What can paper-based clinical information systems tell us about the design of computerized clinical information systems (CIS) in the ICU?

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Summary
Background: Screen designs in computerized clinical information systems (CIS) have been modeled on their paper predecessors. However, limited understanding about how paper forms support clinical work means that we risk repeating old mistakes and creating new opportunities for error and inefficiency as illustrated by problems associated with computerized provider order entry systems.

Purpose: This study was designed to elucidate principles underlying a successful ICU paper-based CIS. The research was guided by two exploratory hypotheses: (1) paper-based artefacts (charts, notes, equipment, order forms) are used differently by nurses, doctors and other healthcare professionals in different (formal and informal) conversation contexts and (2) different artefacts support different decision processes that are distributed across role-based conversations.

Method: All conversations undertaken at the bedsides of five patients were recorded with any supporting artefacts for five days per patient. Data was coded according to conversational role-holders, clinical decision process, conversational context and artefacts. 2133 data points were analyzed using Poisson logistic regression analyses.

Results: Results show significant interactions between artefacts used during different professional conversations in different contexts \( (\chi^2_{(df=16)} = 55.8, p < 0.0001) \).

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Introduction

Screen designs in many computerized clinical information systems (CIS) have been influenced by their paper predecessors, but understanding about how paper-based systems support clinical work is limited. In order to build the case for computerization, past studies that included paper charts tended to emphasize their inadequacies while overlooking their strengths. With increased computerization, the diminishing opportunities to understand the principles underlying paper-based systems has prompted some researchers to undertake a more detailed study. With a more comprehensive understanding we may minimize the risk of repeating old mistakes and avoid creating new opportunities for error and inefficiency. The purpose of this study was to identify principles underpinning successful paper-based CIS designs as a means for informing more effective technology design. The next section shows how some of the adverse effects of computerized medication ordering and administration might have been avoided by a deeper understanding of paper-based medication management.

Paper-based medication records and the negative effects of CPOE implementation

An estimated 15–20% of hospitals in the US and in some European countries (e.g., The Netherlands) have replaced paper-based medication records with computerized provider order entry (CPOE) systems. Although benefits have accrued, the following three categories of CPOE problems have been identified as contributing to errors with high-severity adverse outcomes.

Loss of communication

Remote-user access, the ability to place or modify orders from different locations, is one of the proposed benefits of CPOEs. However, remote-access can reduce face-to-face conversation that in addition to efficient information transfer and flow, promotes social connectedness, and facilitates shared understanding about patient disease processes and care plans. As face-to-face conversation reduces, new inefficiencies may emerge as individuals attempt to uncover the goals and rationales for orders that have 'just appeared', and the risk of errors increases as goals and rationales are assumed and/or misunderstood. Remote-access also reduces the visibility of role-holders such as pharmacists and the expertise they bring to care delivery processes. Without visibility, understanding about how and when to involve different professionals may be compromised resulting in lack of timely advice. Remote-access can also promote batched order entry (entering multiple orders for different patients in one session) by often junior doctors. In this situation, ordering becomes a simple data-entry task that is disconnected from care planning and feedback processes and is vulnerable to transcription and other data-entry errors.

In our study ICU, paper-based medication charts promoted face-to-face conversation. All medication charts were located at patients’ bedside. The care team assembled at the bedside for morning rounds. During the round, orders were written in the context of patient assessment and care planning discussions that integrated different professional perspectives. Between rounds, doctors again came to the bedside to change medication orders in response to laboratory results or other consultations. As others have also noted, doctors coming to the bedside cued nurses to imminent changes and provided an opportunity for both clinicians to update their understanding of the patient’s situation. Thus in the study ICU, ordering was embedded within broader, team-based decision, care planning and delivery processes.

Interruptions to information and workflow

Berg and Toussaint argue that the first step in the design of information systems should be to understand how information flows across different roles...
and responsibilities. Fig. 1 is a generic model of clinical information flow at the level of individual patients. In Fig. 1, information flow involves closed-loop decision processes that include, diagnosing a problem, defining a treatment regime, administering the regime and monitoring its effects. Researchers have found that although nurses attend to therapy administration and patient monitoring relatively more than doctors and doctors attend to diagnoses and treatment planning relatively more than nurses, all team members attend to all aspects of the closed-loop decision process. Thus doctors determine and write orders, but they are also concerned about how and when medications are administered. Similarly, before they administer medications, nurses need to know who ordered it, its indication and whether a pharmacist has verified the order. Thus as suggested in Fig. 1, medication management, like most other care related processes, simultaneously involves unique disciplinary as well as overlapping areas of interdisciplinary concerns.

With some exceptions, CPOE and barcode administration systems are separate systems or modules that support either doctors’ prescription or nurses’ medication administration tasks; overlapping decision concerns are less well supported. Given others’ findings that the separate needs of nurses and doctors can be supported by integrating patient, therapeutic and goal related information in a single CIS design, separating such closely related processes, simultaneously involves unique disciplinary as well as overlapping areas of interdisciplinary concerns.

Data-entry and retrieval issues

Researchers have identified up to 22 types of medication error risks arising from: ambiguity about the meaning of onscreen information and about the state of discontinued, changed, and temporarily suspended orders; cognitive overload due to the inclusion of administrative information and an overemphasis on highly structured data entry; selection errors including wrong patient, and increases in nurses’ charting time that delay other interventions including medication administration.

On each patient’s paper chart, each drug is presented in its own block that structures the medication’s name, dose, route and frequency of administration and its indication (see Fig. 3). Team member contributions are reflected in spaces for the prescriber’s name, the name of the pharmacist who verified it, and for the initials of the nurses who administered it. The number of doses given can be assessed at a glance and in comparison to other drugs. Orders can be struck through wholly or for those days or times when medications should not be given. Annotations can be added to explain anomalies and space restrictions ensure that only information related to medications are included thereby minimizing the creeping information overload that occurs when space is perceived to be unlimited. Thus while also structuring data entry, paper-based systems support an extended range of

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Figure 2  Frequently administered medications (see Fig. 3 for more detailed views).

Figure 3  Selected paper-based medication orders (representative, not to scale).
Lessons to be learned

In summary, paper-based medication records like the ones in Figs. 2 and 3 are successful because they support interdisciplinary information flows and medication management practices in addition to data entry. The overall structure of the paper-design supports different types of prescription and administration criteria and care delivery contexts (once-only, routine and variably administered). At more micro-levels, information is grouped (e.g., prescription with administration; indications with medication name, dose, route, frequency) to preserve and support information relationships and flows.

Research questions

Consistent with Berg and Toussaint’s recommendation, the aims of this study were to examine the use of artefacts in ICU decision processes by applying the information flow model presented in Fig. 1 to the use of artefacts during different role-holder conversations. For the purposes of this study artefacts are defined as any tool (paper-based and/or computerized forms, charts, equipment, notes, etc.) used by healthcare professionals to support information processing and information flow. This approach differs from the more usual ethnographic studies of artefacts. Rather than undertake a highly contextualized analysis, we applied the decision process model in Fig. 1 to provide a more generic characterization aimed elucidating generalizable principles. We used the following research hypotheses to guide our examination.

Hypothesis 1: In the study ICU, paper-based artefacts are used differently by nurses, doctors and other healthcare professionals in different (formal and informal) conversation contexts. Statistically significant interactions between these variables will provide insights as to 'how' artefacts are used, by whom in what contexts.

Hypothesis 2: In a paper-based ICU, different artefacts support different decision processes that are distributed across different role-based conversations. This hypothesis addresses the role interactions, artefacts and the reasons for an artefact’s use. Statistically significant interactions between these variables will allow us to describe ‘why’ artefacts are important in decision contexts and to whom and may provide some insights as to how information flows within an interdisciplinary team.

Method

Context

The study ICU was an Australian, university affiliated metropolitan hospital admitting approximately 2000 patients per year and treating on average 32 patients at once. The combined ICU and trauma center deals with complex conditions for, as a limited example, cardio-thoracic surgery, artificial heart technology, transplantation, and hyperbaric emergencies. In common with other institutions, the study hospital is undergoing a transition from a fully paper-based system to a predominantly electronic one. Although computers were introduced in 2003 to allow clinicians to look up blood results and X-rays, at the time of data collection, all observations charting, medical records, prescribing, nursing care plans and handover information were paper-based.

Participants

Following Human Research Ethics Committee approval, 83 doctors and nurses consented to participate between May and July, 2006. This number included all ICU doctors and 45% of nurses. The next-of-kin of five critically ill patients gave written consent. Three research assistants (RAs), all psychology graduates with acute care hospital experience, were trained by the researcher to collect data. Training included familiarization with the patient care-area, equipment, routines and key staff members as well as orientation to the study’s purpose and data collection procedures.

Materials

Materials setup in patients’ care-areas included:

1. Three microphones, an 8-channel audio-mixing deck to filter background noise, and a set of headphones. Sound was recorded onto mini-tapes in a Canon camera. No visual images were captured.

2. A laptop computer for manually recording the date and time, the conversation content, the speaker’s roles (e.g., doctor, nurse, etc.) and supporting artefacts.

Procedure

The researcher and RAs recorded all patient-related conversations and observed uses of artefacts (paper-based, computerized and procedural equipment) continuously for five days per patient (day,
night and weekend) for five patients for a total of 23 days (one patient was discharged after three days). The RAs were positioned at the back of the patients’ care-areas where they could see speakers and artefacts-in-use without interrupting the conversations. During the night-shift, the previous day’s audio-recordings were replayed and manual recordings were corrected. RAs were quickly assimilated; there was no overt evidence that patient-related conversations were censored.

**Data coding**

The recorded conversations were divided into thematically coherent, grammatically complete conversational units (e.g., questions and answers or sentences), as distinct from speech units that do not require grammatical completeness. Conversational units involving multiple artefacts were subdivided so that each artefact was associated with the topic it supported. Once collated, the following four variables were defined:

1. **Decision process:** Fig. 1 and the five decision processes (Table 1) were developed during research following this study and will be published in subsequent papers. The definition and operationalization of each process is presented in Table 1. Cohen’s kappa for inter-coder reliability, calculated from three randomly selected days of patient data and independently coded by the researcher and a research assistant, was good (kappa = 0.83).

2. **Roles:** Conversations between different clinical roles included: nurse-to-nurse; doctor-to-doctor; mixed role conversations between nurses and doctors; and conversations between nurses or doctors and other healthcare workers such as pharmacists.

3. **Artefacts** used during clinical communication included: paper-based charts (e.g., observation, fluid-balance), notes (free form text reports and personal notes) and orders (specifically, medication charts); non-paper-based computerized information systems (cardiac monitors, radiology scans, laboratory results); procedural equipment (beds, bowls, components of fluid infusion sets, surgical instruments, ventilators); radiology equipment (echocardiograms, ultrasound and X-ray machines); and no-artefact conversations that did not involve the use of an artefact.

4. **Context:** Whether the artefact was used during a formal scheduled conversation (e.g., shift handover or round) or during an informal (not formally scheduled) conversation.

**Statistical methods**

Poisson or log-linear regression models were used to characterize the relationships among conversation features, (1) role, (2) context, (3) decision process, and (4) artefact, while acknowledging or controlling for patient differences. To examine evidence for higher level (e.g., 3-way or 4-way) interactions, we conducted several of likelihood ratio Chi-square (LR\(\chi^2\)) tests for nested models. We first constructed a saturated model that included main effects as well as 2-way, 3-way, and 4-way interactions. The 4-way interaction was tested by comparing the LR\(\chi^2\) statistic for the saturated model to the LR\(\chi^2\) statistic for the nested model that did not include the interaction. Three-way interactions were tested in the same manner (i.e., by comparing LR\(\chi^2\) statistics for nested models). Statistical significance is evidence that the more complex of two nested models provides a superior fit to the data. Upon identifying the statistically significant 3-way interactions, we calculated expected frequencies of all possible covariate combinations and their associated 95% confidence intervals (CIs). These quantities were rescaled to reflect counts per 100 conversations. All analyses were prepared using the R programming language.

**Results**

A total of 2133 entries were collected from the five study patients. The data collected for each patient varied from 10 to 30% (Patient 1: 29%, 2: 29%, 3: 15%, 4: 17%, 5:10%). From these 2133 entries 34% (\(n=798\)) of conversations were not supported by artefacts, 28% were supported by charts (\(n=530\)), 16% involved equipment (\(n=351\)) and 10% of conversations were supported by written orders (\(n=222\)).

Using Poisson regression modeling, there was no statistically significant difference between the fully saturated model containing all main effects and 2-way, 3-way, and 4-way interactions and the simpler model that contained only the main and 2-way and 3-way interactions (LR\(\chi^2\) (df=21) = 28.2; \(p=0.1345\)). Thus we were unable to detect a 4-way interaction between artefact, roles, context, and decision process. Next, a statistically significant interaction was observed between roles, conversation context and artefact (LR\(\chi^2\) (df=16) = 55.8; \(p\text{-value}<0.0001\)). This supports the first hypothesis that different role-based conversations involve the use of different artefacts in different conversational contexts. Finally, we were unable to detect an interaction between roles,
decision process and artefact \( (LR_{X^2}^{2} (df=59) = 41.7; \ p-value = 0.9567) \). Thus these data do not support the interaction proposed in the second hypothesis, although the pairwise interactions: (decision process and artefact—\( LR_{X^2}^{2} (df=24) = 497.7; \) roles and decision process—\( LR_{X^2}^{2} (df=12) = 144.6; \) and roles and artefact—\( LR_{X^2}^{2} (df=18) = 51.5), were all highly significant \( (p<0.0001) \). Each of the hypotheses will be explored in greater detail in the following sections.

**Hypothesis 1.** Paper-based artefacts are used differently by nurses, doctors and other healthcare professionals in different (formal and informal) conversation contexts.

Fig. 4 shows the expected conversation frequencies (rescaled to counts per 100) and 95% CIs for the significant interaction between artefacts, roles and conversational context. The rows in Fig. 1 represent each role category, the columns show each type of artefact, and conversation context is represented using different symbols. The interactions are evident by comparing the CIs within each row and down each column. Thus, for example, formal conversations among nurses were supported by charts more than any other artefact. During formal conversations charts were primarily used among RN—RN exchanges followed by those between RN—MD. In contrast, informal conversations among nurses were associated most strongly with equipment (e.g., ventilators, infusion pumps) and unsupported verbal conversations. Nurse—doctor conversations have a similar profile across conversation types, although charts support both formal and informal nurse—doctor conversations. These two profiles differ substantially from doctor—doctor and nurse or doctor with allied health professional conversations, which were not associated with any particular artefact.

**Hypothesis 2.** Different artefacts support different decision processes that are distributed across all role-based conversations.

### Table 1 Levels of decision processing.

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<thead>
<tr>
<th>Level</th>
<th>Definition</th>
<th>Conversational unit example</th>
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<tbody>
<tr>
<td>Patient care planning</td>
<td>Conversations about the team’s objectives, goals or plans for a specific patient. May include the steps needed to achieve goals over particular timeframes and modifications to existing plans.</td>
<td>“Let’s aim to extubate tomorrow. Go to CPAP now and drop the sedation right back to off over the next 4 hours. We’ll see how she goes over night and T-piece tomorrow at 0600. If all’s well extubate after the round.”</td>
</tr>
<tr>
<td>Diagnosis</td>
<td>Conversations about a patient’s disease state or disease process, including discussions about progress and progression, problem identification and problem solving.</td>
<td>“He’s improved this morning, no longer febrile, passing urine.” “The psychiatrists seem to think it’s a rare side-effect of the cyclosporine.”</td>
</tr>
<tr>
<td>Prescription</td>
<td>Highly specific directions (usually for others) to act using medication or devices (e.g., ventilator). These directions hold the team member legally responsible for the direction—they may be written or verbal.</td>
<td>“Turn the ventilator to CPAP” “Stop the midazolam and start haloperidol instead.” Physician writes an order for Vancomycin (observer note) Nurse checks the ordered dose.</td>
</tr>
<tr>
<td>Administration</td>
<td>Highly specific actions associated with care delivery processes that may be routine or specifically prescribed.</td>
<td>The process of: taking a chest X-ray; administering drugs; enacting protocols; completing medical (CVC line insertion) or nursing procedures</td>
</tr>
<tr>
<td>Monitoring</td>
<td>The acquisition, comprehension and/or transfer/transmission of information about patient states, rates or plans.</td>
<td>‘’His current BP is…” “How are we going, has his SaO2 stabilized yet?” They observe T-waves on the cardiac monitor</td>
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</table>
The non-significant three-way interaction between roles, decision processes and artefacts is clearly evident in Fig. 5. Across all roles for example, charts (4th CI in the charts group) supported monitoring while equipment (3rd CI in the equipment group) supported administrative processes and unsupported verbal conversations were associated with administration, monitoring and patient care planning. Thus the observed differences across role-based conversations were associated with the relative frequency of each artefact’s use (height of the CIs) rather than fundamentally different uses of artefacts.

Fig. 5 also highlights some of the significant two-way interactions. Reflecting the ‘role by decision process’ interaction, conversations involving nurses (i.e., RN—RN and RN—MD) tend to involve administration, monitoring and patient care planning more so than other role-based conversations. Representing the ‘decision process by artefact’ interaction, monitoring is most closely associated with the use of charts, administration with the use of equipment and patient care planning is most closely associated with unsupported verbal exchanges. Diagnoses and prescription were largely unsupported by bedside artefacts.

Discussion

The purpose of this study was to identify principles underpinning successful paper-based CIS designs as a means for informing more effective computerized design. The results of this analysis present a highly interdisciplinary profile of ICU decision processes.
Figure 5  Expected frequencies and 95% CIs for each artefact used by different role-holders for different decision processes.

and artefact use. The major differences associated with artefacts are related to the context in which artefacts are used (informal vs. formal) rather with who uses them (roles) for what reasons (decision processes). Our findings have implications for CIS design and suggest general principles that may be translated from the paper to computerized information environments, but also highlight areas of vulnerability that have not been described previously and that may be reduced in the shift to computerized healthcare environments.

Implications for CIS design and error in a computerized environment

Experience implementing CPOEs currently provides the most reliable source of information about the negative effects and potential adverse outcomes of computerizing clinical information. The most significant negative effects stem from loss of social interaction, interruptions to work and information flows, and data-entry and retrieval problems that create the conditions for error.6–12 These problems may in turn stem from technology development approaches that fail to recognize the collaborative, distributed and interdisciplinary nature of healthcare delivery, and that overwhelmingly emphasize data-entry and storage concerns ahead of the primary purpose of clinical information collection which is to support clinical decision making processes and practice.

Supporting interdisciplinary healthcare delivery

We noted previously that professional groups emphasize different, but highly interrelated aspects of the patient decision processes.14,15 We
also observed that current CPOE and medication administration systems emphasize nurses’ or doctors’ data-entry tasks; the interrelations and interdependencies between say doctors’ orders and nurses’ medication administration are not well supported. In contrast, the artefacts in the study ICU were used by all role-holders. Thus, paper-based artefacts appear to have evolved to support both disciplinary and interdisciplinary perspectives (see Figs. 2 and 3) and by integrating professional perspectives provide a common platform for communication and shared understanding. In retrospect this conclusion seems obvious, but as illustrated in our introduction its importance has clearly been overlooked in clinical information systems design at least with respect to CPOEs.

Using integrated tools, team members with different professional perspectives can share, test, update, tailor and repair mutual understandings about the patient’s situation, about the team’s progress against intended plans and about each team member’s responsibilities. Without an integrated information system the overall communication burden increases because clinicians must actively seek out and integrate narrower disciplinary perspectives, or else tolerate information gaps that increase the risk of adverse events due to faulty assumptions or misunderstandings. This study has also highlighted inadequacies, even in paper-based information systems, in the support of patient care planning in particular. There are at least two possible reasons for the lack of artefacts supporting care planning. First, interdisciplinary communication processes (interdisciplinary rounds for example) are not universally accepted as standard practice. Thus interdisciplinarity is arguably an emerging practice and as such the artefacts to support it are also emerging. Second, ICU patient dynamics can change rapidly. Over short timeframes it may not be as necessary to document team plans that are discussed during daily rounds and updated during informal discussion. However as the complexity of in-hospital care continues to increase as a consequence of shorter staying sicker patients, the need for clearly defined goals and plans that integrate information over time and across different care delivery contexts will also increase. Computerized displays that represent goals and plans, that facilitate progress tracking and that alert clinicians to deviations from anticipated patient care trajectories may assist in minimizing the incidence of breakdowns in care coordination that include delayed, duplicated, missed or erroneous care related activities. Achieving this outcome will, however, require a fundamental shift in systems design philosophy from a single user-group transaction (i.e., doctor orders medication; nurse administers medication) to an interdisciplinary design approach that emphasizes human decision processes in an information environment and that closes the communication and information flow loops represented in Fig. 1.

Limitations and future research directions

This study like most research has a number of short-falls that limit conclusions, but which also provide opportunities for future research. The most significant limitation is that the analysis was undertaken at the level of professional group interactions during broad categories of conversations. This approach has the advantage of capturing aggregate rather than individuals’ patterns of behavior, but has the disadvantage of limiting conclusions about how artefacts support these processes specifically. Further research is needed to better understand the nature of interdisciplinary interactions with charts in particular, including how they are used to support information flows and decision outcomes, and what happens when these contributions are not supported. Given that paper charts have evolved in specific contexts and thus reflect the priorities and eccentricities of those contexts, it will be important to examine the design of paper-based artefacts across institutions. Ideally this examination should focus on design invariances, those aspects of design that are common across units. Invariances provide the broad design skeleton; differences represent those aspects of design that need to be tailored to meet the needs of different contexts.

In addition, the conversations recorded in our study ICU were limited to those undertaken at the bedside. It is possible that some conversations, especially doctors’ diagnoses and prescription conversations were undertaken away from the bedside. Thus physician interactions with artefacts may be under-represented. Finally, data capture was limited to only one ICU, thus results may not generalize to other ICUs or healthcare settings.

Conclusions

The purpose of this study was to elucidate principles underlying successful paper-based CIS designs in an ICU. Thus we present the following two design principles as summaries of our findings and conclusions: Principle 1. Effective CISs support interdisciplinary interaction. Interdisciplinary needs for information should be integrated into the design and implementation of CIS; and Principle 2.
Effective CIS support decision processes, information flows and practice in addition to data entry. Accurate data entry is necessary but not sufficient to the provision of high quality patient care delivery.

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