

**The Relation of User Interface and User Experience Design to Data Integrity
In Electronic Health Records**

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Abstract

This paper explores the relationship of User Interface and User Experience (UI/UX) design to data integrity in Electronic Health Record (EHR) systems. The topic is approached through examination of: foundational concepts of UI/UX design and data security, history and market drivers of EHRs, and scholarly research on EHR usability and patient safety. The author proposes to improve data integrity in EHR systems through a collaborative effort between EHR vendors, hospitals, and clinicians. The proposal focuses on standardization of EHR system implementation and extensive usability testing with actual medical practitioners for all relevant variations on EHR user roles.

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Background

History and Proliferation of Electronic Health IT Systems

For over a decade, the United States has been undergoing an effort to transform the healthcare industry with the application of Health Information Technology (Health IT or HIT) (Pallin et al. 2011, 543). In February 2009, the United States congress passed the *Health Information Technology for Economic and Clinical Health (HITECH)* Act, which provided government funded financial incentives to hospitals and doctor's offices to adopt and implement Health IT systems (Pallin et al. 2011, 543; Wani and Malhotra 2018, 1). This was largely driven by the belief that widespread implementation of Health IT could reduce healthcare costs and improve patient care while creating efficiencies (Pallin et al. 2011, 543; Wani and Malhotra 2018, 1). In 2008, direct medical liability costs, such as medical malpractice insurance, claims, and litigation, totaled approximately \$55.6 billion in the United States (Talmadge 2017, 202). It was hoped that incorporation of Health IT would improve patient care and reduce costs by helping clinicians to recognize errors, such as those that can occur when clinicians place an order for treatment (Taieb-Maimon et al. 2018, 383).

In particular, the HITECH Act sought to increase the adoption of Health IT systems that are used directly by healthcare providers, such as doctors, nurses, and other medically trained personnel (Pallin et al. 2011, 543; Wani and Malhotra 2018, 1-2). Adoption of Electronic Health Record (EHR) systems to replace traditional paper charting was one of the act's primary aims (Wani and Malhotra 2018, 1). EHR systems offered potential for efficiency in sharing patient healthcare data between providers, as well as the potential to aid healthcare providers in

making and carrying out clinical healthcare decisions (Mosaly, Guo, and Mazur 2019, 1883; Wani and Malhotra 2018, 1).

Similarly, the HITECH Act also sought to incentivize Computerized Provider Order Entry (CPOE) systems, which are often a part of EHR systems (Middleton et al. 2013, e2-e3; Pallin et al. 2011, 543). CPOE systems allow physicians, and other advanced practice providers, such as nurse practitioners and physicians assistants, to directly place orders for their patients (Taieb-Maimon et al. 2018, 383). Those orders could include prescriptions, diagnostic tests, and other medical procedures (Taieb-Maimon et al. 2018, 383).

Implementation of these Health IT systems was a significant change for healthcare providers, who are the intended users of such systems. It has also affected millions of individuals as patients. Healthcare accounts for nearly 20% of the gross domestic product (GDP) of the United States (Wani and Malhotra 2018, 1). In 2016 alone, Americans made over 883 million visits to physicians' offices (Rui and Okeyode 2017). Of those visits, over 74% utilized entirely electronic medical records, and another 14% utilized at least partially electronic medical records (Rui and Okeyode 2017).

Usability and Health IT Systems

The hope of these healthcare provider facing systems was that they could serve as a means to aid providers in making healthcare decisions and reduce errors (Mosaly, Guo, and Mazur 2019, 1883). However, these systems themselves also potentially create new risks to the integrity of the medical data. Since these systems are designed for the input and manipulation of patient medical data, any error on data entry may negatively affect a patient's medical care. With electronic medical records, data integrity is potentially a life and death issue.

Ensuring data integrity has long been viewed as a goal of information system security. Conversations about data security often focus on intentional efforts to harm data integrity or system errors that can corrupt or destroy information. However, user error upon record creation or alteration can also pose a threat to data integrity (Harris and Fernando 2016, 4). This is of particular concern if the system's design contributes to such errors. In the case of healthcare provider facing systems, such as EHR systems, errors can put patient health at stake. Indeed, over half of reported patient safety events related to Health IT involve some type of human data entry or retrieval error (Mardon et al. 2014, 19-20).

The Problem to Be Addressed

This paper will seek to examine the relationship of User Interface and User Experience (UI/UX) design to data integrity in healthcare provider facing IT systems. The goal is to better understand this relationship and determine if system usability design can improve data integrity by reducing errors made by medical staff, who are the intended users of such systems.

Better understanding of this issue could potentially enable system designers and developers to reduce errors in patient medical records. Such improvement in the data integrity of medical records could improve patient care and potentially save lives.

By contrast, insufficient focus on UI/UX by developers of EHR systems may make those systems more prone to user error when inputting or manipulating patient records. Such errors, thus pose an unnecessary threat to the integrity of data and, in turn, patient care.

Approach

In examining the relationship of UI/UX design to data integrity in healthcare provider facing IT systems there are three primary areas of research. The first area for research is User

Interface and User Experience design or “usability”. The second will be into data integrity, particularly as related to user input and user input errors. Finally, extensive research will be conducted into Health IT systems and their development. In particular, those systems whose intended users are healthcare providers will be the focus.

Studies that directly examine the usability of healthcare provider facing systems, such as EHR and CPOE systems, will be the greatest area of focus. This paper will seek to examine how much knowledge on this topic currently exists and how widely understood the issues are within the fields of healthcare and Health IT.

The proposed solution will be suggested drawing from what is known regarding the relationship of UI/UX and data integrity, as well as how that relates specifically to the medical field and healthcare providers. Drivers of the development of EHR and CPOE systems will also be discussed to the extent they may play a role in affecting patient medical data integrity.

Literature Review

Data Integrity and System Usability

Data Integrity

One of the primary goals of information system security is to ensure the integrity of data. The ability to rely on accurate system data is crucial for the success of any information system (Harris and Fernando 2016, 4). Simply put, “data integrity” is the ability of authorized users to trust that the system data they require is accurate and reliable (Harris and Fernando 2016, 4).

There are a great many potential threats to data integrity. Unauthorized access and manipulation of data, such as by an outside hacker, is a commonly considered threat (Harris

and Fernando 2016, 4). However, there are other potential threats as well. Among them is error by users, which is the concern most relevant to the subject at hand (Harris and Fernando 2016, 4). Users can unintentionally harm data integrity by entering incorrect values into the database, or manipulating the wrong data record (Harris and Fernando 2016, 4). It is for this reason that it is a best practice for the system to help validate user input (Harris and Fernando 2016, 4). This could include only allowing specific options or ranges in a given field, or alerting users to unexpected or unusual entries (Harris and Fernando 2016, 4).

This ability to help validate input to prevent errors was, in fact, a major driver for the adoption of Health IT systems (Taieb-Maimon et al. 2018, 384; Wani and Malhotra 2018, 1). However, Health IT systems, such as EHRs, also opened new avenues by which errors may be committed (Taieb-Maimon et al. 2018, 384). This is where User Interface and User Experience design become relevant to the discussion.

System Usability

The field and study of Human-Computer Interaction (HCI) is a relatively new one. Born out of the field of human factors, HCI examines how people perceive and interact with computer systems to achieve their goals (Johnson 2014, Acknowledgements, Forward). Most everything that a user does on a computer system is to accomplish some goal, such as write a paper, send a message, or document patient health data. The computer itself acts as an intermediating device between the user and their goal (Johnson 2014, Forward). Because of this, it is widely acknowledged that the computer or computer system's user interface may aid, or hinder, the user in accomplishing their goal (Johnson 2014, Introduction; Martins et al. 2015, 133; Middleton et al. 2013, e2).

User Interface and User Experience design draw heavily on the study of HCI and its focus on how users perceive elements of an interface, as well as the cognitive psychological effects that the interaction can have on the user (Johnson 2014, Acknowledgements). The user interface (UI) portion of UI/UX focuses on how the interactive elements are presented to the user (Johnson 2014, Introduction). The user experience (UX) portion focuses on how the user actually uses the system, in light of his or her understanding and goal (Caddick and Cable 2011, 1).

Taken together, the overall focus of UI/UX design is “usability” (Caddick and Cable 2011, 1; Johnson 2014, Introduction). System usability refers to, “how useful, usable, and satisfying a system is for the intended users to accomplish goals by performing certain sequences of tasks” (Middleton et al. 2013, e3). Or, to put it another way, usability seeks to ensure that, “real products can be used by real people to achieve their tasks in the real world” (Martins et al. 2015, 133).

Finally, development of systems with significant, if not primary, focus on this kind of practical usability is commonly referred to as User-Centric Design (UCD) (Martins et al. 2015, 133; Ratwani et al. 2016, e35-e36). Placing the needs of actual users at the center of system development can make them easier to use and less frustrating for their intended users. However, as will be examined in more detail later on, this kind of strong focus on usability can also improve data integrity (Taieb-Maimon et al. 2018, 392-393).

Drivers of Usability in EHR Systems

Federal Requirements for EHR Systems

As was introduced in the background section, adoption of Electronic Health Records in the United States was driven largely by federal legislation (Pallin et al. 2011, 543; Wani and Malhotra 2018, 1).

The federal government created a system for certifying vendors of EHR systems through the Department of Health and Human Services' Office of the National Coordinator for Health Information Technology (ONC) (Ratwani et al. 2015, 1070; Wani and Malhotra 2018, 2-3). Financial incentives encouraged the adoption of EHR systems based around demonstration of what federal regulators defined as "meaningful use" of EHR systems (HealthIT.gov 2019; US Congress 2009, H.R. 1—353; Wani and Malhotra 2018, 2-3). This "meaningful use" included a number of functions, such as,

capturing patient information electronically in a standardized format, using patient information to track key clinical conditions, integrating test and imaging results and using decision support tools, communicating the information to all providers for the purposes of care coordination, initiating reporting of key clinical quality measures, and ... using the information to engage families and patients in their care (Wani and Malhotra 2018, 2).

The government-sponsored incentives also added additional responsibilities for providers such as an increased care process, population health management, and documentation requirements (O'Malley et al. 2015, 426).

These needs were intended to be met with use of certified EHR systems (Ratwani et al. 2015, 1070; Wani and Malhotra 2018, 2-3) The ONC authorizes third-party organizations, who

in turn certify EHR systems as having met the ONC's certification requirements (Ratwani et al. 2015, 1070). In the early years following the HITECH Act, those certification requirements were largely focused on meeting the "meaningful use" standard, with less focus on the usability of those systems (Savage, Fairbanks, and Ratwani 2017, 769-770). More recently, the requirements have been changed to include a requirement that EHR vendors attest to a User-Centered Design process (Ratwani et al. 2015, 1070; Savage, Fairbanks, and Ratwani 2017, 769-770).

Federal Requirements and Usability in Practice

This more recent effort to improve EHR usability seems to have been less than entirely successful. A 2015 study of 41 EHR vendors found that 34% had not met the ONC certification requirements for usability, despite being certified EHR vendors (Ratwani et al. 2015, 1071). In addition, 63% used fewer than the standard 15 participants for usability testing, and only 22% used 15 participants with backgrounds as clinical healthcare providers (Ratwani et al. 2015, 1071).

In addition, there seems to be a widely held view among many clinicians that federal requirements are a significant hindrance towards EHR usability (Savage, Fairbanks, and Ratwani 2017, 769; Stack 2015; Terry 2015). Scholarly literature on the question of whether federal regulations are in fact a significant hindrance towards EHR usability seems to be rather thin. As a result, analysis is often anecdotal and quite possibly rather subjective. None-the-less, clinicians are, in fact, the intended users of EHR systems, and given that this view seems to be rather widely held, their views, even if largely anecdotal, demand consideration.

For example, the American Medical Association (AMA) describes itself as, “a health care advocacy organization made up of dedicated and engaged physicians ... [that] works to inform lawmakers, guide decision-making and generate support for policies on critical issues that impact physicians, patients and the health care environment” (American Medical Association, n.d.). In 2015, the AMA held a town hall meeting with physicians on the subject of EHRs (Stack 2015). In response to this meeting, the former president of the AMA commented in a post on the organizations website that, “the message from physicians is loud and clear: Electronic health record (EHR) systems have so much potential, but frustrating government regulations have made them almost unusable” (Stack 2015). This sentiment is intended to be reflective of the statements of “many” physicians in attendance at the meeting and seems to be shared more broadly beyond that particular town hall meeting (Savage, Fairbanks, and Ratwani 2017, 769; Stack 2015; Terry 2015). Again, while somewhat anecdotal, this frustration by EHR systems intended users also conforms to scholarly finding on EHR use, as will be discussed later in more detail (Shanafelt et al. 2016, 843).

EHR Usability and the Marketplace

Usability can also be a difficult feature to gauge for consumers in the market. Different vendors use very different UCD processes, ranging from only nominally user-centric ones to highly sophisticated processes and dedicated usability staff members (Ratwani et al. 2016, e36). This variance can be somewhat opaque to purchasers of EHR systems (Ratwani et al. 2016, e36). This historically has limited the ability of EHR customers to purchase based on usability (Ratwani et al. 2016, e36). It is reasonable to conclude that this also limited the need of vendors to place true emphasis on usability.

Experts in the field have since proposed frameworks to aid purchasers and end users in better understanding the usability processes utilized in EHR system development (Ratwani et al. 2016, e38). One proposal seeks to apply a score to each EHR system based on the stated UCD process, their testing method, and testing results (Ratwani et al. 2016, e38). Such a system may help create demand for more usable systems, particularly given their cost. EHR systems upfront and yearly costs are estimated to range from \$15,000 to \$70,000 per healthcare provider (Reisman 2017, 574).

Established Information on EHR Usability

Clinician Experience with EHR Usability

The intended users of EHR systems are clinicians, such as medical doctors, nurses, and advanced practice providers, such as nurse practitioners and physician's assistants. As the intended users of these systems, their experience and satisfaction with EHR systems can likely speak to overall usability. As mentioned previously, EHR system usability has been a source of frustration for many of these intended users (Friedberg et al. 2014, Main Findings). Physician surveys show that clinicians broadly see the potential of EHR systems to improve both patient care and the professional satisfaction of clinicians (Friedberg et al. 2014, Main Findings).

However, surveys also show that the current state of EHR systems has greatly worsened clinician's professional satisfaction (Friedberg et al. 2014, Main Findings). Physicians with high usage of EHR systems have been shown to experience greater pressure on their time (Babbott et al. 2014, e105). This is consistent with a significant national study of physician satisfaction with EHR systems that found that only approximately 33% of physicians thought the amount of time spent on clerical tasks directly related to patient care was reasonable (Shanafelt et al.

2016, 843). Only 25% thought that the amount of time spent on tasks indirectly related to patient care was reasonable (Shanafelt et al. 2016, 843). In short, EHR systems have increased demands on clinician's time and energy (Babbott et al. 2014, e105). As a result, physicians who used EHR systems were at higher risk of burnout (Shanafelt et al. 2016, 844). Dissatisfaction among clinicians is so pronounced as to raise potential concerns about its effect on overall patient care (Friedberg et al. 2014, Main Findings).

Making Do with Existing EHR Systems

Physicians and other medical professionals have had to make do with EHR systems that leave much to be desired. At the same time, the demand on them as healthcare professionals has been increased (O'Malley et al. 2015, 426). Policy makers and healthcare providers have since been moving to a more team based approach to medicine, in part because of the recognition that the burden on physicians is so significant (O'Malley et al. 2015, 426). Helping to facilitate this teamwork has since become a goal of EHR systems (O'Malley et al. 2015, 426). Studies into team healthcare usability have thus far been mixed in their findings (O'Malley et al. 2015, 432-433). There are certain ways in which EHR systems have been found to be quite helpful to clinicians, such as facilitating communication and task delegation (O'Malley et al. 2015, 432-433). However, it seems there is still considerable room for improvement, such as better following of practical clinical workflows and the development of new team based features (O'Malley et al. 2015, 433).

Examples of Specific Barriers to EHR Usability

Despite considerable efforts to make do, EHR systems have a number of substantial known usability problems. As alluded to, healthcare is a complex process often involving a

number of different healthcare providers, each with their own role (O'Malley et al. 2015, 426). Doctors, nurses, advanced practice providers, and medical assistants have differing legal authority and scope in providing medical care (O'Malley et al. 2015, 430-431). From a technical standpoint, this means that developers of EHR systems have to develop for a number of different user roles, with different access control permissions (Middleton et al. 2013, e4). While that is not uncommon for many application development projects, in the context of modern healthcare this can be a very significant challenge (Middleton et al. 2013, e4). Medical professionals have highly complex roles and work in a highly complex social and professional setting (Middleton et al. 2013, e4). As a result, the knowledge base of these target users of EHR systems is very different from that of the typical developers of such systems, to whom professional medical roles and idiosyncrasies are quite foreign (Middleton et al. 2013, e4).

This is also compounded by the wide variety of different medical specialties, each with their own needs, workflows, and particulars (Friedberg et al. 2014, Conclusions; Shanafelt et al. 2016, 837). "General hospitals," for instance, admit all types of medical and surgical patients needing short-term acute care (Encyclopedia Britannica, n.d.). As a result, they cover a very wide breath of medical specialties, all of whom EHR systems must serve (Friedberg et al. 2014, Conclusions).

Each of these different tasks, for different types users, in different specialties, creates an enormous number of "use cases" which developers of EHR systems must try and serve (Middleton et al. 2013, e3-e4). "Use cases" are common tools for application development (Middleton et al. 2013, e3). Each use case defines a particular task that a particular user wants or needs to perform (Middleton et al. 2013, e3). The complexity of medical professionals' roles,

variety of medical specialties, and resulting high number of potential use cases makes for a difficult project for EHR system developers (Middleton et al. 2013, e3-e4).

However, the difficulty and number of possible use cases does not end there. EHR system implementation can also be a significant barrier to system usability. EHR systems typically provide a high degree of flexibility in configuration (Middleton et al. 2013, e4). This can result in different providers using very different implementations and processes, thus further compounding the number of potential use cases (Middleton et al. 2013, e4).

A Collaborative Approach to Usability

As described, one of the challenges related to development of EHR systems is the vast number of potential use cases and the expertise of the intended users. As a result, gathering actionable usability data for system developers can be difficult. Here the Collaborative Usability Evaluation (CUE) model is noteworthy (Hundt, Adams, and Carayon 2017, 294).

The CUE model is based on the principles of participatory ergonomics, wherein individuals are encouraged to be involved in planning and controlling significant portions of their work, in order to help achieve the desired outcomes of their work (Hundt, Adams, and Carayon 2017, 287). In the CUE model, usability experts provide individuals from a given organization with training on usability principles and methods, and help them to develop the skills necessary to conduct meaningful usability evaluations (Hundt, Adams, and Carayon 2017, 287-290). Those newly training individuals can then serve as an ongoing and self-reinforcing group within the organization for conducting actionable usability evaluations (Hundt, Adams, and Carayon 2017, 288).

In a study by Hundt, Adams, and Carayon, the CUE model was applied to a Health IT implementation at a hospital system in Pennsylvania (Hundt, Adams, and Carayon 2017, 288). In the study, a number of the organization's Health IT professionals, with no formal usability training or education, were selected to participate (Hundt, Adams, and Carayon 2017, 288-289). Over the course of two days, the participants received training on usability principles, evaluative usability methods, and considerations when dealing with competing factors, such as end user satisfaction and implementation feasibility (Hundt, Adams, and Carayon 2017, 289). Then six weeks later, participants were asked to conduct scenario-based usability evaluations with end users under the supervision and guidance of the usability experts (Hundt, Adams, and Carayon 2017, 289-290). Participants then shared their experiences and insights as well as the results of their evaluations (Hundt, Adams, and Carayon 2017, 288-289).

Upon following up with participants of the program five months after the training concluded, researchers found that many of participants continued to consider the CUE model training valuable (Hundt, Adams, and Carayon 2017, 292-293). This suggests that the CUE model may be quite valuable for EHR system evaluation and improvement (Hundt, Adams, and Carayon 2017, 294).

EHR Usability, Data Integrity, and Their Effect on Patient Safety

Scholarly research has shown that User Interface and User Experience design can in fact affect data integrity in Electronic Health Records. It is also not merely a hypothetical issue, given that, as mentioned earlier, over half of reported patient safety events related to Health IT involve some type of human data entry or retrieval error (Mardon et al. 2014, 19-20).

User Interface and Data Integrity Errors

“Wrong-patient errors” are a common reason for errors in Computerized Provider Order Entry systems (Mardon et al. 2014, 20; Taieb-Maimon et al. 2018, 383). As the name suggests, wrong-patient errors occur when a clinician places an order or attempts to administer patient care and unintentionally selects the wrong patient (Taieb-Maimon et al. 2018, 383-384). This results in a care order administered for someone other than the intended patient (Taieb-Maimon et al. 2018, 383-384). Such errors can occur if multiple patients have similar names, or if the user simply clicks on the wrong patient from a list (Taieb-Maimon et al. 2018, 384). Research has also shown that, after selecting a patient record to place an order, nearly 75% of users do not actively verify they have in fact selected the correct patient (Taieb-Maimon et al. 2018, 383). In response to such errors, another study sought to examine if improvements in the user interface design could reduce these wrong patient errors (Taieb-Maimon et al. 2018, 383).

The study used a simulated design of a standard CPOE interface as a control (Taieb-Maimon et al. 2018, 387-390). Examples of this “standard” control can be seen in *Figure 1*. The control was then used to compare results with several alternate versions that made use of various UI techniques (Taieb-Maimon et al. 2018, 387-390). One version highlighted selections, one incorporated pictures of patient’s faces, and one did both (Taieb-Maimon et al. 2018, 387-390). Participants were asked to place CPOE orders for a series of patients (Taieb-Maimon et al. 2018, 387). After allowing participants to place enough orders to get comfortable using their version of the system, a wrong-patient error was forced by the testing system, so as to gauge if the participants would notice the error (Taieb-Maimon et al. 2018, 387-388). Then, researchers

compared the rates at which users recognized the error with each variation of the simulated user interface (Taieb-Maimon et al. 2018, 387-391).

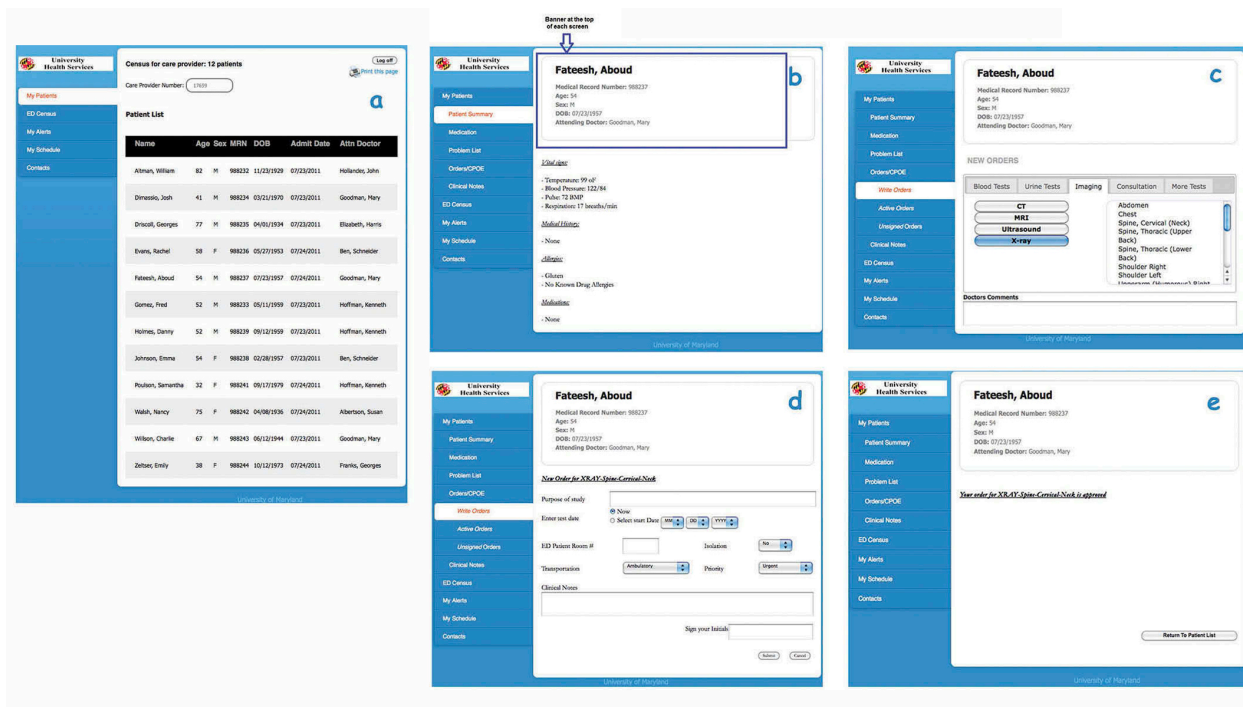


Figure 1. User interface screens from the “standard CPOE interface” that acted as the control in the study. *Left*, list of patients; *middle top*, patient medical data summary; *right top*, test selection; *middle bottom*, data entry of patient information; *Right bottom*, order confirmation (Taieb-Maimon et al. 2018, 388)

The results demonstrated that incorporation of the additional UI techniques significantly improved rates of recognition of the wrong patient selection (Taieb-Maimon et al. 2018, 391-392). The study also demonstrated that the users recognized the error faster when using the improved versions of the UI (Taieb-Maimon et al. 2018, 391-392). Examples of these improved alternate versions of the interface can be seen in *Figure 2*. All alternate versions of the UI showed significant improvement over the standard CPOE interface, with the version of the interface that incorporated both selection highlighting and patient pictures showing the greatest improvement (Taieb-Maimon et al. 2018, 391-395). Thus, this study seems to clearly

demonstrate that user interface design can have a significant effect on data integrity and, in turn, patient care.

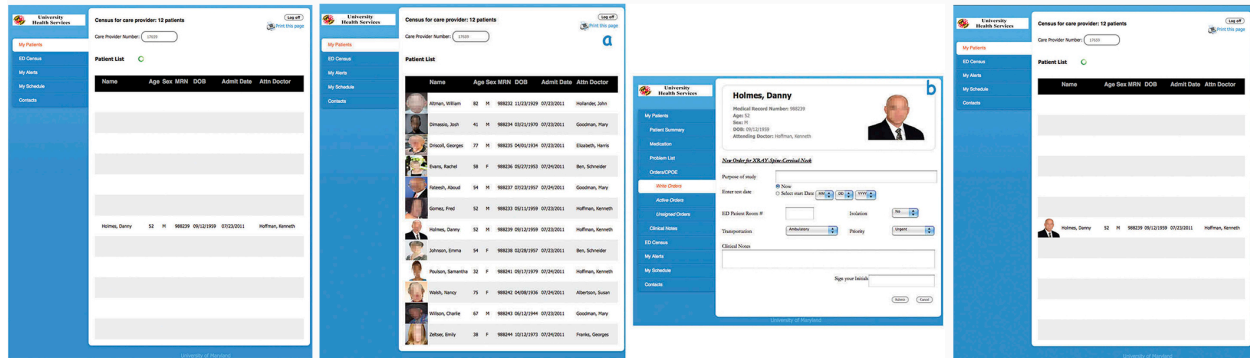


Figure 2. User interface screens from the alternate versions of the CPOE interface used in the study. *Left to right*: highlighted selection version displaying the selection made; version incorporating patient pictures listing screen; version incorporating patient pictures data entry screen; version that incorporated both selection highlighting and patient pictures displaying the selection made (Taieb-Maimon et al. 2018, 389-390)

User Experience and Data Integrity Errors

The user experience can similarly affect data integrity. As mentioned previously, one of the goals and rationales for encouraging adoption of EHR systems was the potential of such systems to help healthcare providers reduce errors when placing orders for treatment (Taieb-Maimon et al. 2018, 383). In many ways this has in fact been the case (Schiff et al. 2015, 264). However, due to the user experience of these systems, they can still be prone to facilitating errors (Schiff et al. 2015, 264; Taieb-Maimon et al. 2018, 383).

One of the ways EHR systems are intended to help to prevent errors is by alerting clinicians when they are attempting to enter potentially unsafe orders (Schiff et al. 2015, 264; Taieb-Maimon et al. 2018, 383). However, excessive alerts to the end user can condition them to ignore the alerts (Taieb-Maimon et al. 2018, 383). This is commonly referred to as “alert fatigue” and is particularly common when alerts are both frequent and perceived by the user to

be unhelpful (Meeks et al. 2014, 1054; Taieb-Maimon et al. 2018, 383). The danger of this can be seen easily via a case study:

[A] patient was administered a dose of a diuretic that exceeded the prescribed amount. This error occurred due to a number of interacting sociotechnical factors. First, a pharmacist made a data entry error while approving the order for a larger-than-usual amount of diuretic. Although a dose error warning appeared on order entry, this particular warning was known to have a high false positive rate. Owing to diminished user confidence in the warning's reliability, the warning was over-ridden. The over-ride released the incorrect dose for administration by nursing staff. The nurse, unaware of the discrepancy between the prescribed amount and the amount approved by the pharmacist, administered the larger dose. (Meeks et al. 2014, 1055)

As described in the case study, the conditioning of the user to ignore alerts as unhelpful or even wrong, contributed to a data integrity concern being overlooked, and patient care was negatively impacted.

Similarly, examination of reported medication errors involving CPOE systems found that nearly 80% of erroneous medication orders were able to be placed (Schiff et al. 2015, 267). In addition, 28% overall were able to be placed without any warning at all and another 28.3% overall were able to be placed with only "minor workarounds" (Schiff et al. 2015, 267). This again seems to suggest that users are somewhat conditioned to ignore system alerts to the detriment of EHR data integrity and patient care.

Failure to support real world medical workflows is another area in which the user experience contributed to data integrity issues. Examination of reported patient safety concerns revealed that the most common type of patient safety incident reported dealt with the fact that EHR systems did not provide data to the user that was relevant to the medical task the user was performing (Meeks et al. 2014, 1053-1055). This again suggests the need of EHR

system developers to better understand the way in which users actually use and require data, so as to be able to accommodate with an appropriate user experience.

Finally, part of the user experience is the effect interacting with the system has on the user. It has been thoroughly studied and shown, in a wide variety of settings and fields, that tasks that are more mentally taxing are also more prone to error (Mosaly et al. 2018, 467-468). The same has been shown to be true when physicians are interacting with EHR systems (Mosaly et al. 2018, 471-473). Clinicians interact with EHR systems frequently. When those interactions themselves require more mental effort by the user than necessary, the users in turn become more prone to error (Mosaly et al. 2018, 473).

Acceptance of the Relationship Between UI/UX Design and Data Integrity in EHR Systems

That usability design can affect the data integrity of EHR systems has been broadly accepted by many leaders in the healthcare industry (Middleton et al. 2013, e2-e3; Mosaly et al. 2018, 467). In response to analysis of reported patient safety events, Patient Safety Organizations have attempted to draw attention to human-computer interaction problems such as data display errors and wrong-patient errors (Mardon et al. 2014, 19-21). As mentioned previously, over half of reported patient safety events related to Health IT involve some type of human data entry or retrieval error (Mardon et al. 2014, 19-20).

Professional organizations such as American Medical Informatics Association (AMIA) have also formally acknowledged the relationship between EHR system usability, data integrity, and their role in patient safety (American Medical Informatics Association, n.d.; Middleton et al. 2013, e2-e3). As the AMIA described it,

Given the potential impact of EHR technology to improve healthcare delivery and increase inadvertent patient harm, AMIA believes it is now critical to coordinate and accelerate the numerous efforts underway focusing on the issue of EHR usability. Vendors and users of health IT both seek to improve the quality of care delivered with EHR, but current evidence suggests that some health IT may facilitate certain types of adverse events and medical errors, and that these problems may be related to usability issues. (Middleton et al. 2013, e5)

As a result, the AMIA has issued a number of recommendations to help improve EHR usability including: increased usability research, prioritization of standard use cases, promotion of implementation best practices, formal usability assessments, and recommendations from clinical end users (Middleton et al. 2013, e5-e6).

In summation, EHR systems have shown great promise for improving patient care. However, usability can directly affect data integrity in these systems for both better and worse. Clearly, User Interface and User Experience design can impact data integrity in EHR systems. That data integrity, in turn, can have major consequences for patients.

Solution

Usability in User Interface and User Experience design must be viewed as an integral component of EHR system design and development in order to help ensure the integrity of patient data. System usability is often viewed as a positive but not an essential. Such a view has led to EHR systems that are frustrating to their users, and more conducive to data manipulation error by users than is necessary. This in turn has and will continue to lead to patient harm. EHR system developers, EHR system customers such as hospitals, and end users such as doctors and nurses, must closely collaborate in efforts to improve EHR usability.

In order to reduce data integrity problems caused or enabled by EHR usability, the author proposes the creation of a collaborative real-world usability testing and improvement infrastructure.

In the proposed plan, a vendor of EHR systems would partner with several hospitals to create a collaborative infrastructure for ongoing real-world usability testing. This would incorporate every common type of clinician, in every common medical specialty. The proposed infrastructure would include:

- The identification of several suitable hospital organizations to act as partners to the EHR system vendor
- The creation of a UX team at each of the partnering hospitals
- Implementation of ongoing usability testing with clinicians at each partnering hospital
- Close collaboration between hospital UX teams and EHR system developers

EHR system usability has been plagued by the difficulty of building highly complex IT software applications for users, who possess advanced knowledge and understanding of their highly complex field and its subspecialties. In addition, the user base of medical professionals is a relatively small one as compared to the general population. These issues are compounded significantly by system implementation variations.

The proposed infrastructure would provide the mechanisms necessary to significantly improve EHR system usability and thus, data integrity and ultimately, patient care. The solution provides for ongoing usability testing and improvement of EHR systems with actual medical clinicians of every variety. It would do this while limiting the required scope of development.

Additionally, it could accomplish all this with minimal out-of-pocket cost to all parties involved, and minimal disruption to clinician's work.

Discussion

Exploration and Analysis of Proposed Solution

Central Issues Addressed

It has been demonstrated that User Interface and User Experience design in EHR systems can directly affect integrity of patient medical data. This was shown in theory with use of studies, such as the experiment demonstrating that incorporation of UI design features can reduce wrong-patient errors. This was also shown in practice, such as in the case study wherein clinicians ignored relevant safety alerts because of alert fatigue. Furthermore, as was shown, the relation of system usability to data integrity has been widely accepted in the medical field as a problem for some time.

However, efforts to improve EHR usability have been extremely slow coming. Efforts by government officials to simply mandate the desired outcome via regulation have been demonstrated to be largely ineffective. Even in cases where federal usability regulations are met, non-clinicians are frequently used as test subjects. This results in usability test data that does not truly reflect the target users. In addition, frequent customizations of EHR system implementations often result in using EHR system variations that have not undergone any usability testing at all.

Rationale for Proposed Solution

A serious effort to improve EHR system usability must be based around robust and continuous UX testing and improvement. In order to effectively improve data integrity, UX

testing must focus on real world application of EHR systems, and real world clinicians must be utilized as UX test subjects.

Clinician usability testing must be conducted with all relevant variations on user roles. That is, testing must be done not only with and for physicians in their role as healthcare providers, but also for pharmacists, nurses, advanced practice providers, and medical assistants, all in their respective roles as clinicians and users of EHR systems. In addition, real world user testing must be conducted for those same roles, in every medical specialty, since every medical specialty has its own processes and workflows.

In addition, EHR system vendors should work with their customers to develop standardized EHR system implementations. Essentially unlimited variations on system implementations make it nearly impossible to improve system usability across the board.

Explanation of Proposed Solution

The first element of the proposed solution is the identification of several suitable hospital systems to act as partners in the effort. As with most every part of the proposed solution, this step requires collaboration between EHR vendors and their client hospital organizations.

Ideal hospital partners would have already implemented the vendor's EHR system. This would shorten the time required to enact the proposed solution, and such hospitals presumably have a clinician user base that is already familiar with the EHR software. Preferred hospital partners would also have an EHR system implementation, which is likely to be broadly applicable to other hospitals. This allows the EHR vendor to treat the particular EHR implementation as a standard one. The vendor can then develop usability improvements that

can be applied to the partner hospital and any number of future hospitals that adopt the given standardized implementation. This is also aligned with the recommendation from the AMIA for the promotion of implementation best practices. The selection of several hospital systems to participate with the EHR vendor allows the vendor to offer several “standard” implementation options, while also limiting the number of potential use cases to something that, over time, can be managed by system developers.

Suitable hospital organizations would also need to offer a full range of medical treatments. Each hospital system should house every major medical specialty, so as to be able to provide clinical users with the given specialty’s knowledge and expertise. In addition, offering the full range of major medical services makes it likely that the hospital will be able to provide experienced users from every major clinical role including doctors, pharmacists, nurses, advanced practice providers, and medical assistants. General hospitals are excellent candidates to meet this criterion.

Finally, suitable hospital partners must also have the backing of top executives at the organizations. The proposed solution includes ongoing usability testing with a wide breadth of hospital staff. This cannot be done without utilizing clinician’s time. Medical staff’s time is valuable. This is true in terms of the pressing demand to help their patients, as well as financially to their employer. The financial implications for hospitals will be examined in more detail later. For the moment however, it is important to note that since the partner hospital will likely be financially responsible for paying for its staff members’ time in usability testing, leadership of the organization must be on board with the effort to improve usability and data integrity.

The second element of the proposed solution is the creation of UX teams at each of the partnering hospitals. Since the goal is to have ongoing testing for every user role and in every major medical specialty, a decent amount of usability testing capacity will be required in order to be effective. In addition, the UX team will also need time to write up their findings into meaningful development use cases. Once use cases are then submitted, the UX teams will also require time to work with both system developers and end users in the effort to fulfill the use case objectives and balance development capacity. This suggests that UX teams will need a moderate amount of staffing.

The CUE model suggests that under the guidance of a usability expert, less experienced usability staff members can be utilized effectively. Thus, having each team lead by a single usability expert who supervises less experienced staff members can reasonably be used to lower this staffing cost.

The third element is the commencement of ongoing usability testing with clinicians at each of the partnering hospitals. Once the UX teams are in place, with the support of hospital leadership, they can begin usability testing. This is where the goal of having ongoing testing for every user role and in every medical specialty in a real world setting, with real world clinicians, can finally be achieved.

Slowly but surely, UX team members can conduct testing for every user role in every specialty following UX industry standard practices. The sheer scale of the project, every user role multiplied by every medical specialty in the hospital, means that the UX team would be conducting a great many usability tests. In addition, iterative improvements to the EHR system from developers would mean that the same areas would have to be retested over time.

However, this scale also means that time spent by individual usability test subjects would be distributed among a great many clinicians and long periods of time. As a result, time spent by any particular clinician in usability testing would be fairly short and infrequent, thus minimizing disruption to their work as healthcare providers.

The final element of the proposed solution is the close collaboration between hospital UX testing teams and vendor EHR system developers. This would take place in accordance with common software development practices as appropriate. Once usability testing has been completed on given particulars of the EHR system, the UX staff members at the partner hospital would translate their findings into actionable data and use cases for the EHR system developers. In many cases, due to the demands of technical constraints or development capacity, back and forth discussions would then need to take place, so as to find the best solution to balance technical constraints, developmental capacity, and usability. In such cases, the UX team members would be in a good position to consider usability demands, having conducted the interviews themselves. If additional follow up with users is required to seek clarification, the on-site UX team is again well positioned for the task.

Potential Drawbacks

There are three notable potential drawbacks to the proposed solution. The first is the limitations placed on EHR system implementation. Customers presumably enjoy, at least to some degree, the flexibility in customization that is currently available in EHR systems. The proposed solution suggests removing much of this flexibility, and instead creating a series of standardized EHR system implementations. The rationales for this have been discussed, but there is in fact a tradeoff being proposed to help improve EHR system usability.

The second potential drawback is that the proposed solution, as described, is not mandatory. Rationales for this will be discussed further later on, but it is none-the-less a proposal that does not seek imposition by legal or regulatory force. As a result, it requires the cooperation of different parties in the industry, all with their own goals and motivating pressures. The proposed solution provides incentives for all involved and seeks to minimize costs to all involved as well, as will be discussed further. However, the proposed solution does require at least some degree of buy-in from all parties involved.

Finally, the proposed solution is one that is primarily focused on usability in hospital settings. It largely does not address smaller independent clinics and private practice physicians' offices. However, this shortcoming could be addressed through a modified version of the proposed solution. Such a modification could be accomplished by increased action from the EHR vendor, as the direct sponsor of an independent UX team that would work with a number of smaller clinics and offices in a given area.

Positives of the Proposed Solution

In the short term, the proposed solution would yield actual, real-world usability data to aid in EHR improvement. It would do so for all-manner of EHR system users, and in all major medical specialties. In addition, the standardization of EHR system implementations would limit the number of potential use cases on which system developers can focus their efforts. It would also provide guidance to EHR system customers for achieving best results in usability and data integrity with their EHR system implementation.

In the long term, it is reasonable to conclude the proposed solution would yield overall improvement in EHR system usability. As a result of usability improvements, this would likely

result in clinicians having to devote less time to EHR system use. This in turn, would likely decrease clinician frustration with EHR systems, increase job satisfaction, and decrease burnout. Most importantly, it is reasonable to conclude the proposed solution would improve data integrity in patient health records, and thus improve patient care.

Financing and Motivating Factor Considerations

As discussed previously, top-down governmental solutions to the problem of EHR system usability have been demonstrated to be, at best, largely ineffective. At worst, federal regulatory efforts may be a contributing factor to the problem of EHR system usability. As such, the proposed solution is designed to be feasible without governmental intervention. However, the proposed solution does require investment of time, energy, and finances by vendors of EHR systems, hospitals, and clinicians. As such, financial realities and potential motivating factors should be considered.

The primary costs of the proposed solution are, first, the investment of resources by EHR vendors to locate suitable hospital partners and create standardized EHR system implementations. Second, the employment costs of the new UX team members. Third, the financial expense of clinician time spent in usability testing. And finally, the investment of time and energy by clinicians spent in UX testing.

For EHR system vendors, the proposed solution could be a major competitive advantage. Recognition of usability problems with EHR systems is widespread within the industry. A significant and visible effort to improve usability based on continuous feedback from clinicians with real world experience could be a significant selling point to potential customers when selecting or changing EHR systems. In particular, the improved usability would likely be a

selling point to physicians who have long voiced their frustration with EHR systems and for whom EHR system use is a contributing factor for career burnout. In addition, potential customers may be persuaded by the fact that improved data integrity in patient care is likely to lower the risk of negative patient safety incidents and, in turn, lower the risks of lawsuits.

In light of these potential competitive benefits, it would be reasonable for EHR system vendors to absorb at least some of the cost of UX team member employment or simply employ them directly. Additionally, it would not be unreasonable to suggest that the sponsoring EHR vendor may also absorb some portion of the cost of clinician time spent in UX testing. Since, in the proposed solution, EHR system vendors are working with existing clients, this portion of expenses could be absorbed over time and without any out-of-pocket expense. This could be accomplished by offering the participating hospitals a reduction in their EHR system licensing fees.

With regard to the hospitals acting as partners, the expense of clinician time spent in testing is the major expense. Even if the sponsoring EHR vendor were to absorb a portion of the cost of clinician time in UX testing as described above, some amount of cost would likely remain. However, this cost of participating should be weighed against potential cost savings.

For hospitals participating in the proposed solution, their EHR system implementation becomes a standardized one, with no, or minimal cost to change their current implementation. As such, the cost in IT staff changing an existing implementation and lost productivity of clinicians learning a new system is saved. In addition, since clinician frustration with existing EHRs is so widespread, involvement in the proposed solution is potentially a competitive advantage in hiring. The partner hospital would be able to offer an EHR implementation that is

being optimized for usability and the ability of employees to directly offer suggestions to improve EHRs.

In addition, time spent by clinicians in UX testing may be better seen as an investment, rather than simply an expense. As mentioned previously, a significant majority of physicians are of the opinion that EHR systems require an unreasonable amount of their time in order to perform required tasks. If improved usability indeed reduces this excessive time lost performing required tasks, over time, hospital employers would regain a portion of clinicians' time spent in testing. Finally, hospitals must consider the cost savings that are likely from fewer lawsuits. It is reasonable to assume that improved data integrity, as a result of improved usability, will result in fewer patient safety events from Health IT. This in turn, would likely yield fewer lawsuits against medical practitioners.

As described, the proposed solution requires no direct financial investment from clinicians. Instead, clinicians must be willing to donate their time and expertise to the effort of improving EHR usability through their participation in UX testing. However, clinicians may also be able to act as advocates in their organization to back such an effort. In addition to the described benefits to the care of their patients, it is in clinicians' personal interest to support such an endeavor. Healthcare providers interact very frequently with EHRs, and those EHRs have long been a source of their frustration. Thus, they may wish to participate in such an effort for their own sake as well.

Thus, all parties involved can be reasonably expected to benefit from the proposed solution. However, the final motivating factor for all involved should not go without particular focus. It is reasonable to conclude that the proposed solution would yield substantial

improvement in EHR system usability. This would likely yield improved data integrity of patient medical data. In turn, this would likely improve patient care, and potentially, save lives.

Project Analysis

Limitations

This project is not without limitations. First and foremost, the author did not have a background in EHR systems or the medical field. As a result, there may be particular considerations and/or drivers of which the author was unaware, having failed to discover them through research.

In addition, efforts to reconcile the financial implications and costs of the proposed solution are conceptual and broad. They do not account for actual dollar costs to the parties involved. Efforts were made to keep the financial considerations reasonable and practical. However, it is impossible to know the true cost-benefit of the proposal without a true financial analysis regarding the particular parties who would be involved in an effort to enact the proposed solution.

Contribution to the Field

It is the author's hope that this project contributes in some small way to the fields of UI/UX design, Electronic Health Record development, and their application to the medical field. The fact that usability can directly affect the integrity of system data, potentially with disastrous results, is a finding with applicability to most every area of information and communications technology. Leaders in the field must understand and advocate for this important understanding. Usability is not merely a feature that is nice to have. It is an element that is crucial to the security, integrity, and success of an information system.

Recommendations

The first and foremost recommendation as a result of this project is continued advocacy for increased usability in EHR systems. Clinicians, hospital leadership, and Patient Safety Organizations must continue to advocate strongly for increased attention to this issue.

Governmental officials should recognize that efforts to improve EHR system usability have been largely unsuccessful. Ideally, legislators should reevaluate the existing legal and regulatory framework and seek to encourage efforts to improve EHR system usability. Lawmakers and regulators should also examine the existing legal and regulatory requirements and seek to remove potential barriers that may unnecessarily contribute to usability problems or unnecessarily hinder efforts to improve usability.

Information and communication technology professionals should seek to apply the insights contained herein well beyond the area of Electronic Health Records. That usability and data integrity are intertwined in information systems is an important fact that is easily overlooked. Cognizance of this reality has wide application and should be utilized in all areas of Information Technology.

Finally, vendors of EHR systems must increase their focus on improving EHR system usability. Though undoubtedly contending with numerous competing interests, EHR system developers are the only ones actually in a position to enact the changes necessary to improve usability. As described, the problem of EHR system usability is a complex one. It will require cooperation among all parties involved to improve EHR usability and data integrity. This is necessary because of the direct impact it can have on patient health. While cooperation

between all parties is necessary, it is action by EHR system vendors that is most central and most crucial.

Possible Implementation Methodology

The proposed solution envisions at a minimum, multiple separate partnerships between an EHR vendor and several separate hospital organizations. Each separate partnership would have its own UX team. All UX teams would be working in parallel to improve usability in several standardized EHR system implementations. This methodology would result in a more substantial upgrade in EHR usability and provide the vendor with multiple standardized implementations to offer into the marketplace.

However, a trial of the proposed solution could be conducted with a single partnership and single standard implementation. This would reduce the expense to EHR vendors and allow a lower risk trial of the proposed solution. If the trial proved successful, vendors could then expand the effort to be more in line with the proposed solution, if desired.

Next Steps and Further Study

The best place to start toward the goal of enacting the proposed solution would be with a detailed financial analysis of the cost. As mentioned previously, the financials discussed were only conceptual. A true financial analysis is the prudent next step to evaluate the true cost of the proposed solution.

In addition, academic study of EHR system usability must be continued. The body of scholarly research on this subject allows ever expanding understanding of the issues involved. It also helps to continue to place focus on this important issue.

Conclusion

This paper sought to examine the relationship of User Interface and User Experience (UI/UX) design to data integrity in Electronic Health Record systems. The goal was to better understand this relationship so as to determine if system usability design can improve data integrity, by reducing errors made by medical staff, who are the intended users of EHR systems.

Research demonstrated that UI/UX design can, in fact, directly affect data integrity in EHR systems. Poor usability as a contributing factor to data errors by clinicians is, unfortunately, a widely accepted and understood problem. Yet despite a fair amount of focus, significant usability problems persist, posing an unnecessary threat to EHR data and patient care.

This is a significant problem for hospital organizations, vendors of EHR systems, medical practitioners, and most of all patients. In addition, the central finding, that UI/UX design can have a direct negative effect on data integrity is applicable far beyond application in the medical field. It is applicable to all areas of information and communications technology.

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