12-29-2009

A Usability Analysis Framework for Healthcare Information Technology

Surendra Sarnikar
Dakota State University, sarnikar@acm.org

Maureen Murphy
Dakota State University, Maureen.Murphy@dsu.edu

芽|Sprouts Working Papers on Information Systems ISSN 1535-6078

A Usability Analysis Framework for Healthcare Information Technology

Surendra Sarnikar
Dakota State University, USA

Maureen Murphy
Dakota State University, USA

Abstract
Healthcare organizations are investing in healthcare information technology (HIT) to improve quality and outcomes. However, HIT has also been known to introduce unintended consequences and adverse effects. The adverse effects range from process changes to serious clinical errors. In order to ensure the safety of healthcare information technologies, we propose a usability analysis framework for healthcare information technology that can help identify, classify and prioritize potential errors. Such a framework can help design better usability studies specifically targeted at studying technology-induced errors and therefore help in the design of safer healthcare information technologies.

Keywords: Usability, Healthcare Information Systems, Medical Errors

Permanent URL: http://sprouts.aisnet.org/9-62

Reference: Sarnikar, S, Murphy, M. (2009). "A Usability Analysis Framework for Healthcare Information Technology," . *Sprouts: Working Papers on Information Systems*, 9(62). http://sprouts.aisnet.org/9-62

1. INTRODUCTION

Healthcare organizations continue to invest in healthcare information technology (HIT) such as electronic medical records, clinical decision support systems and various hospital information systems to reduce healthcare costs, improve quality of care and outcomes (Monegain, 2009; Pizzi, 2007). In order to justify the continued investment in HIT, there is a need to conduct empirical studies to evaluate the impact of healthcare information systems on quality of care and costs. While several studies have identified the positive impacts of healthcare information technology (Chaudhry et al., 2006), recent studies have also documented cases where healthcare information technology introduces unintended consequences and adverse effects (Ash et al., 2007; Harrison et al., 2007).

The unintended consequences of healthcare information technology include changes in work and communication patterns, changes in organizational structure and resource requirements and errors induced due to poor usability of HIT systems (Ash et al., 2007). In this paper, we focus on the errors introduced due to poor design of HIT systems that could potentially have a serious impact on patient safety and clinical outcomes (Koppel et al., 2005; Kushniruk et al., 2004; Nebeker et al., 2005).

Given the critical nature of healthcare and the potentially serious consequences of errors in the healthcare setting, healthcare information technologies need to be thoroughly evaluated to prevent the introduction of new errors. In addition, to ensure the intended quality outcomes, health information technologies need to be made safer and tested for usability and errors. Specifically, there is a need to design HIT-specific usability tests that can detect the potential for errors in a clinical work context.

While several studies have looked at usability in the healthcare context (Borycki et al., 2006; Rose et al., 2005; Santiago et al., 2006; Ziemkowski et al., 1999), and a few recent studies have observed and documented technology-induced errors in the healthcare setting (Ash et al., 2008; Koppel et al., 2005; Kushniruk et al., 2005; Nebeker et al., 2005), there is limited literature that focuses on classifying usability errors in the healthcare context. Identification and classification of the errors that can take place in a healthcare setting is necessary to design usability tests that can help evaluate safety and efficacy of HIT systems. Given the limited literature on classifying usability errors in the context of healthcare information technologies, there is a need for a framework that can help identify, classify and prioritize errors in the healthcare context.

In this paper, we study past theoretical and conceptual work on usability problems and usability errors and its application in various contexts to build a HIT-specific framework of usability errors. The proposed framework can be used for identifying, classifying and prioritizing errors in the context of healthcare information technologies. The objective of the framework is to help design usability studies that can identify potential technology-induced errors in a healthcare setting, and help evaluate the cause and effect of those errors. We begin with a review of relevant work in usability problems and technology-induced errors, followed by an overview of our proposed framework in the following section. We then present an evaluation plan and conclude with an overview of future work.

2. LITERATURE REVIEW

Different frameworks and classification schemes have been proposed to identify usability problems in human-computer interaction research. Keenan et al. (1999) propose a usability problem taxonomy to classify usability problems. The authors categorize usability problems into five primary categories; three of those categories relate to the artifact components, while the remaining two relate to the task component. The categories under artifact component—visualness, language and manipulation—focus on usability problems that arise when the user interacts with individual user interface components. The categories under task component—task-mapping and task-facilitation—focus on usability problems that arise as a user moves through a task. Hartson et al. (1999) propose a User-Action Framework for classifying usability problems. In this framework, the authors extend the usability problem classifier to include a new decision branch that identifies when a usability problem occurred prior to classification.

Sutcliffe et al. (2000) propose a "model mismatch method to identify usability design flaws and missing requirements from user errors." The model mismatch method includes a walkthrough analysis and taxonomic analysis of observed usability problems and causes of error. The taxonomy of genotype causes of usability problems used by the authors include task fit problems due to missing functionality, poor task support or inadequate functionality, poor location and predictivity of prompts, cursor manipulation problems, missing or inadequate feedback, hidden effects and user error. Other proposed frameworks include the classification of usability problems scheme (Hvannberg and Law, 2003) which consists of a list of attributes of defects and possible attribute values (Hvannberg and Law, 2003) and the usability errors classification scheme which classifies errors along the dimensions of cause, effect, task impact and business impact (Gorlenko and Englefied, 2006).

In addition to classification of usability problems and errors that arise due to interface defects and task characteristics, some researchers have analyzed human errors, or errors that stem from user actions. Zapf (1992) presents a classification of errors consisting of functional mismatches and usability mismatches. While functional mismatches are caused by the system, usability mismatches arise due to user actions and can be observed as users interact with a system. In addition to the above mentioned generic usability problem and error taxonomies, several domain-specific usability problem taxonomies have also been proposed. For example, Panko (2008) proposes a taxonomy of spreadsheet errors that is customized to the errors and usability problems that arise in spreadsheet applications.

Several studies have documented technology-induced errors in the healthcare context. Kushniruk et al. (2005) explore the relationship between usability problems and prescription errors in the context of a hand-held prescription writing application. The paper classifies usability problems into interface problems and content problems. Koppel et al. (2005) present a study of medication errors induced by a computerized physician order entry system is presented. The authors classify the errors into information errors, which are caused due to non integration of information across systems and human machine interface errors. In addition to studies documenting technology-induced errors in a healthcare setting, researchers have also proposed simulation based usability testing mechanisms to prevent such errors (Andre et al., 2008; Borycki and Kushniruk, 2005).

However, while some studies explore technology-induced errors in the healthcare setting, currently there is no framework that can help identify, classify, and prioritize the errors to help design effective usability tests to ensure the safety of healthcare information technologies.

3. PRELIMINARY FRAMEWORK FOR HIT USABILITY ANALYSIS

In this section, we integrate results from the past studies in usability problems and errors and empirical studies on technology-induced errors and medical errors in the healthcare setting to develop a framework for identifying, classifying, and prioritizing technology-induced errors in the healthcare setting. We begin with a description of the key requirements that the framework should satisfy.

3.1 Framework Requirements

(1) Reliability: The proposed framework should be reliable across coders, across systems and across testing situations.
(2) Prioritization: The framework should support the prioritization of errors. Errors that have the potential to result in severe adverse events need to be differentiated from errors that are unlikely to cause adverse events. Once the potential errors are prioritized based on severity of outcomes, more extensive usability studies can be conducted to determine possibility of high severity errors.
(3) Customization: The proposed framework should be customized to the healthcare context and help readily identify impact of the errors on clinical tasks.
(4) Basis in Theory: The proposed framework should be theory-based to help make behavioral predictions related to error rates and help identify and fix causes of errors.
(5) Completeness: The proposed framework should account for all the observed errors and usability problems. A complete and reliable framework can help design usability studies to better detect technology-induced errors.

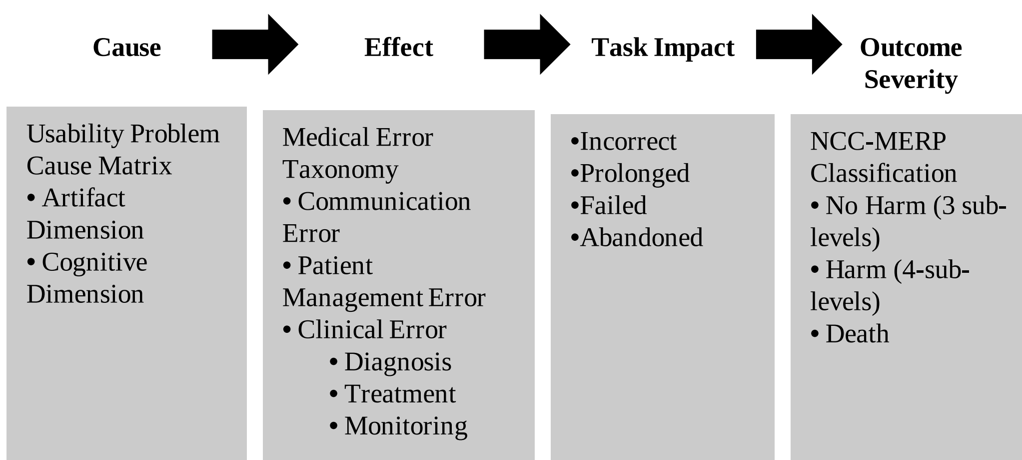

Figure 1. A Preliminary Design for a HIT Usability Framework

3.2 Preliminary Design of a Usability Analysis Framework for HIT

In Figure 1, we present a preliminary design of the framework for usability analysis in the healthcare setting that integrates results from previous studies in usability research, healthcare information systems, and medical errors. We use the four dimensions of error classification proposed by (Gorlenko and Englefied, 2006) to capture the cause, effect, task impact and outcome severity of a technology-induced error.

We propose a two dimensional matrix to capture the cause of usability problems. The cause of a technology-induced error can be classified along two dimensions, the artifact characteristics that trigger the error, and the human cognitive actions that contribute to the error. The artifact components that are the sources of error are captured by the usability problem taxonomy as described by Keenan et al. (1999). The main categories along this dimension include Visualness, Language, Manipulation, Task facilitation, and Task mapping.

The category visualness captures the artifact interface aspects that contribute to an error. Examples of items coded under this category include errors that occur due to problems related to user interface, presentation of information, screen layout, object appearance and movement, non-message feedback etc. The language category captures artifact errors due to naming or labeling of objects, feedback message, error and other system messages and on screen text. The manipulation category captures errors that result from manipulation of user interface objects. Task mapping relates to the structuring of a user task in the system and captures errors due to incorrect mapping of a user task in the system such as navigation and system functionality. Task facilitation captures the system's ability to keep the user task on track.

The cognitive dimension of the errors are captured by the usability mismatch taxonomy as proposed by (Zapf, 1992). The cognitive errors are further sub-categorized into knowledge errors, intellectual regulation, flexible action patterns and sensorimotor errors. Knowledge base errors result when the user does not know the system commands or special keys used in the system. Intellectual regulation errors occur when a complex plan of action is developed by the user to attain a goal but is forgotten or inadequately developed. These are further sub-classified into thought errors, memory errors and judgment errors. Flexible action pattern errors occur when the user fails to execute well known sub-plans or ignores well known feedback. These are further sub-classified into habit errors, omission errors and recognition errors. Sensorimotor errors are those that result from mistakes in using keyboards and other input devices.

In our framework, the cause for each error is coded along both cognitive as well as artifact dimensions. For example, when a clinician erroneously selects an adjacent medication from a long drop down list, the error could be classified as a sensorimotor error along the cognitive dimension and as an object presentation error along the artifact dimension. Table 1 summarizes the two dimensions of the usability problem-cause matrix.

Table 1. Dimension of the usability problem cause matrix

Artifact Dimension	**Cognitive Dimension**
Visualness	Knowledge base
Language	Intellectual regulation
Manipulation	Flexible Action Pattern
Task facilitation	Sensorimotor
Task mapping	

In the proposed framework, the effects of the interface defects and cognitive errors are coded using a medical error framework that details the effects of the human-computer interaction (HCI) errors in clinical terms. Technology-induced errors can ultimately lead to medical errors impacting patient safety. Based on our analysis of past literature on technology-induced errors in the healthcare setting, and frameworks for medical errors, we observe that most technology-induced errors can in turn be mapped to a medical error. Thus, we propose to use a medical error framework to capture the effect of HCI errors in the clinical context.

Several different medical error frameworks have been proposed. The National Coordinating Council for Medication Error Reporting and Prevention (NCC MERP) prescribes a standard taxonomy for classifying and reporting medication errors (National Coordinating Council for Medication Error Reporting and Prevention, 1998). The error type taxonomy includes categories such as dosing errors, monitoring errors, and wrong patient. However, the taxonomy of error types is limited to drug or medication errors and does not include the larger context of medical errors.

Dovey et al. (2002) propose a preliminary taxonomy of medical errors in primary care. The taxonomy was developed based on detailed reports of medical errors observed by family physicians in clinical practice. The taxonomy categorizes the errors into process errors and knowledge and skill errors. The process errors capture the errors that occur within the healthcare delivery process, whereas knowledge and skill errors are those attributable to a clinician's lack of clinical knowledge or skill. The process errors are further categorized into office administration errors, investigation related errors, treatment process errors and communication errors.

Elder and Dovey (2002) present a synthesis of literature and a classification that integrates results from studies on medical errors and preventable adverse events. In addition to process errors, the classification includes categories of preventable adverse events along the dimensions of diagnosis, treatment and preventive services. Chang et al. (2005) present a more recent and comprehensive classification of errors, the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) Patient Safety Event Taxonomy.

The JCAHO taxonomy was developed based on review of various medical error and adverse event reporting frameworks and followed by an assessment of the taxonomy's face and content validity and an evaluation of the taxonomy's comparative reliability. The error types in the JCAHO taxonomy include communication errors, patient management errors, and clinical performance errors. Given the comprehensive nature of the JCAHO framework, and its evaluation for validity and reliability, we propose to use this framework to document the effect of usability problems on the clinical tasks.

Specifically, the errors observed during usability studies are classified per the JCAHO medical error classification framework. Within this framework, communication errors are further sub-categorized as incomplete information, questionable advice or interpretation, consent process errors, disclosure process errors and documentation errors. Patient management errors are further classified into delegation errors, tracking or follow-up errors, referral errors and resource use related errors. The third category of errors deals with clinical performance errors and is further classified into diagnosis, treatment, and monitoring related errors.

The third dimension of the HIT Usability framework relates to the impact of the error on the task. As proposed by Gorlenko and Englefied (2006), the impacts in this dimension are summarized as Incorrect, Prolonged, Failed and Abandoned. The fourth dimension of the proposed framework indicates the severity of the adverse effects caused by the error. This severity can be captured using the NCC-MERP classification of outcomes which ranges from no harm, to harm, to death (National Coordinating Council for Medication Error Reporting and Prevention, 1998). The sub-level under the no-harm category includes different scenarios of errors which result in no harm to a patient. The sub-levels under harm category include scenarios that result in temporary or permanent impairment of the patient. The NCC-MERC categories are able to capture severity of the potential adverse clinical outcome as a result of the error and different scenarios where there is a possibility to recover from the error.

4. EVALUATION PLAN

In this section we present an evaluation plan to test the utility of the proposed HIT Usability framework and the extent to which it satisfies the requirements identified in the earlier section. Specifically we state the design features of the framework and elements of the design process that seek to address the requirements, and propose evaluation activities to test the extent to which the framework satisfies the given requirements.

4.1 Reliability

The reliability of the framework is essential to ensure that it will deliver consistent results when used across coders, systems, and situations. The design feature employed to ensure reliability and the proposed evaluation activities to test reliability are given below.

Design Features: The classification and coding schemes used in the framework are derived from tested and validated instruments from previous research.

Evaluation Activities: The reliability of the framework components can be measured through usability studies and measuring inter-coder agreement.

4.2 Prioritization

Given the high costs of usability testing, prioritization of errors can help save costs while ensuring safety. The related design features and evaluation activities are as follows:

Design Features: The use of the medical error taxonomy and the Cause-Effect-Impact-Outcome Severity structure of the HIT Usability Framework enable the assessment of the impact of usability problems and associated medical errors on clinical outcomes through the use of tools such as cascade analysis. Based on the severity of the outcome, additional usability tests focused specifically on specific usability problems can be conducted to estimate the likelihood of such errors, estimate risks, and develop mitigation measures.

Evaluation Activities: The extent to which the proposed HIT-specific framework can help identify and classify critical errors can be measured through a comparative evaluation of the framework with alternative generalized usability analysis frameworks.

4.3 Customization

A key requirement for the HIT usability framework is to customize it to the needs of the healthcare context.

Design Features: Customization of the proposed framework to the healthcare context is achieved through the integration of the medical error taxonomy into usability analysis. The integration of the medical errors taxonomy helps identify the technology-induced causes of medical errors as well as the clinical impact of usability problems.

Evaluation Activities: The ability of the proposed framework to capture healthcare specific errors can be measured by a comparative evaluation of the proposed framework with an alternative generalized usability analysis framework. Such a comparative evaluation would use HIT-specific usability scenarios and measure the number of clinical errors identified and the extent of inter-coder agreement when using HIT-specific and a general usability analysis framework.

4.4 Theoretical Basis

While some components of the proposed framework such as the medical error taxonomy and artifact and task dimensions of the usability problem categories are not theory-based, they have been developed based on extensive analysis of error reports and have been tested for reliability.

Design Features: The theoretical basis of the proposed HIT-specific usability analysis framework is derived from the use of theory-based classification frameworks and the use of established risk analysis tools such as failure mode effect analysis (FMEA). The cause-effect-impact-severity structure of the proposed HIT usability analysis framework is a variation of the failure mode effect analysis tool used to analyze potential risks and prioritize the investigation of potential failure modes.

Evaluation activities: A strong theoretical basis can help make behavioral predictions about error rates and help identify and fix causes of error. This aspect of the framework can be evaluated over time through the conduct and analysis of numerous usability studies.

4.5 Completeness

Design Features: In order to ensure completeness, the proposed framework employs medical error and usability problem classification schemes that are comprehensive and have been derived based on extensive literature review and data analysis.

Evaluation Activities: The completeness of the framework can be evaluated by measuring the percentage of observed usability problems and medical errors that can be classified using the proposed framework.

5. LIMITATIONS AND FUTURE WORK

The framework presented in this paper requires further development in two key areas. Specifically, further analysis of HIT and usability literature is required to develop a comprehensive understanding of the HIT usability requirements and the utility and limitations of the current framework under varying healthcare systems and environments.

In future work, in addition to addressing the above limitations, we intend to further enhance the framework to ensure that its design satisfies all the requirements outlined in this paper. We also plan to conduct usability and comparative evaluation studies as outlined in the evaluation plan to test the utility of the framework and the extent to which it satisfies HIT usability analysis requirements.

6. CONCLUSIONS

Given the critical nature of healthcare information technologies, comprehensive usability testing of healthcare information technologies is a key necessity. In this paper, we focus on the problem of technology-induced errors in the healthcare setting. We present a review of relevant literature in the area and identify the need for a framework for technology-induced errors in healthcare that can help identify, classify and prioritize potential errors. We outline the requirements for a HIT Usability Framework and propose a preliminary design that integrates medical error taxonomy with usability problem taxonomy with an underlying risk analysis tool. We also describe the design features of the proposed framework and evaluation activities that can be used to evaluate the framework. Further development of the proposed framework can help design usability studies to better detect HIT design and usability issues that result in technology-induced errors.

REFERENCES

Andre, K., Elizabeth, B., James, G. A., and Marilyn, M. A. (2008). Combining two forms of simulation to predict the potential impact of interface design on technology-induced error in healthcare, in *Proceedings of the 2008 Spring simulation multiconference*, Ottawa, Canada, ACM.

Ash, J. S., Sittig, D. F., Dykstra, R., Campbell, E., and Guappone, K. (2008). The unintended consequences of computerized provider order entry: Findings from a mixed methods exploration, *International Journal of Medical Informatics*.

Ash, J. S., Sittig, D. F., Poon, E. G., Guappone, K., Campbell, E., and Dykstra, R. H. (2007). The Extent and Importance of Unintended Consequences Related to Computerized Provider Order Entry, *Journal of the American Medical Informatics Association*, 14, 4, 415-423.

Borycki, E., and Kushniruk, A. W. (2005). Identifying and Preventing Technology-Induced Error Using Simulations: Application of Usability Engineering Techniques, *Healthcare Quarterly*, 8, 99–105.

Borycki, E. M., Kushniruk, A. W., Kuwata, S., and Kannry, J. (2006). Use of Simulation Approaches in the Study of Clinician Workflow, in American Medical Informatics Association, 61.

Chang, A., Schyve, P. M., Croteau, R. J., O'Leary, D. S., and Loeb, J. M. (2005). The JCAHO patient safety event taxonomy: a standardized terminology and classification schema for near misses and adverse events, *International Journal for Quality in Health Care*, 17, 2, 95–105.

Chaudhry, B., Wang, J., Wu, S., Maglione, M., Mojica, W., Roth, E., Morton, S. C., and Shekelle, P. G. (2006). Systematic review: impact of health information technology on quality, efficiency, and costs of medical care, *Ann Intern Med*, 144, 10, 742–752.

Dovey, S. M., Meyers, D. S., Phillips Jr, R. L., Green, L. A., Fryer, G. E., Galliher, J. M., Kappus, J., and Grob, P. (2002). A preliminary taxonomy of medical errors in family practice, *Quality & Safety in Health Care*, 11, 3, 233.

Elder, N. C., and Dovey, S. M. (2002). Classification of medical errors and preventable adverse events in primary care: a synthesis of the literature, *The Journal of family practice*, 51, 11, 927.

Gorlenko, L., and Englefied, P. (2006). Usability error classification: qualitative data analysis for UX practitioners, in ACM New York, NY, USA, 803–808.

Harrison, M. I., Koppel, R., and Bar-Lev, S. (2007). Unintended Consequences of Information Technologies in Health Care—An Interactive Sociotechnical Analysis, *Journal of the American Medical Informatics Association*, 14, 5, 542–549.

Hartson, H. R., Andre, T. S., C. Williges, R., and Rens, L. v. (1999). The User Action Framework: A Theory-Based Foundation for Inspection and Classification of Usability Problems, in *Proceedings of HCI International (the 8th International Conference on Human-Computer Interaction) on Human-Computer Interaction: Ergonomics and User Interfaces, Volume I*, L. Erlbaum Associates Inc.

Hvannberg, E. T., and Law, L. C. (2003). Classification of Usability Problems (CUP) Scheme, in *INTERACT 2003*, Zurich, Switzerland, 655–662.

Keenan, S. L., Hartson, H. R., Kafura, D. G., and Schulman, R. S. (1999). The Usability Problem Taxonomy: A Framework for Classification and Analysis, *Empirical Software Engineering*, 4, 1, 71–104.

Koppel, R., Metlay, J. P., Cohen, A., Abaluck, B., Localio, A. R., Kimmel, S. E., and Strom, B. L. (2005). Role of Computerized Physician Order Entry Systems in Facilitating Medication Errors, Am Med Assoc, 1197–1203.

Kushniruk, A., Triola, M., Stein, B., Borycki, E., and Kannry, J. (2004). The Relationship of Usability to Medical Error: An Evaluation of Errors Associated with Usability Problems in the Use of a Handheld Application for Prescribing Medications, in 1073–1076.

Kushniruk, A. W., Triola, M. M., Borycki, E. M., Stein, B., and Kannry, J. L. (2005). Technology induced error and usability: The relationship between usability problems and prescription errors when using a handheld application, *International Journal of Medical Informatics*, 74, 7–8, 519–526.

Monegain, B. (2009). Global market for hospital IT systems pegged at $35B by 2015, in: *Healthcare IT News*.

National Coordinating Council for Medication Error Reporting and Prevention. (1998). NCC MERP Taxonomy of Medication Errors.

Nebeker, J. R., Hoffman, J. M., Weir, C. R., Bennett, C. L., and Hurdle, J. F. (2005). High Rates of Adverse Drug Events in a Highly Computerized Hospital, Am Med Assoc, 1111–1116.

Panko, R. R. (2008). Revisiting the Panko-Halverson Taxonomy of Spreadsheet Errors, *Proc. European Spreadsheet Risks Int. Grp.(EuSpRIG) 2008* 199–220 ISBN 978-905617-69-2.

Pizzi, R. (2007). U.S. EHR market to approach $5 billion by 2015, in: *Healthcare IT News*.

Rose, A. F., Schnipper, J. L., Park, E. R., Poon, E. G., Li, Q., and Middleton, B. (2005). Using qualitative studies to improve the usability of an EMR, *Journal of Biomedical Informatics*, 38, 1, 51–60.

Santiago, O., Li, Q., Gagliano, N., Judge, D., Hamann, C., and Middleton, B. (2006). Improving EMR Usability: A Method for Both Discovering and Prioritizing Improvements in EMR Workflows Based on Human Factors Engineering, in American Medical Informatics Association, 1086.

Sutcliffe, A., Ryan, M., Doubleday, A., and Springett, M. (2000). Model mismatch analysis: towards a deeper explanation of users' usability problems, *BEHAVIOUR & INFORMATION TECHNOLOGY*, 19, 1, 43–55.

Zapf, D. (1992). Errors in Working with Office Computers: a First Validation of a Taxonomy for Observed Errors in a Field Setting, *International Journal of Human-Computer Interaction*, 4, 4, 311–339.

Ziemkowski, P., Kalamazoo, M. I., and Gosbee, J. (1999). Comparative Usability Testing in the Selection of Electronic Medical Records Software, in *AMIA Symposium*.

芽|Sprouts
Working Papers on Information Systems | ISSN 1535-6078