Context Sensitive Health Informatics: Human and Sociotechnical Approaches
M.-C. Beuscart-Zéphir et al. (Eds.)

doi:10.3233/978-1-61499-293-6-91

The Usability-Error Ontology

Peter L. ELKIN[a,1], Marie-Catherine BEUSCART-ZEPHIR[b], Sylvia PELAYO[b], Vimla PATEL[c], Christian NØHR[d]
[a]*Department of Biomedical Informatics, University at Buffalo, Buffalo, NY, USA*
[b]*INSERM CIC-IT-Evalab, Lille; CHU Lille; Univ Lille Nord de France, UDSL EA 2694; F-59000 Lille, France*
[c]*New York Academy of Medicine, New York, NY, USA*
[d]*Department of Development and Planning, Aalborg University, Denmark*

Abstract. Clinical Systems have become standard partners with clinicians in the care of patients. As these systems become integral parts of the clinical workflow, they have the potential to help improve patient outcomes, however they have also in some cases have led to adverse events and has resulted in patients coming to harm. Often the root cause analysis of these adverse events can be traced back to Usability Errors in the Health Information Technology (HIT) or its interaction with users. Interoperability of the documentation of HIT related Usability Errors in a consistent fashion can improve our ability to do systematic reviews and meta-analyses. In an effort to support improved and more interoperable data capture regarding Usability Errors, we have created the Usability Error Ontology (UEO) as a classification method for representing knowledge regarding Usability Errors. We expect the UEO will grow over time to support an increasing number of HIT system types. In this manuscript, we present this Ontology of Usability Error Types and specifically address Computerized Physician Order Entry (CPOE), Electronic Health Records (EHR) and Revenue Cycle HIT systems.

Keywords: Usability, Patient Safety, CPOE, EHR, Ontology

Introduction

Patient Safety is a significant medical issue. The Institute of Medicine report "To Err is Human" found that as many as 98,000 patients die every year in the United States from Medical Error [1]. The follow-up report "Crossing the Quality Chasm" showed the role of Health Informatics and clinical systems in helping to improve patient safety [2, 3]. As more systems have been implemented we have found that clinical systems need to be designed to improve quality in order to affect that result. Also we find that clinical systems as well as being able to improve quality have the potential to harm patients if they are not well designed [4].

An example was the implementation of a system, which changed the workflow of medication ordering so that medications could no longer be pre-ordered while the patient was on route by ambulance to the hospital. This resulted in an increase in infant mortality [5].

Jos Aarts and Ross Koppel in 2009 showed that CPOE systems usability flaws can lead to medical error [6]. Koppel and Kreda showed that vendors add specific clauses

[1] Corresponding Author: Peter L. ELKIN. Email: elkinp@buffalo.edu

in their contracts holding their systems harmless for errors which they cause [7]. Some investigators believe that HIT vendors should have legal exposure for medical errors which are HIT system related. The authors agree that medical error reporting is an important step toward the development of improved and safer clinical systems [8, 9].

Usability Errors are well defined usability problems or usability flaws. These are based on violations of the usability design principles and are considered weaknesses in the system design or its interface to users. According to the IEC 62366 standard (or ANSI AAMI HE 74 & 75 standards) use errors are human errors for which root causes are "usability flaws" (or "usability problems") of the system with which people are working. The Oxford English Dictionary defines “Error” as a mistake or the state or condition of being wrong in conduct or judgment. As this is a stronger and more specifically defined word than problem or flaw we believe it better represents the types of assessments that we wish to classify with the concepts from this Ontology. This is analogous to a diagnosis vs. a problem clinically. Problems encompass diagnoses and symptoms or findings; however we see Usability Errors as diagnoses (usability assessments) related to the system design or implementation.

Human Factors scientists and engineers, who study the intersection of people, technology, and work processes have advocated for the development of a Usability Error Ontology [10]. Wang and Patel and colleagues described cognitive factors that influenced medical error [11]. Vankipuram and colleagues demonstrated a technique for automated workflow analysis [12]. However, the authors are not aware of other efforts to put forward an OWL representation of a Usability Error Ontology. Furthermore, there is a need in Healthcare for the standardization of reporting of errors in clinical systems. In the US the National Institute for Standards and Technology (NIST) has advocated for Usability testing of medical devices and medical software [13].

1. History of Classification in Health

Although many see William Farr from the 19th Century as the father of terminology and classification, we can find evidence in the work of Hippocrates that earlier efforts were underway and meaningful.

Hippocrates was born in 460 BCE to Heraclides, a physician. In his contributions to the Corpus of Hippocrates, he organized medical knowledge into categories such as cautery or excision. He wrote disease oriented treatise based on organ systems such as lung cancer and lung emphysemas. He organized treatments by disorder. This type of systematic organization of health concepts can be said to be the beginning of controlled vocabularies.

Aristotle, approximately 100 years later, credited Hippocrates with the first organized thinking in healthcare. Aristotle himself is credited with the development of the first formal logic [14]. This began with categorization which concerned itself with the natural naming of things and extended itself in his volume named *On Interpretation* which defined the language and form of propositional statements and their elementary relations.

Aristotle was a student of Plato in the school of Athens. Plato looked for Universals and applied principally deductive reasoning to reach his conclusions. Aristotle extended this work to define not only Universals but also Particulars. This included not only deductive but also inductive reasoning. Here we see the first use of logics to define Instance knowledge. This also implies the ability to direct the development of clas-

sification using real world data rather than universal forms. Universals can be things such as an apple or can be a property such as the shape of the apple.

Aristotle defined the term "natural philosophy" to define the development of classification using phenomenon observed from the natural world. This has been extended to cover biology, health and healthcare. He dissected many animals including fertilized eggs through maturation and systematically described what he observed.

Aristotle defined what he called "term logic" which later became known as propositional logic. Here he defined the term as an entity or something. A proposition is defined as consisting of two terms where one is either affirmed or denied. The syllogism is where one proposition (the conclusion) follows from two other propositions (the premises) [15].

The term has evolved in modern thinking to the concept. Here the notion is that the concept is an abstract representation of the thing or abstract notion such as good or evil. The concept should be language independent, have meaningless identifiers and can be formally defined. Epidemiology requires aggregating data by a common meaning.

William Farr, a British Epidemiologist is often regarded as the father of medical statistics [16]. In 1836, he took a job as the first compiler of scientific abstracts. His department was responsible for cataloging and recording the causes of death categorized by occupation. He called this catalog Vital Statistics and was elected as President of the Royal Statistical Society. This eventually became the London Bills of Mortality which was the precursor of the International Classification of Diseases (ICD) [17]. We use ICD9 Clinically Modified or ICD9-CM for morbidity coding and ICD10 for mortality coding in the US today. ICD11 is currently under construction by the World Health Organization (WHO).

Terminology efforts such as SNOMED CT [18], the UMLS, RxNorm [19] and LOINC [20] have created a set of large scale clinical terminologies aimed at general health knowledge representation. SNOMED CT is a description logic based terminological effort that is moving the field toward the use of standard ontologies. OBO holds many basic science related ontologies [21, 22].

Elkin and colleagues published a validated scale for measuring interoperability that was shown to have good inter-rater agreement [23].

An ontology is defined as an explicit formal specification of how to represent the objects, concepts and other entities that are assumed to exist in some area of interest and the relationships that hold among them. Knowledge representation is the process of designing models and systems that represent knowledge, facts and rules.

2. Methods

We used Protégé [24] from Stanford to build the Usability-Error Ontology. We employed the OWL version of Protégé which supports the standard OWL DL semantics. The METHONTOLOGY method was used to create the Ontology [25, 26]. The initial semantics were derived from a literature review and the expert opinion of the lead author. Then we used a participatory design method to obtain input and feedback from a broad variety of stakeholders. The stakeholders included representatives from Human Factors Specialists, Cognitive Psychologists, Physicians, and the Social Scientist communities. The main top level organizing types in the ontology are Cognitive and Non-Cognitive Usability Errors (See Figure 1). We also include aggregation of the types of errors related to specific systems. The Ontology has a set of system types and also a set

of findings that can be used to define specific Usability Errors. This Ontology starts by defining errors related to CPOE (See Figure 2), EHR and Revenue Cycle systems.

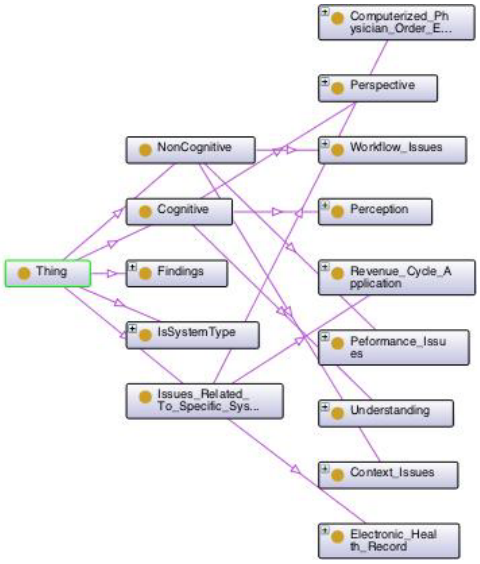

Figure 1: Top level Categorizations for the Usability Error Ontology.

Table 1: OWL Object Properties which serve as relationships in the UE Ontology

Relations	Level 1	Level 2
	Has function	
		Has higher order function
	Has etiology	
	Has status	
	Has deficit	
	Is system type	
	Has referent	
	Has understanding	
	Has subject	

As this is intended to be a living language, we can add other system types and additional errors in future releases of the Ontology. We will keep the version and change log so that all versions of the terminology will be backward compatible. This requires that we agree with the formal definitions that we have developed thus far.

The UEO has over 150 classes and 9 Object Properties (relations) (See Table 1).

3. Discussion

This manuscript describes an open source development effort to standardize the naming for Usability Errors. We have distributed the Ontology at:
http://code.google.com/p/usability-error-ontology/.

With use and experience the Ontology will grow and evolve to serve the needs of the human factors community. This also fits well into the standardization effort ongo-

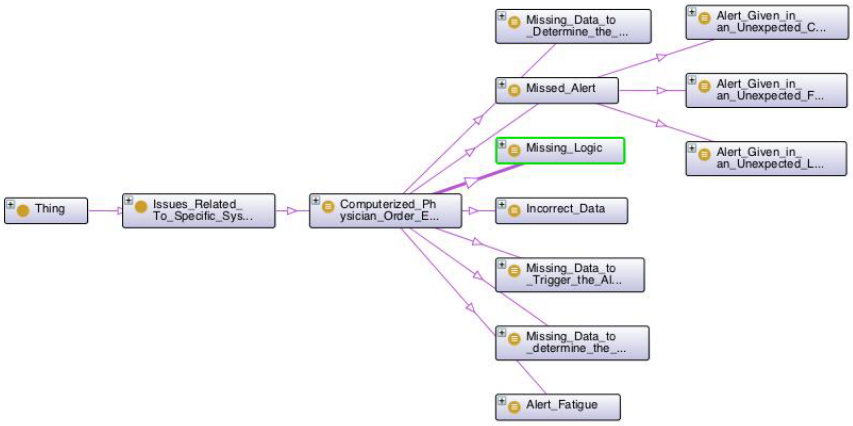

Figure 2. Graph of the types of Usability Errors found in CPOE Systems

ing at the University of Amsterdam by Monique Jaspers and Linda Peute and their colleagues who are using the Delphi method to help standardize Usability Report Formats [27] and with Khajouei who worked on a classification of the actions associated with usability problems [28]. We included the relevant concepts from Rassmussen in the Ontology that were necessary for Usability Error representation of HIT evaluations [29].

Improvements in the patient safety of clinical systems require standardized reporting of Usability Errors. The Usability Error Ontology is a step in the right direction toward more standard and interoperable reporting of Usability Errors in clinical systems.

Correcting Usability Errors in clinical systems has the potential to improve the patient safety of clinical systems and to decrease the harm which is known to occur when using Unusable systems.

References

[1] Institute of Medicine (IOM), *To Err Is Human: Building a Safer Health System*, L.T. Kohn, J.M. Corrigan, and M.S. Donaldson, eds., National Academy Press, Washington, D.C, 2000.
[2] Institute of Medicine (IOM), *Crossing the Quality Chasm: A New Health System for the 21st Century*, National Academy Press, Washington, D.C, 2001.
[3] Institute of Medicine (IOM), *Patient Safety: Building Safer Systems for Better Care*, The National Academies Press, Washington, DC, 2012.
[4] L. Harrington, D. Kennerly, C. Johnson. Safety issues related to the electronic medical record (EMR): synthesis of the literature from the last decade, 2000-2009, *J Healthc Manag* **56** (2011), 31-43; discussion 43-44.
[5] Y.Y. Han, J.A. Carcillo, S.T. Venkataraman, R.S. Clark, R.S. Watson, T.C. Nguyen, H. Bayir, R.A. Orr, Unexpected increased mortality after implementation of a commercially sold computerized physician order entry system, *Pediatrics* **116** (2005), 1506-1512. Erratum in *Pediatrics* **117** (2006), 594.
[6] J. Aarts, R. Koppel, Implementation of computerized physician order entry in seven countries, *Health Aff (Millwood)* **28** (2009), 404-414.
[7] R. Koppel, D. Kreda, Health care information technology vendors "hold harmless" clause: implications for patients and clinicians, *JAMA* **301** (2009), 1276-1278.

[8] H.S. Kaplan, B.R. Fastman, Organization of event reporting data for sense making and system improvement, *Qual Saf Health Care* **12** (2003), 68-72.
[9] F. Magrabi et al., A comparative review of patient safety initiatives for national health information technology, *Int. J. Med. Inform* **82** (2013), e139-48.
[10] UPA Workshop Position Paper 2007,http://www.ipgems.com/content/sample_position_paper_2007.pdf
[11] D. Wang, V.L. Patel & J. Zhang, Creating the Links Between Medical Errors and the Underlying Cognitive factors, *Medinfo* **11** (2004).
[12] M. Vankipuram, K. Kahol, T. Cohen, V.L. Patel, Toward Automated Workflow Analysis and Visualization in Clinical Environments, *Journal of Biomedical Informatics* **44** (2011), 432-440.
[13] National Institute of Standards and Technology, *Technical Evaluation, Testing, and Validation of the Usability of Electronic Health Records*, technical report NISTIR 7804, 2012, Available from URL http://www.nist.gov/healthcare/usability/upload/EUP_WERB_Version_2_23_12-Final-2.pdf.
[14] I.M. Bocheński, *Ancient Formal Logic*, North-Holland Publishing Company, Amsterdam, 1951.
[15] E. Rose Lynn, *Aristotle's Syllogistic*, Charles C Thomas Publisher, Springfield, 1968.
[16] S. Halliday, W. Farr, Campaigning statistician, *Journal of Medical Biography* **8**, 220-227.
[17] World Health Organization (WHO), *International Classification of Diseases (ICD)* available from URL http://www.who.int/classifications/icd/en/
[18] International Health Terminology Standards Development Organization (IHTSDO), *SNOMED CT*, available from URL http://www.ihtsdo.org/snomed-ct/
[19] U.S. National Library of Medicine (NLM), *Unified Medical Language System (UMLS), RxNorm*, available from URL https://www.nlm.nih.gov/research/umls/rxnorm/overview.html
[20] Logical Observation Identifiers Names and Codes (LOINC®), available from URL http://loinc.org/
[21] B. Smith, W. Ceusters, Ontological realism: A methodology for coordinated evolution of scientific ontologies, *Appl Ontol* **15** (2010), 139-188.
[22] P.L. Whetzel, N.F. Noy, N.H. Shah, P.R. Alexander, C. Nyulas, T. Tudorache, M.A. Musen, BioPortal: enhanced functionality via new Web services from the National Center for Biomedical Ontology to access and use ontologies in software applications, *Nucleic Acids Res* **39** (2011), W541-5.
[23] P.L. Elkin, D. Froehling, B.A. Bauer, D. Wahner-Roedler, S.T. Rosenbloom, K. Bailey, S.H. Brown, Aequuscommunissententia: defining levels of interoperability, *Stud Health Technol Inform* **129** (2007), 725-729.
[24] *Protégé*, available from URL http://protege.stanford.edu/
[25] O. Corcho, M. Fernandez-Lopez, A. Gomez-Perez, Methodologies, tools and languages for building ontologies. Where is their meeting point? *Data Knowledge Eng* **46** (2003), 41–64.
[26] C.E. Kuziemsky, F. Lau, A four stage approach for ontology-based health information system design, *Artificial Intelligence in Medicine* **50** (2010), 133–148.
[27] L. Peute, K. Driest, R. Marcilly, S. Bras Da Costa, M.C. Beuscart-Zephir, M. Jaspers, A framework for reporting on Human Factor/Usability studies of Health Information Technologies, *Stud Health Technol Inform,* 2013 (this issue).
[28] R. Khajouei, L.W. Peute, A. Hasman, M.W. Jaspers, Classification and prioritization of usability problems using an augmented classification scheme, *J Biomed Inform* **44** (2011), 948-957.
[29] J. Rasmussen, Cognitive control and Human error mechanisms, in J. Rasmussen, K. Duncan, J. Leplat, editors*, New Technology and Human error*, pp. 53-61, John Wiley & Sons, New York, 1987.