
VizCom: A Novel Workflow Model for ICU Clinical Decision-Support

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Abstract

The Intensive Care Unit (ICU) has the highest annual mortality rate (4.4M) of any hospital unit or 25% of all clinical admissions. Studies show a relationship between clinician cognitive load and workflow, and their impact on patient safety and the subsequent occurrence of medical mishaps due to diagnostic error - in spite of advances in health information technology, e.g., bedside and clinical decision support (CDS) systems. The aim of our research is to: 1) investigate the root causes (underlying mechanisms) of ICU error related to the effects of clinical workflow: medical cognition, team communication/collaboration, and the use of diagnostic/CDS systems and 2) construct and validate a novel workflow model that supports improved clinical workflow, with goals to decrease adverse events, increase safety, and reduce intensivist time, effort, and cognitive resources. Lastly, our long-term objective is to apply data from aims one and two to design the next generation of diagnostic visualization-communication (VizCom) system that improves intensive care workflow, communication, and effectiveness in healthcare.

Author Keywords

Visualization; healthcare; cognition; human error; interface design; critical decision-support; activity

ACM Classification Keywords

H.5.m. Information interfaces and presentation

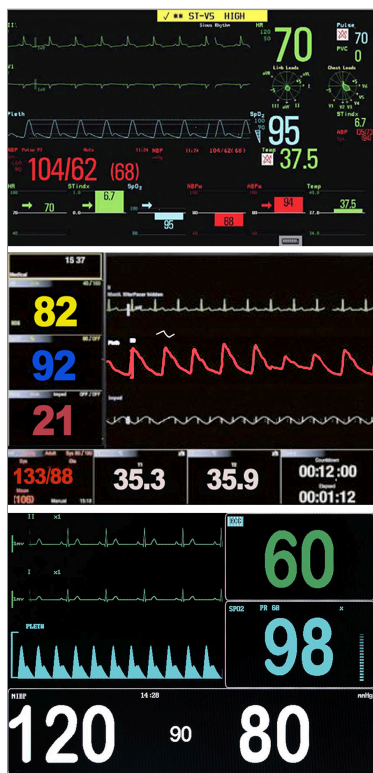


Figure 1. Standard ICU bedside device interfaces, with traditional real-time data streams giving only one-time snap-shot of patient data. Medical interfaces only utilize primary high key colors on black background.

Introduction

The Intensive Care Unit (ICU) holds the critically ill who require continuous and coordinated monitoring and frequent intervention [16]. With over 4.4 million US admissions annually [1], ICUs have the highest annual mortality rate of any hospital unit (12-22%) [17], impacting nearly one-quarter of all admissions. In sum, approximately 25% of all deaths occur in ICUs [1, 20]. Although ICU patients are the most monitored, tested, and examined of all hospital patients, medical conditions are missed. Studies consistently demonstrate that the complexities of ICU clinical workflow and decision-making directly impact patient safety [5, 14]. The scope of this problem continues to worsen as the number and type of procedures performed surge. Moreover, the ICU is an intensely challenging and complex clinical environment, with each provider being inundated with thousands of independent pieces of information daily from multiple sources [14, 20]. Adding to the cognitive load of ICU practitioners are the inadequacies of health information technology (HIT) and electronic medical records (EMR) systems [2, 8, 16]. These challenges create the potential for missing critical signs of an unrecognized deadly medical condition. In an era of patient-centered care, the utilization of the entirety of information, resources, and services by clinical teams serves as a lynchpin in delivering appropriate care [18]. Hence, it is imperative to understand the *underlying mechanisms of error* within existing workflow models, from which innovative clinical decision-support (CDS) systems can be designed to more effectively improve care delivery in the ICU [6, 18]. Clinical errors related to diagnostic error and errors of omission, such as inaction, delayed action, or incorrect action [6, 20] continue to occur in spite of advances in CDS systems and *smart* bedside devices.

The causes of these errors provide two sources of workflow-related error. First, human factors studies demonstrate that 80% of HIT “user error” is attributed to cognitive overload [4,

20] in which the use of diagnostic bedside devices resulted in incorrect use or user error in analyzing medical data. This key factor of user error can be attributed to poor or inadequately designed system interfaces or interaction sequencing that can directly impact cognitive load during medical diagnosis. However, information visualization can amplify cognitive processes by providing computer-supported visual representations of patient data. Within this model, the purpose of visualizing data is not for good design, but *rapid information assimilation*, pattern recognition, and insight when examining large amounts of data [4]. Hence, compared to traditional bedside visual displays (Figure 1), to reduce user error, the ICU intensivist (ICU physicians, nurses) can be supported by appropriate visualization systems that have the power to ease cognitive load.

The second cause of workflow-related error points to factors related to communication and collaboration [11, 14]. Findings suggest that 91% of all medical mishaps are due to communication difficulties (e.g., breakdown) and inefficient team collaboration among intensivists [18]. Communication among clinicians, including but not limited to face-to-face interaction, is often interrupted and of poor quality [13]. This leads to inefficiencies and potential error in the ICU, where rapid and accurate communication is essential for delivering safe patient care [19]. In addition, inadequate and inefficient collaboration among nurses and doctors has been shown to increase the average length of stay of patients, leading to increased patient mortality [17].

Previous research suggests that many intensivists using communication technologies (e.g., wireless technology) improve team relationships as well as staff satisfaction and patient care [13]. Studies show that such technologies improve communication speed by 92%, communication reliability by 92%, co-ordination by 88%, reduced staff frustration by 75%, and result in faster and safer patient care [12]. Communication



Figure 2. (Above) The MIVA interface designed to enhance and maximize the clinician's ability to control all data visualizations and communication exchange during a specific context-related patient episode or general periodic diagnosis [6], as noted below [8].

among clinical staff should consist of more than face-to-face, but rather the use of synchronous and asynchronous communication technologies (e.g., cell phone, email, text and video conference) in order to optimize and enable bi-directional, rapid, secure, and non-disruptive transmission of content-rich messages and patient data [15], for purposes of expediting and increasing the accuracy and effectiveness of decision-making.

Research shows that without a comprehensive understanding of the context in which care occurs, it is improbable that systemic factors that lead to error will be adequately understood [12]. Although CDS systems have received increasing attention in biomedical informatics and human-factors engineering literature, none has taken an integrated workflow approach that considers the following five factors as closely interrelated: (1) patient status, involving continuous monitoring of patient organ function and vital sign function; (2) patient data, such as that generated from treatment and bedside devices; (3) medical cognition and cognitive resources of intensivists; (4) communication among ICU team-members; and (5) need for collaborative decision-making: joint ownership of decisions and collective responsibility for outcomes.

The *aim* of our research is to: 1) investigate the root causes and underlying mechanisms of ICU error related primarily to the effects of clinical workflow resulting in ICU error: medical cognition, team interaction (communication/collaboration), personal happiness/challenge, and existing diagnostic systems and 2) construct and validate a novel workflow model that supports increased protection to patients from adverse events, while providing greater long-term safety by decreasing human error and reducing intensivist time, effort, and expenditure of cognitive resources. Our *long-term goal* is to apply data gathered to design the next generation of integrated diagnostic visualization-communication (VizCom) CDS system to improve intensive care workflow, communication, and effectiveness.

Studies completed

Our paper discusses studies that have been completed to-date and provides the rationale for future work. Clinical activity involves distributed cognition [9], where intensivists, who are part of a greater clinical team engage in-patient support either face-to-face or through an assortment of communication technologies. Failure of adequate and efficient team communication has often been reported as the "root cause" for medical mishaps [16]. In an attempt to address this issue, the governing framework resulting from our project will be used to design an integrated decision-support system for data visualization alongside intensivist inter-communication tools that optimize ICU team collaboration, and distributed knowledge sharing and decision-making. The human visual system holds enormous untapped potential when enhanced by external visualization. When large datasets are made visual, massive amounts of information can be compressed into visualizations that allow trends, patterns, and correlations to be made explicit and rapidly interpreted [4]. Extracting relevant information from data visualization enables ICU intensivists the ability to formulate and enhance their cognitive model of a patient's diagnosis and/or prognosis. By removing, consolidating, augmenting, and limiting extraneous visual, textual, or numeric information, visualization systems afford the clinicians effective high-density graphical representations of datasets. Our initial research involved the creation and testing of a decision support system, Medical Information Visualization Assistant (MIVA) (Figure 2), which produced significant findings and resulted in a US Patent, awarded on 2/4/2014 (#8645164).

In study 1, a usability study using paper medical charts and static interface visualization images from the MIVA prototype was conducted. Sixteen participants from the clinical population of the Indiana University School of Medicine [7] volunteered. The participants were randomly assigned to one of the two

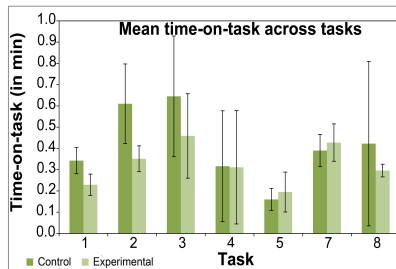


Figure 3. Graph shows significant difference in time-on-task between the control and experimental groups in Study 1. Note: significant difference in time-on-task between the experimental and control groups for tasks 3 and 4. Task six was removed from the analysis since each participant from each group performed task six incorrectly [7].

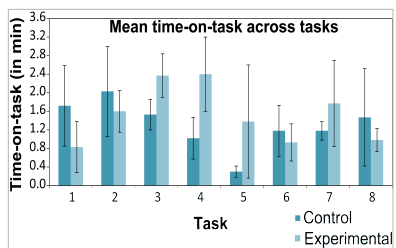


Figure 4. Graph shows significant difference in time-on-task between the control and experimental groups in Study 2. Note: significant difference in time-on-task between the experimental and control groups for tasks 3 and 4 [8].

groups: the control group using paper charts and the experimental group using MIVA screenshots displayed on a PC. Both groups were given the same clinical scenario and eight diagnostic questions for which data analysis was required. However, each group used different resources to arrive at viable clinical solution: the experimental group using traditional paper charts and the control group using the MIVA interface visualizations. Time-on-task (in min.) and accuracy were measured for each participant. Both groups of participants were provided a five-minute priming session to understand the basic placement of data on the medical charts and MIVA interface. After completion of the eight tasks, participants from both groups answered a post-test questionnaire. Using SPSS (v17.0.2), the Mann-Whitney test identified the experimental group to be generally faster than the control group, and significantly faster in answering two questions of the eight: $U=7.0$, $p=.01$, $r=.66$; $U=7.5$, $p=.01$, $r=.64$. The Chi-squared test was used to identify a significant difference in accuracy between experimental and control groups for question one: $\chi^2(1, 16)=6.35$, $p=.041$. The experimental group participants were found to respond positively in the post-task survey, with an overall mean score of 3.78 (Likert 1-5), which in sum, attributed to the acceptance of MIVA in supporting critical decision-making. (Also see Figure 3.)

In study 2, a follow-up dynamic prototype was developed and tested using the same clinical scenario and eight questions as the initial study by six participants each: the control group using paper charts and the experimental group using the MIVA interactive prototype. Four data points were collected: 1) time-on-task (in min.) and accuracy in the clinical scenario-based questions, 2) usability and context-of-use information through post-test questionnaire, 3) close-ended questions while using MIVA, and 4) open-ended interviews based on usability and activity-related questions [8]. For time-on-task, the control group ($M=1.30$, $SD=.78$) was found to be generally faster than

the experimental group ($M=1.53$, $SD=.87$). Using SPSS (v21.0), an independent sample t-test showed no overall significance, the experimental group was found to perform significantly faster than the control group in answering two questions: $t(10)=3.11$, $p=.011$, $r=.70$; $t(10)=3.65$, $p=.004$, $r=.76$. The experimental group participants were faster in four of the five questions than the control group, to lesser degrees. The Chi-squared test identified an overall significant difference in accuracy between the experimental and control groups: $\chi^2(1,12)=5.04$, $p=.03$. Also, participant comments described that MIVA: a) provided added data visualization points without the need to review traditional paper charts, b) was consistent with clinical practice, c) provided external representations of activities for clues about group coordination, and d) was a solution to resolve conflicts about interpreting others' activity. (Also see Figure 4.)

From the above results, 75% of both the control and experimental group (of clinical) participants agreed that the current way to collect and present ICU critical care data is not sufficient for supporting an accurate diagnosis of the critically ill and that MIVA has the potential to do so. In summary, participants agreed that MIVA provided a unique analytical perspective and a broader context of real-time ICU experiences, characterized by a rich social matrix of human activity. Hence, MIVA's contribution to workflow effectiveness shows promise to significantly impact clinical decision-support.

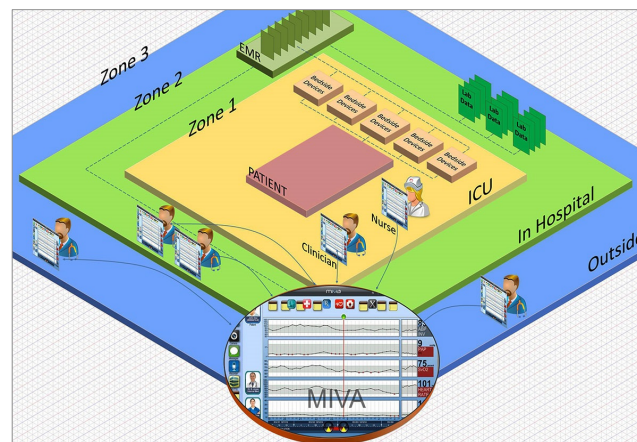
Reflection and impact: Implications of this work for the HCI community and future work

Based on the aforementioned research, we believe that clear, rapid, appropriate, and accurate communication is essential to developing human-centered technology that will deliver safe and effective patient care, from which seamless collaboration among clinical professionals is vital [15]. We propose a workflow model (Figure 5) where MIVA will be used by intensivists who are spread across three different zones, defined by location as:

inside the ICU (Zone 1), inside the hospital but outside the ICU (Zone 2), and outside the hospital and on-call (Zone 3).

Future work proposes to include an evaluation of ICU workflow, including a research methodology that is grounded in traditional Activity Theory (AT) [10]. We envision ICU workflow comprising “activity-centered” components such as goals and motives leading to actions and operations by intensivists (physicians and nurses). AT provides a framework to study real-time events that frame the historical development of clinical knowledge. Through knowledge-building activities in the ICU, we use AT to observe and identify points of interaction and conflict that have the potential to cause error or other adverse events. For instance, an ICU patient from a severe car accident is exhibiting abnormal cardiac rhythm after six hours of admission, requiring clinicians to form a motive (stabilizing the patient’s condition) and goal (preparing for treatment) leading to actions (assessing the patient’s condition) that build up an operation (treating for cardiac arrest). Our intent is to understand the impact of mediating HIT used in the ICU during collaborative work. Hence, we propose a novel workflow model that will inform clinical care

Figure 5. (Right) The proposed model illustrates clinical workflow that uses the MIVA collaborative groupware for efficient communication through an assortment of media communication technologies to support clinician team work, whether they are within (Zone 1) or outside (Zone 2 & 3) the primary care zone area. According to our proposed workflow model, patient data flows from bedside devices to the EMR system) to MIVA. Communication and data visualization components of MIVA enable clinicians across all three zones to collaboratively work in unison towards diagnosing patient condition.



through a VizCom (i.e., MIVA) system that aligns with the theoretical framework of AT.

To accurately determine how to model critical-care and diagnostic solutions, our future work will identify intensivist cognitive load, workflow, and CDS system use by means of data collection methods that will take place in the ICUs of three Indianapolis hospitals, including: a) rapid ethnography: shadowing and group observation), b) self-reporting: survey, one-on-one interview, and social network analysis, and c) the experience sampling method. Within the framework of AT, data analysis will identify and compare cognitive load and workflow which contribute to error, team communication patterns and distribution of clinical intelligence, subjective levels of happiness and degrees of challenge, and use of technology: CDS systems, bedside devices, and communication tools/devices. Our primary objective is to: identify the root causes and underlying mechanisms of ICU error related to the effects of diagnostic tools/systems on clinical work and cognitive load; with the long term goal to design transformative CDS’s that protect patients from adverse events, provide greater safety, while reducing intensivist time, effort, work, and cognitive resources. Hence, we intend to gain a more complete and advanced understanding of the individual, interrelated, and interactive factors of CDS, cognitive workflow, and inter-team communication that contribute to medical error in the ICU.

In conclusion, cognitive activity in healthcare is now the focal point of much research in HCI, Informatics, and Health Services. Existing studies consistently suggest that medical cognition should focus on complex social systems that constitute distributed knowledge, collaborative performance and clinical group workflow. Our project will inform the design of a clinical visualization-communication decision support tool that provides intensivists with capabilities for greater control of ICU data and inter-communication at the point-of-care.

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