Cognitive Engineering Applications in Health Care

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Health care is an environment with classic components of complexity – time pressure, risk, uncertainty, and multiple, interacting components. The environment is further complicated by the multiple levels or domains of concern. For instance, within a patient, there are numerous, interacting systems, which may not all be well understood, and for which only limited or indirect information may be available. The complexity of the patient domain is compounded by the socio-technical working environment addressing patient needs: the health care system. This system is comprised of many people, working both individually and in teams, who must coordinate their actions, and who have different and sometimes competing goals (e.g., health care providers vs. government regulators vs. insurance companies vs. hospital administrators). Within the environment, individuals interact with a range of information sources and technologies, ranging from handwritten charts, to pagers and phones, to electronic medical records and digital imaging systems. Resources (such as caregiver time, hospital beds) in the environment are limited, and demands on the system (i.e., incoming patients) are unpredictable.

Methods in cognitive engineering have been developed to uncover and represent both the complexities within such high consequence, complex fields as health care, and the knowledge and strategies experienced practitioners use to perform successfully in such environments (Bisantz & Roth, 2008; Crandall, Klein, & Hoffman, 2006; Vicente, 1999). The results of cognitive engineering analyses can have a critical impact on the design of information, tasks, and training that enhance (rather than disrupt) successful work practices, and allow practitioners to respond appropriately to the diverse and unpredictable events in their environment.

Cognitive engineering research in health care environments, within the general goal of supporting safe and effective performance, has had different research threads. These include characterizing the complexities of the environment and the demands on practitioners, sometimes with a focus on prevention of medical errors, as well as a focus on the design and/or impacts of new technology in support of medical work. Understanding the demands placed on practitioners by the domain, the strategies they use in performing work, and the role that current sources of information and technologies play in work practices, is essential in designing new information systems that improve patient care.

A commonly used method to represent the complexities of the work domain (the abstraction hierarchy, see Rasmussen, Pejtersen, & Goodstein, 1994; Vicente, 1999) represents high level goals, balances and priorities, processes, and physical structure, and has been applied to the medical domain. Within the patient system, for instance, researchers have modeled physiological functions and anatomical structures, and methods for their control, in order to provide support for diagnostic decision making, to understand information needs across clinicians, and to design monitoring displays (Hajdukiewicz, Doyle, Milgram, Vicente, & Burns, 1998; Miller, 2004; Sharp & Helmicki, 1998; Watson & Sanderson, 2007). Enomoto, Burns, Momtahan, and Caves (2006) and Burns, Enomoto, and Momtahan (in press) studied the tasks of cardiac care telehealth nurses, as well as the underlying patient structure and processes, to understand the challenges faced and strategies used in diagnosing cardiac patients through phone interviews. They designed and tested a set of innovative visualizations to support diagnoses, which alternately emphasized mappings of symptoms to diagnoses, clusters of co-occurring symptoms, or symptom severity. Hall, Rudolf, and Cao (2006) used similar techniques to simultaneously represent aspects of a surgical team, the patient, and equipment used in surgery, to characterize more or less successful problem-solving strategies used by anesthesiologists.

A particular complexity of interest in medicine is the need for multiple individuals (e.g., physicians, nurses, technicians, support staff) to communicate with each other to coordinate their work in producing patient care, particularly in hospital settings. Communication has been cited as a frequent cause of medication related errors (c.f. Rogers, Cook, Bower, Molloy, & Render, 2004). There are numerous cognitive engineering oriented studies of communication functions, patterns, and sometimes, breakdowns, within medical environments.

For example, Moss, Xiao, and Zubaidah (2002) characterized the mode (e.g., face-to-face, phone); recipient, and topic of communications of an operating room charge nurse, who had responsibility for coordinating patient, surgical team, equipment, and room preparation schedules, in order to make suggestions about how electronic scheduling systems could be shared and used effectively. Guerlian, Turrentine, Bauer, Calland & Adams (in press) found a positive effect of providing training to surgeons on specific types of communication and teamwork skills, such as methods for conducting a pre-operative briefing,. Several studies have investigated communication strategies during shift change or other transitions, when one set of caregivers must transfer information about patient status to a different set (Nemeth et al., 2006; Patterson, Roth, & Render, 2005; Sharit, McCane, Thevenin, & Barach, 2005; Wears et al., 2003). Patterson, Roth, and Render (2005) observed nurses during shift change in acute care hospital wards, to identify strategies and technologies used by the staff to obtain necessary information effectively. Both audiotaped, and face-to-face, communication was observed, and the technologies facilitated different strategies for understanding. For instance, incoming staff could not directly question the outgoing staff if the information was audiotaped; however, incoming nurses tended to listen to audiotaped information as a group, and conversed together regarding the status of patients, which could lead to better shared awareness of patient states and team coordination to meet patient needs. Wears et al (2003) contrasted two cases of transition between emergency department physicians. In one case, the transition was the source of error recovery, because incoming physicians suggested an alternative, and ultimately correct, diagnosis; while in the second case, communication was the source of breakdown, because critical information about the state of a medication order was misunderstood across transitions, and an essential treatment was delayed.

Advanced technology has often been advocated as a solution to the problems of errors and adverse events in health care (Aspden, Corrigan, Wolcott, & Erickson, 2004; Committee on Quality of Health Care in America, 2001; Kohn, Corrigan, & Donaldson, 1999). In many cases, however, new technologies are designed without an in depth understanding of the work they need to support, or are designed to facilitate functions other than patient care (e.g., record keeping; billing). Without a careful understanding of how new technologies will be used in practice, or the barriers to their use as expected, new technology can lead to unanticipated, undesirable consequences. These include increased workload due to new processes or work-arounds needed to integrate the technology into workflow, or serious safety compromises if systems are bypassed or abandoned, or critical tasks interrupted (Ash, Berg, & Coiera, 2004; Ash et al., 2007; Webster & Cao, 2006). For instance, in a study of new operating room technology that integrated multiple monitoring systems into a single electronic display, Cook and Woods (1996) described how the change forced practitioners to both adapt their activities, as well as aspects of the new system, in order to force the system to display critical information at appropriate times.

In another example, Patterson, Cook, and Render (2002) and Patterson, Rogers, Chapman, and Render (2006) studied unanticipated effects and workarounds developed after the implementation of system intended to reduce errors in medication administration. The system uses bar codes on medication and patient wrist bands to confirm type, dosage, and timing of medication administration. Unanticipated effects included reduced physician review of current medications because it was more difficult to access the information in the computerized system vs. a paper record; and nurses feeling pressure to administer medication “on time” even if other higher priority tasks were pressing (both which could increase the chances of adverse events). A key workaround identified was that nurses would type the patient barcode number into the system, or scan a secondary wristband kept separate from the patient, because it saved time (the cart with the scanner could be difficult to maneuver, or in cases with longer medication distribution passes, needed to have a computer plugged in to maintain battery life), avoided disturbing sleeping patients, and was more reliable than scanning wrist bands on patients, particularly in longer term care areas where the bands were older and in poorer condition. Additionally, it was possible to “pre-pour” medications (place medications in cups for multiple patients at once, rather than scanning a patient wrist band, scanning and administering medications, and moving to the next patient), which reduced time by grouping similar tasks together. Scanning the medications in a batch also made it more likely that the medication was recorded as being administered “on time” (which eliminated additional work associated with documenting late medications). While the barcode system could reduce the chances the wrong type or dose of medication was accessed, the workarounds actually increased the chances of medication being given to the wrong patient. The researchers suggested both system design changes (such as simplifications to the system interface; wireless or easily maneuverable scanners, and longer life computer batteries); and procedural changes (providing more realistic times for medication administration) that could reduce the likelihood of unanticipated effects or workarounds that increase the chances of medication errors.

Like the need to consider unanticipated effects of new technology, understanding the role that extant tools or artifacts play within a work system is a critical step in designing new systems that support the functional purposes, rather than simply duplicate the surface features, of the artifact (Nemeth, 2004; Pennathur et al., 2007; Xiao, 2005). Bauer, Guerlain, and Brown (2006) conducted a detailed analysis of an artifact used in intensive care, in order to inform the design of an electronic system. The artifact, a patient flow sheet, is paper form that supports both structured and unstructured data capture (e.g., grids for sequential vial sign information as well as allowing freeform notes). By observing the form in use, they were able to identify characteristics of the form that would need to be included in an electronic system. These features may not have been included had the new system simply duplicated the surface feature of the form. For instance, an important property of paper forms is that they allow flexible, rather than sequential, information entry; allow unstructured annotations (e.g., information does not have to be entered in a particular place, or with keyboard characters); and allow information to be omitted (see Sellen & Harper, 2003 for a discussion of the functionality of paper artifacts). In this case, the paper form supported work in that it was portable, grouped information in ways that allowed easy comparisons, allowed flexible annotation for unique circumstances, and allowed data to be represented in familiar notation. An electronic system could provide addition functionality, such as automated data analysis and calculations (which had to be done manually with the paper form); and allow multiple caregivers to access the information at once. However, any new technology would still need to support the flexibility in annotation and commonly used notations and comparisons present in the current paper form.

Some of our own work has focused on new technology implementation in hospital emergency rooms (Pennathur et al., 2007; Pennathur, Cao et al., 2008; Pennathur, Guarrera et al., 2008; Wears, Bisantz, Perry, & Fairbanks, 2005). In these settings, electronic patient tracking systems are being implemented to replace manual status boards ("whiteboards") that are commonly used for managing clinical work. The status boards contain medical and logistical information about patients and provide clinical and support staff with information about patient status (designated providers, treatment status, test and laboratory results, location) as well as higher level information regarding hospital state (e.g., number of patients in the ED, admitted patients staying in the ED, available ED beds, rooms that need cleaning) and team coordination information (e.g., assignments of providers to patients or bed zones; status of on-call providers). Information on the manual status boards is encoded in locally developed (e.g., by providers in one hospital or department), and locally meaningful ways. Manual status boards are used extensively to track the process of patient care, through annotations that indicate potential diagnoses, progress through treatment plans, needs for consultations or tests, and admission or discharge processes. Information written on the boards is available to all care providers working, and can be used to support coordination of activities across individuals, and time. While electronic versions of the status boards may mimic the look and layout of manual boards, support automated recording keeping and reporting, and allow information on the status board to be accessed at different locations in the hospital, they also impose new constraints on use. Access to add or change information is limited by available computer terminals which typically require sign-on sequences; the form of information is limited to characters or icons available on a keyboard or through the interface, and the length and placement of entries is prescribed (e.g., free-form annotations cannot be added).

Our studies have examined the transition from manual to electronic status boards in two university affiliated, urban hospital emergency departments (Pennathur et al., 2007; Pennathur, Guarrera et al., 2008; Wears et al., 2005; Wears & Perry, 2007). One hospital transitioned to an electronic system 10 months prior to our study, but kept using manual boards in parallel with the new system. We studied the second hospital before and after the transition, in which the manual boards were removed and replaced with an electronic system. We conducted a combination of semi-structured interviews, focus groups and observations with care providers (physicians and nurses), secretaries, IT specialists, and administrators. Additionally, we captured images (photographs or screen shots) of the status boards at one hospital to allow detailed comparison of the information content and form across the two systems.

Results from our studies indicated a number of issues that arose from the transition to the new technology. Shortly after the electronic system was implemented at the second hospital, providers felt that the transition had a negative impact on communication and their ability to "make sense" of the overall state of the emergency department, in part because the system was shown only on desktop screens, and had limited room for displaying, and limited flexibility for encoding, information about treatment plans and diagnoses. For instance, a limited number of entries were visible in the column used to show treatment plans, and providers could no longer use hand-drawn checkboxes to indicate progress in treatment. Because it was more difficult for providers to document and track patient progress on the whiteboard, some providers resorted to carrying notes: while this supported the work of individual providers, the information was no longer publically available, reduced people's ability to coordinate their work with each other. Additionally, staff developed an unanticipated use of the system as a method to track and provide a hard copy list of patient dietary needs, to give to the staff delivering meals. Although this function provided a benefit to some caregivers/staff, the constraints on space in the area where these entries were placed meant that the ability of others to use these fields to display critical clinical information was reduced. IN fact, at the first hospital, where electronic and manual boards were maintained in parallel, clinicians tended to rely on the manual technology, while non-clinical stuff used the electronic system for administrative functions such as finding patients or assessing room status. While some of these difficulties may be traced to the particular implementation and interface for the system others are of a more fundamental nature (e.g., the removal of a public, easily modified information source that supported relatively simple coordination of work within and across individuals).

The health care system has critical needs for enhanced efficiency, effectiveness, and safety. In order to those needs, it is necessary to understand the complexities faced by health care workers, and the knowledge, strategies, and tools they use to work effectively. Cognitive engineering provides the methods and tools which will allow new technologies and processes to be successfully developed and implemented in this environment.

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