

Messages and notices

Notes can be easily written in empty spaces to alert all staff to critical issues. Two examples of such notes are depicted in Fig. 8. In the first example, the message "Please remember to turn off the argon tanks" is placed in a location on the board that is not used for representing daily schedules. In the second example, the message “We need shoe covers” occupies the area of the board that is in regular use (within the workspace of ORs #2 and #3).



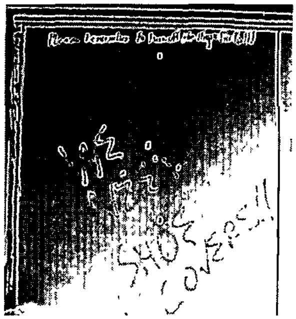


Fig. 8. Sign on top of the board serves as a reminder to staff· “Please remember to turn off the argon tanks ” The photo on the right demonstrates one use of the board for passing messages to the charge nurse.

Physical and perceptual interaction with and through the OR board

When observing the activities in front of the OR board, we were amazed by the utility of the OR board. Its immense size easily accommodates 10 or more individuals standing in close proximity either discussing or modifying the board Its canvas-like appearance invites new uses for its surface The magnetic strips and name tags are like pieces on a chessboard to be moved about to assess the impact of scheduling possibilities. Below we will examine how the board functions as a critical component of a cognitive system.

Display-based cognition

One of the tasks confronting the charge nurse is to balance demands for and availability of resources, both of which are constantly changing. On the demand side, the number and complexity of the requested surgery cases, their urgency, and the preferences of surgical and nursing personnel must be considered. On the supply side, the availability of staff, the conditions of the operating rooms, and the status of the patient and necessary equipment are also taken into account. The end result is the allocation of an operating room for a case in a given time or order. Arriving at any schedule seems to be difficult, let alone a schedule that approaches maximising the efficiency while at the same time satisfying individual preferences.

With the assistance of the OR board, the difficulty of scheduling appears greatly reduced. Below we will examine some of the ways in which the OR board is used.

- Placing name tags of OR staff according to the staffing pattern for the day (Fig 1b). With one glance, one can tell how many OR staff members there are today and at which shift (8-hour or 12-hour).
- Marking the arrival status of same day surgery patients (Fig 9). Same day surgery patients arrive early to the waiting area and await their surgical case to be performed on that day. Occasionally, there have been problems in that same day surgery patients arrive late for their cases or do not come at all. The charge nurse was observed to confirm the status of same day surgery patients and put a dot near their case strips. In this way, the charge nurse can keep track of when patients arrive for same day surgery on the OR board.

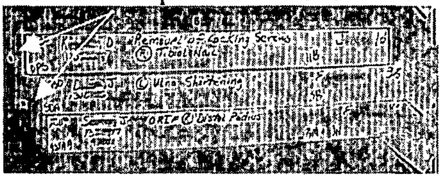


Fig. 9 A list of same day surgery cases Note the dots to the left of the case strips The dots were made after the charge nurse confirmed that the patients had already registered in the facility and were ready for surgery

- Trying out schedules by re-arranging case strips. The add-on cases are always in blue strips and are usually placed in the holding area on the board. They prompt the charge nurse to finish the scheduling task of assigning add-on cases an operating room and a starting time and sequence (i.e. which case the add-on case follows). Since the information for each case is written on a movable magnetic strip, rearranging the sequence and room assignment can be easily accomplished by moving the case strip around the OR board.
- Status tracking. When a surgical case is near completion, we observed that the charge nurse placed the corresponding case strip at a slanted angle on the OR board to indicate that a case was nearing completion (Fig. 5).

Discussions

In the last two decades, many have (re-)discovered the limitations of studying cognitive processes in artificially impoverished settings. Larkin (1989) commented that "problem solving is often done in the context of an external display. Often there are the physical objects that are part of a problem situation. Alternatively the solver may construct equations and diagrams as an aid to solving the problem" (p.319). By having external representation, humans can solve problems leveraging perceptual capabilities. Larkin (1989) noted several features of such "display-based" problem solving: (1) the process is easy, (2) it is largely error-free, (3) it is no degraded by interruption, (4) the steps are performed in a variety of orders, and (5) the process is easily modified.

Payne (1991) discovered the importance of display in users' cognitive activities. Through experiments on how users interacted with word processors, Payne found that human action relies upon patterns in the external environment in the computer display and is to an important degree "display-based"

Zhang and Norman (1994) reported a series of experiments on the role of external representation in problem-solving The term "distributed cognition" was used to describe the nature of problem solving when information processing is distributed in the environment (external representation) and in the problem solver's mind (internal representation). Zhang and Norman (1994) summarised how external representation helps problem solving: (1) external representations can provide memory aids and (2) external representations can provide directly perceivable information (such as constraints and options)

These and other studies on individual cognition with the support of the external environment point out the importance of examining in detail how artefacts are used, particularly in work settings. One important role of the OR board is to support the cognitive activities of its users. Much of the critical capabilities of the joint human-board cognitive system is accomplished by *externally* representing task status and by physically manipulating objects on the display The board becomes part of the joint human-board cognitive system:

- It "remembers" cases to be scheduled, the status of the cases, and results of scheduling
- it "displays" constraints and options to the user
- it "simulates" possible scheduling solutions

With constant interruptions to the charge nurse, the OR board enhances the reliability of the joint human-board cognitive system (Larkin, 1989).

Distributed cognition and display-based joint cognition

By some staff members' account, the OR board is the nerve centre for the OR unit. The board area is accessible to a multitude of people who work in the trauma centre. The wide corridor at the intersection of the TRU and OR (Fig. 1) serves as a major gathering point for all providers (e.g. surgeons, nurses, technicians, anaesthesia staff, housekeeping staff, unit clerks, supply staff). Communications of all purposes occur in front of the OR board by all providers.

Although the charge nurse is considered the "owner" of the OR board and is the primarily author of the board, the board is viewed by a number of people. We describe here several types of interaction with the board by people working in the trauma centre and the types of inter-personal interaction with the assistance of the board.

Negotiation of scheduling solutions

On those occasions when complex and dynamic situations require multidisciplinary input, the OR board serves as an excellent site for negotiations. The following are two excerpts from an interview in front of the board between one of the authors (YX) and an attending surgeon (AS), just before the nominal operating room start time:

YX: So, is this the first time you've come to see the board?

AS: Yeah. You see, usually when I have this kind of the day I try to see if I can stagger the room a little bit because the cases are not that long. If a case is prepared in another room, the patient is put to sleep and prepped, I can go over and start the case in that room

..

YX: During the day do you come to the board as well?

AS: If I am trying to do a case quicker I will. I have got to have a look to see how busy it is. If I can move quicker I will....I use [the board] to see if I can push, like "Why can't I follow that case" or "move to there." Like that case [the scheduled case on the right side, with no room assignment yet. It was assumed that the case would go to the OR which has not started yet], I don't see any follow up case. So I might be able to move one of my cases to follow that case.

Surgeons put in requests for time slots in operating rooms. In order to accomplish their goals, it may be to their advantage to understand what the overall schedule is. In this segment, one can see the surgeon (AS) used the board to negotiate with the charge nurse ("Why can't I follow that case") based on an appreciation of what the charge nurse had to consider.

The board facilitates the joint planning and decision-making by allowing workers to reason from the common status representation. It also eases the communication through indication of gaze directions and pointing. Here are several segments from observation notes:

06·30 Orthopaedic attending negotiating with OR charge for room and case assignments due to special requirements of the type of rooms. The surgeon looked for cases that may bump his case.

07·41 Plastic fellow: checking board for availability if he wants to add-on a case.

07:45 Orthopaedic attending: rearranging cases on board because same day admit patient did not show up. Magnetic strip rearranged. Cases moved to other rooms.

08:45 Orthopaedic attending: checking board related to which cases have started, who is doing what and expectations. Advises OR charge while pointing to board that one case will take much longer that what is posted

0740 OR charge & Orthopaedic attending· While viewing board Ortho attending asks, "can I get a different scrub tech for my case, one with experience?" OR charge replies, "she will do just fine."

At 06.30am, the orthopaedic attending surgeon wanted to make sure that the room type was suitable for the surgery he was to perform. When asked, he expressed that he also wanted to assess the possibility of the cases preceding his case dragging on longer than scheduled. At 07 41, a plastic reconstruction surgeon ("plastic fellow") came to see if he could add a unscheduled case. By coming to the board, he could assess, jointly with the charge nurse, the likelihood of adding on his case. At 07:45, just after the nominal starting time for the operating rooms, the schedule was already dramatically changed. Note that the surgeon involved came to the OR board to assess the impact of the changes with the charge nurse. At 08:45, the orthopaedic attending updated the charge nurse. On a different day, at 07:40, the orthopaedic surgeon was negotiating with the charge nurse over the OR staff assignment.

Joint planning

The charge nurse is given the responsibility to make decisions related to scheduling However, our observation found that the charge nurse approached this responsibility with the intention of incorporating individual preferences as much as possible. This is best reflected by the following observation note segment:

> 06:45 OR Staff Nurses and Scrubs: Arriving at board for report from OR charge nurse. OR charge nurse pointing to board while providing staff report Accepting requests from staff for specific room assignments. Staff placing their names next to room numbers indicating their requests for specific cases while placing indicators for 8 hour shifts next to their names. OR charge nurse points to board while announcing anticipated changes in cases that have not occurred yet. OR charge nurse asks for volunteers for especially difficult cases while pointing to board.

In this segment, the board provided a shared problem space. operating rooms to be staffed, with cases scheduled for each of the rooms Everyone involved could see which rooms had and had not been assigned, and what were the cases scheduled for a given operating room. According to one of the charge nurses, the board injects a sense of fairness among the staff since everyone gets to see what is available and who selects what.

The following segment shows a different kind of joint planning

> 07:00 Charge Anaesthesiologist and OR charge viewing the board and deciding how to rearrange rooms for an additional opening.

In this segment, due to the large case load, the charge nurse was exploring the possibility of opening an additional operating room. In order to do this, the charge nurse would need the cooperation from the anaesthesia care providers, who might not have enough resources to support an additional room. The charge nurse and the charge anaesthesiologist jointly viewed the board to evaluate options.

"Intra-system" display

In some sense, the board is a display interfacing various information processors of a joint cognitive system. Many people were observed to come to the board frequently to update themselves. Here are note segments from observation on two separate days:

07.10 Radiology technician: "I'm looking at the board to see which rooms I will be needed in through out the day and to see what times I should be there."

06:31 Charge anaesthesiologist viewing OR schedules for caseload and acuity of patients; attempting to match ability of anaesthesia care providers with appropriate patient/case. Checking for add-on cases and obtaining overall view of the day's work ahead.
06:40 OR attendants checking OR schedules to anticipate when they will be needed to collect patients from the floor or same day admits.
06:57 Resident first meets Charge Anaesthesiologist who explains board so that the resident may anticipate intubation training opportunities.
07:05 Orthopaedic technician checking board to anticipate any equipment required for specific orthopaedic surgery cases.
07:06 An anaesthesiologist came by. When asked why came here, he answered "taking the pulse of the ORs".
07.30 PACU charge: checking board against printed schedule making notes. Estimating type of day the PACU will have by number and acuity of patients.
07:31 Plastic attending: checking board for when he can anticipate his scheduled case will start.

At 07:10, the radiology technician, who might be needed during surgical cases, came to see the schedule.

On a different day at 06:31, the person who was responsible for coordinating anaesthesia care providers (Charge anaesthesiologist) came to the OR board to get an update. Like a number of other people in similar position, he received a print-out of the day's scheduled cases the day before. As on most days, the print-out he received was already out-dated at such an early time of the day. At 06.40, 50 minutes before the nominal starting time for operating rooms, the technicians (OR attendants) came to plan their own activities. At 06·57, the information on the board was used to anticipate training opportunities At 07·30, the person who coordinated activities in the "downstream" of the operating rooms, the post-anaesthesia care unit (PACU) came to update her schedule.

This segment demonstrated the central role of the board as a conduit for passing information among collaborative workers. Each worker by him- or herself is agent who plans for his or her own activities. Viewed as a single cognitive system with multiple agents and external environment, how do the agents choreograph and weave individuals' activities into streams of coherent joint activities? The board seems to hold part of the answer to this question.

Augmenting inter-personal communication

Scheduling operating room activities requires the management of multiple conflicts Conveying situations at hand clearly would likely reduce misunderstanding and facilitate the management of conflicts.

08:00 Ortho attending: "which room am I in" while looking at board. OR charge explaining while pointing to board that his room was bumped for an emergency.

In this segment, an emergency case had pushed a scheduled case. As described earlier, emergency cases are on strips with red tapes on the ends and are conspicuous to the viewer. The orthopaedic surgeon was quick to appreciate the circumstances under which "his" case was bumped.

Discussions

People always work in a meaningful physical environment which one can adapt, change and share. Realization of this nature of work has profound implications on the study of cognition and team performance. The approach of distributed cognition (Hutchins, 1995a) has taken this nature of work as the most fundamental premise in studying people at work In a study of work in aircraft cockpit, Huchins (1995b) demonstrated that the physical environment of a cockpit became part of a cognitive system which "remembers" speed He also noted the active role of pilots in creating a more informative environment by, for example, placing sticky notes in the instrument panel. Hutchins (1995b) advocates that "system-level cognitive view directs our attention beyond the cognitive properties of individuals to the properties of external representations and to the interactions between internal and external representations. Technological devices introduced into the cockpit invariably affect the flow of information in the cockpit."

Several previous studies have examined the use of public displays like the OR board. In evaluating a computerised patient scheduling system, Bardram (1997) found that users maintained a planning board to re-represent the information in the computer system. The board allows the user to put in post-it notes for additional and detailed information. The board also allowed movement of physical objects (Lego bricks) to represent rescheduling results. Furthermore, Bardram noted the perceptual characteristics: the planning board show schedules to all people and has visual cues of overall workload and visual overview of all case status. In comparison, Bardram noted that computerised system "failed to support … important aspects of providing highly visible, malleable, and sharable representation of the scheduled treatments."

Bellotti & Rogers (1997) found that news organisations used wall displays for representing personnel/work status and for discussing designs. The shared display of assignment provides a way for teams to visualise current team activities and resource availability. Suchman (1988) examined the role of visual representation in the face-to-face settings. A central theme was that the representation media formed a referential base for interaction. Mynatt et al (2000) investigated how large display boards are used and how objects on display boards are grouped. In a study on operations in emergency resource centres (Garbis & Waern, 1999), public displays (e.g. a flip chart) were noted to perform central roles in indicating status information and facilitating discussions. In a train control room (Garbis, 1999), the wall display of train track status not only supports individual controllers' information needs but also enables the controllers to refer and discuss.

Artefacts and articulation work

Managing interdependency has been noted as the core of coordination (Malone & Crowston, 1990). Given the fact that potentially the activities of everyone in the OR unit are dependent on those of someone else, the effort needed to coordinate could be overwhelming. The OR board alleviates much of the burden of coordination.

The patient call slip (Fig 4) is a good example for reducing the effort in articulating several people's activities. When an operating room is ready for the patient, the charge nurse notifies the appropriate unit that they will be coming for the patient, then assigns an OR technician to pick up the patient. The OR technician removes the patient call slip and leaves to fetch the patient. When the patient call slip is no longer under the patient's case strip, this sends a signal to all staff that the patient has been retrieved for surgery and is either en-route to the OR or is currently in surgery.

As another example, the OR board served as a messaging board (Fig 8). There was an immediate need for a certain supply. One of the OR nurses wrote the message on the board in an area where surgery schedules are usually placed. Without prompting, the first OR technician that saw the message located the appropriate supply, restocked the area, and then erased the message from the OR board.

The following segment is a third example:

0710	OR charge delaying two rooms' start time by placing blue magnetic strips diagonally across white magnetic strips. Rooms delayed due to patient unavailability

In this segment, the charge nurse wanted to signal to all who might pass the OR board the delays She placed a conspicuous sign on the board (Fig. 10). In this way the charge nurse did not have to update individually with the essential message yet still achieved purpose of communication.

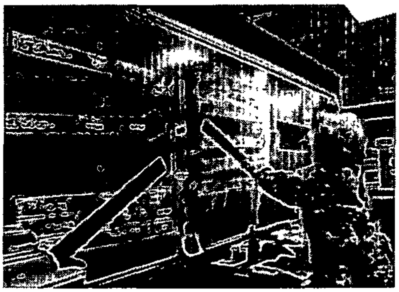


Fig 10 The charge nurse placed two slating strips over scheduled cases in two operating rooms The cases in these two rooms were delayed

As a fourth example, we observed that the charge nurse sometimes slanted the case strip to alert staff that an operating room would soon be vacant and supporting personnel could plan to clean and equip the room.

Discussions

With the support of the OR board, accurate and timely communication is not dependent upon face to face communication nor in real-time. When looking at the OR board, all personnel have an instant understanding of the current state of the OR environment without talking to or interrupting each other.

The first of the five major strategies for coordination described by Bardram (1997) is minimising articulation among collaborators. Bardram noted that artefacts were used to accomplish this strategy. Two examples were given by Bardram. paper-based order forms and in/out trays for holding incoming order forms and outgoing answers. Bardram also described the practice in a hospital that copies were made to share information about patient schedules. By having access to the overall patient schedules, workers could coordinate with minimal effort in articulation.

The use of artefacts, which may be paper notes or otherwise low-technology systems, may have a profound impact on coordination processes. Boguslaw and Porter (1962) give an example about the use of a "spindle wheel" in the short-order restaurant industry. Waitresses could place their written order checks on the wheel. The wheel

> "first of all acts as a memory for the cook, he does not have to remember orders, the wheel does it for him The wheel also acts as a buffer drum The input rate and output rate need no longer be one-to-one Ten waitresses may come to the wheel almost simultaneously, but the cook takes the order one by one The wheel also acts as a double queuing device Waitresses no longer need to stand in line to put in their orders, the wheel stands in line for them Moreover, the wheel does not get the order mixed up, but keeps them in proper queue sequence Finally, the wheel also serves as a display of all the information in the system at a given time The cooks, by having random access to the information, are enabled to organize their work around larger work units, such as the simultaneous preparation of three or four similar orders The fact that the order is recorded on a check, equally available to waitress and cook to check back upon when an error has been made, permits feedback and the consequent elimination of habitual errors" (Boguslaw & Porter, 1962, P. 393)

Two important aspects of the above example are that (1) the artefact, spindle wheel, facilitates the communication across the temporal barrier, and (2) it helps to reduce the memory burden.

Berg (Berg, 1999) argues for the approach of treating computerised information technologies with those "low-tech": paper forms, lists, and whiteboards. The rationale is that one needs to focus on what IT does as opposed to what IT consists of. Treating IT as writing and reading artefacts, according to Berg, is one way of understanding IT. Just as Berg has found out in his observational studies of record keeping in intensive care units, the forms (electronic or otherwise) constrain what doctors or nurses do. The forms also change as care progresses as entries are added, thus producing cues of what has been done to the patient and what needs to be done in the future. The paper form co-constructs activities (i.e. documents the progress of activities so far and provides guide of future activities).

Mackay (1999) described a study on the use of paper flight strips used by air traffic controllers. Through observational studies, the controllers were found to exploit the use of paper strips. For example, controllers were found to arrange paper strips to represent the aircraft's spatial positions in the sky. Another study by Berndtsson (1999) on paper strips in air traffic control describes the use of camera through closed circuit TV combined with paper strips in air traffic control. Such a system has the advantage of traditional paper-strip based system while also providing remote users visual access to strips in nearby airspace.

Conclusions and Implications

Public displays are common coordinative tools used in many settings. The users of the OR board in our study made use of the flexibility of the board to satisfy the need of distributed cognition: storing status and scheduling information, communicating tasks and updates, visualising workload and staffing patterns, and referencing during face-to-face discussions. We were particularly intrigued by the clever use of magnetic strips and tags so that the representation of task activities and work schedules could be easily changed to match the frequent changes in the work environment.

In designing intelligent public displays, much of the previous attempts seem to focus on individual operations of objects on display. In the board we studied, the manipulation of the display objects can be accomplished jointly. In addition, the magnetic strips and tags "afford" direct manipulation by moving and placing both demand and supply elements. Our study also suggests that computerised public displays should consider the possibility of inventive use of coordinative artefacts. In complex organisations, changes over time such as the nature of workload and staffing, make it important to consider the possibility of adaptation, or "design enhancement", by the users. It would be difficult to anticipate all possible uses of such boards

As another implication, the sheer physical sizes of public displays, like the one studied, change the nature of interaction. For example, we observed little access conflicts in front of the board, even when six or more people were observed accessing the board.

. . Our research calls for future studies to pay close attention to details in how artefacts are used in support collaborative work. The tailorability issue has recently been discussed (e.g. Teege, 2000). The needs of users change in response to not only their preferences but also changes in task requirements. As the current study indicates, users are very inventive in exploiting tools for coordination. Providing ways for users to improvise is an important function for public displays. Finally, we would like to caution that the current study is limited in that only one board was studied. The types of interactions observed need to be tested in future studies of other public displays

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