Chapter 4
Usability and Clinical Decision Support

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Abstract Clinical decision support systems (CDSS) link clinical observations with health knowledge to assist clinical decisions. The systems influence clinicians' decisions and consequently enhance healthcare quality. Unfortunately, widespread adoption and user acceptance have not been achieved in most clinical settings since CDSS are not immune to common usability problems of health information technology. This chapter describes clinical and technical issues related to the usability of CDSS.

The clinical issues that affect usability are mainly associated with workflow integration and the growing body of knowledge that needs to be incorporated in clinical decision making. Technical issues include those related to knowledge representation, knowledge base construction and maintenance, and system implementation. The chapter also includes discussions on reducing alert fatigue and improving human-computer interaction in CDSS. It is expected that integrating CDSS with electronic health records will improve healthcare quality and patient safety and improve the timeliness of the adoption of research into practice.

Keywords Usability • Ontology • Workflow integration • Alert fatigue • Knowledge base • Human-computer interaction • Knowledge representation

4.1 CDSS Usability and Functionality

"Clinical decision support systems (CDSS) are computer systems designed to assist clinicians in making decisions regarding individual patients at a specific point in time" [1]. By linking clinical observations with health knowledge, CDSS influence

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clinical decisions and consequently enhance healthcare quality. Researchers have been striving to produce viable CDSS to support all aspects of clinical tasks. However, except for minor successes in the pharmacy and billing sectors [2], most CDSS suffer from common problems in usability, which have received significant attention in the patient safety community [3–8].

Usability is widely accepted as a crucial feature in industrial product design in industries such as aviation, nuclear power, automobile, consumer software, consumer electronics, etc. In contrast, the use of usability principles in the design of Electronic Health Records (EHR) and CDSS has been sporadic and unsystematic, partly due to the lack of attention and effective design and assessment frameworks [9].

"Usability refers to how useful, usable and satisfying a system is for the intended users to accomplish goals in the work domain by performing certain sequences of tasks [10]." "Useful" is described by Zhang and Walji as "how well a system supports the work domain where users accomplish goals for their work independent of how the system is implemented"; how "usable" a system is can be measured by learnability, efficiency and error tolerance; "satisfaction" refers to the subjective impression of how useful, usable and likable a system is to a user [10].

Usability is an emergent quality that reflects the grasp and the reach of human-computer interaction (HCI). HCI is defined as "the study of how humans interact with computers, and how to design computer systems that are easy, quick and productive for humans to use" [11]. It is crucial that CDSS incorporate a greatly improved HCI paradigm for the presentation of both solicited and unsolicited recommendations. Sittig et al., in discussing what they refer to as "grand challenges" of CDSS, emphasize that one of the usability challenges for CDSS is to make them operate unobtrusively, in the background, yet still be effective and specific in reminding the users of things that they may have forgotten, misinterpreted, or overlooked or present new data prior to the decision, rather than correcting users after the fact [12]. Currently, a major concern has been the massive number of alerts presented to the user. When exposed to frequent and overwhelming alerts in daily practice, clinicians may become insensitive to the alerts and consequently may pay less attention, or even override them without offering meaningful reasons. This phenomenon is called "alert fatigue" and it reflects how busy clinicians become desensitized to safety alerts [13]. Alert fatigue can be extremely dangerous because the critical alerts that warn of impending or serious harm to the patient may be unheeded along with the bothersome or clinically meaningless alerts. Ironically, computer generated alerts intended to improve safety may result in increasing the chance of harm to the patient. Since EHR systems are being widely used in today's healthcare environment, alert fatigue has been recognized as a major, unintended consequence as well as a significant patient safety concern [14].

Usability problems of CDSS involve both clinical and technical challenges. The challenges are summarized below with the hope that further discussion and research endeavors will be directed toward this important area. By solving these critical challenges, the full benefits of CDSS are more likely to be achieved.

4.1.1 Clinical Challenges

Disseminating Existing Knowledge About CDSS

Although studies consistently demonstrate successful CDSS, there has not been an easy way to organize the lessons learned in these implementations and disseminate them widely, so that others can learn from them [12]. Sittig et al. argue say that there is a need to build on initial efforts in developing more robust methods to identify, describe, evaluate, collect, catalog, synthesize and disseminate best practices for clinical decision support (CDS) design, development, implementation, maintenance, and evaluation [12].

Clinical Workflow Integration

In the past, many CDSS were not well integrated with computer-based physician order entry (CPOE), and physicians chose to ignore CDSS just because of the "double data entry" requirement which is interruptive to the patient care process [1]. As more and more CDSS have been integrated into EHR systems, the double data entry issue is no longer a major problem for clinicians, although several diagnostic decision support systems remain standalone, not integrated into EHR systems.

A key success factor that is strongly supported by empirical studies and expert recommendations is that CDSS should be integrated into the clinical workflow [15, 16]. CDSS could be more effective when the support of workflow is integrated. For instance, if clinicians do not do their documentation while the patient is present, CDSS are unlikely to influence the clinician-patient interaction. Without feedback from users or observation of the care process, CDSS developers may not realize why their products are not being used effectively. Karsh describes a study where the researchers utilized rapid prototyping with iterative feedback in order to design a CDSS that would efficiently integrate into the workflow of the users. However, Karsh also indicates that care processes themselves are not standardized, making it difficult to develop a set of universally applicable guidelines for CDSS integration. There is no single "workflow"; rather each clinician often has a unique way to approach the care process [16]. More efforts for collaboration are needed between health information technology (HIT) professionals who integrate CDSS into the care process and clinicians who use CDSS in practice to better understand and effectively integrate clinical workflow with CDSS.

Keeping Abreast of New Clinical Research Developments

New clinical evidence is being published on an ongoing basis. Each year, tens of thousands of clinical trials are published [17], which means a large amount of new knowledge must be incorporated into the existing knowledge bases. Accordingly, reasoning modules in CDSS need to be re-evaluated or updated to reflect the advances in science. In some situations, the updates may trigger unexpected conflicts of rules between new knowledge and previous knowledge. Although computational power has been used to assist the updating and maintenance, labor-intensive manual work is still needed [18]. Most research groups cannot afford such an expense in the long run. As a result, CDSS projects that are initially grant funded may stop as soon as the funding ends. The vendors of commercial systems also suffer from similar financial challenges in providing the necessary, but costly, maintenance teams for a long period to support their products. Financial issues may lead to less frequent updates of the knowledge base, which can seriously impact the usability of the systems.

4.1.2 Technical Issues

Variety in Types of Data

A CDSS usually uses a wide range of relevant data, which may potentially increase the difficulty of selecting algorithms for data integration. For example, a CDSS might use data from an EHR such as a patient's symptoms, medical history, family history and it would not be a surprise in the near future if the EHR included genetic information as well. These data might be used in conjunction with the historical and geographical trends of disease occurrence. Such a large database may consist of many types of data including, but not limited to, discrete, continuous, binary, matrix, or even natural language represented in a free text format. Therefore, it may be technically challenging to handle the variety of types of data.

The integration of these data could generate patient summaries, which would be a great help to clinicians since it is not easy for them to recall the important facts and conclusions based on such complicated patient data [12]. Moreover, it has been a challenge to automate the filtering and summarizing of all of the clinical data in EHR systems [12]. The primary difficulty is that the data may be represented in both free text and coded formats, which are difficult to integrate. Furthermore, because of the different requirements of clinicians and their workflows, multiple versions of summaries may be needed to optimize the data output for better decision-making [19, 20].

In order to model or organize the challenging textual data, researchers have applied ontologies to describe the data. However, the lack of a universally accepted standard for clinical vocabulary limits the development of ontologies for CDSS. For example, CDSS may use different words for the same concepts or an identical word

for totally different concepts. Although the Unified Medical Language System (UMLS) makes connections among prevailing controlled vocabularies such as International Classification of Diseases (ICD), Current Procedural Terminology (CPT), Logical Observation Identifiers Names and Codes (LOINC) and SNOMED Clinical Terms (SNOMED CT), etc., the problems of ambiguity and redundancy in vocabulary still exist.

Synthesizing Clinical Knowledge

Another challenge is that a large amount of clinical knowledge is waiting to be fully synthesized, developed, and put into use in CDSS. To reflect the clinical knowledge in a timely manner, there is a need for the creation, testing, and execution of the algorithms to make use of the data in EHR systems and other clinical repositories [12]. If clinical knowledge could be more easily synthesized and deployed in CDSS, the new clinical guidelines and CDS interventions would undoubtedly be helpful in promoting improved outcomes.

4.2 Strategies to Improve the Usability of CDSS

The implementations of CDSS often suffer from usability issues, which have a direct impact on the adoption and effectiveness of CDSS [21]. Imagine that a physician is trying to prescribe a medication to his patient, and the physician keeps suffering from all kinds of alerts in the process with the "help" of a CDSS. After carefully reading the first several alerts which are meaningless, the physician may start to override the rest of the alerts in order to speed up the process. Unfortunately, he may have missed an important drug-drug interaction. The prescription is then sent to the pharmacy with unfortunate results. Therefore, in real-world clinical settings, usability design and validation are some of the most important perspectives of successful CDSS implementation.

The most typical result due to poor usability is alert fatigue. This phenomenon has been regarded as a significant factor in several high-profile errors. For example, an article described an investigation where failure to attend to alarms in a patient monitoring system led to more than 200 deaths over 5 years [22]. Most alert fatigue events occur while using CPOE and CDSS, where a major class of alerts are those for drug-drug interactions or incorrect dosage of medications. Patient Safety Network (PSNet), an online journal and forum on patient safety and healthcare quality sponsored by the Agency for Healthcare Research and Quality (AHRQ) provides several suggestions on how to minimize alert fatigue in CDSS [23] as shown in Table 4.1.

The proposed solutions for alert fatigue issues, once being fully implemented, may significantly advance patient safety and healthcare quality. In addition, the patient safety community will also need to learn from other industries. For example,

Table 4.1 Solutions of alert fatigue in CDSS

	Potential solutions
1	Increase alert specificity. Examples of ways to increase specificity include classifying medications as individual agents (rather than by classes of medication) and specifying the route of administration.
2	Tier alerts according to severity. Presenting each alert level in a different way to users (e.g., different colors, different signal words) allows prescribers to identify important alerts quickly and may result in fewer important alerts being missed or overridden. This approach, although intuitive, is problematic due to the lack of widespread agreement regarding what constitutes a high-level or low-level alert.
3	Apply human factors principles when designing alerts (e.g., format, content, legibility, and color of alerts), and include only high-level (severe) alerts in an alert set. Low priority alerts have been shown to cause user frustration and slow down the medication ordering process. Low priority information could be presented in a non-interruptive way (e.g., as a hyperlink on the prescribing screen).
4	Tailor alerts to patient characteristics. As an example, integrate laboratory results into the alert system to ensure alerts are more patient-relevant. Other strategies include presenting pregnancy alerts only for patients who are pregnant, not all female patients in the hospital, and only presenting allergy alerts for patients in whom a complete list of allergies has been documented.
5	Customize alerts for physicians. Presenting specific alert types to specific specialties or skill levels would ensure that specialists with a high level of knowledge in an area do not receive alerts related to that area (e.g., nephrologists may not need to receive alerts about nephrotoxic drugs). This approach is sometimes viewed as problematic because computerized alerts are meant to serve as a safety net in times of forgetfulness or time pressure, even for experts.

From Baysari [23]. Available at: https://psnet.ahrq.gov/webmm/case/310/

in the aviation industry, the alerts in the cockpit are minimized so that only the most important ones are displayed to the pilots, thus allowing them to avoid the distractions of less important alerts. This approach can provide a useful model for CDSS design [13]. Tiered alerts are recommended, where only the most significant alerts require a hard stop [24].

The effectiveness of CDSS highly depends on the implementation of workflow integration and usability in complex healthcare settings [25]. Most CDSS were generally designed for healthcare providers, but might not fully consider the diversity of providers and their requirements, as well as their expertise levels. When using CDSS, physician experts may expect to make decisions more precisely and quickly, while nurses may hope to take care of their patients in a better way [26]. Sometimes, even patients are encouraged to get engaged in CDSS in retirement living communities, such as TigerPlace in Columbia, Missouri. In TigerPlace, smart home technologies are installed within the private apartments of the residents. The technologies may include devices for emergency communication, falls detection, gait and movement monitoring, cognitive reminder systems, and medication management. The devices are monitors, sensors, and even personal PDAs which need the residents to engage in the information collection [27, 28].

The increasing amount of knowledge represented by diverse types of data and purposes of potential users have an effect on the usability, even though the algorithms or reasoning approaches of CDSS may be well-designed and solid. For example, a multi-site study indicated that nurses routinely override CDSS recommendations that do not fit their local practice, leading to a potential increase in errors [29]. User-centered design can improve HCI by providing personalized and targeted support [30]. Improved HCI design may include individualized interfaces according to the user group and purpose, increased sensitivity to the needs of the current clinical scenario, or may even provide patient interfaces for some special CDSS such as those used for aging-in-place, in order to enhance the patients' self-efficacy and awareness to reduce patient safety events. Chapter 10 discusses patient-focused CDSS in more detail.

4.2.1 Perform User-Centered Design

Norman proposed the term user-centered design (UCD) in his co-authored book published in 1986 [31]. The term has become widely used since then. Norman and Draper presented seven principles of design which are essential for facilitating the designer's task [31]. Below we list and explain these principles (Norman and Draper's principles are italicized):

1. "*Use both knowledge in the world and knowledge in the head.*" To assist the user in building conceptual models about how a system works, one should write easy-to-understand manuals prior to the design to assist the user in understanding the system and which can also be a good reference tool. Writing the manual prior to designing the system may also aid in the design of the system itself.
2. "*Simplify the structure of tasks*." Designers should not overload either the short-term memory, or the long term memory of the system user. The user's task should be consistent with mental aids, so that the user can easily retrieve information from long-term memory. Users should have control over the task.
3. "*Make things visible.*" The visibility should help users to figure out the use of an object, for example, by seeing the right buttons or devices for executing an operation.
4. "*Get the mappings right*." The user needs to understand the relationship between what the user wants to do and how the system works. One way to improve this understanding is to use effective graphics.
5. "*Exploit the power of constraints*, *both natural and artificial.*" Design the system so the correct way to use it is obvious and make any incorrect ways of using the system impossible or difficult, so that the user is automatically guided to the correct way.
6. "*Design forerror.*" Assume that user will make errors and build in strategies to help recover from errors.

7. "*When all else fails*, *standardize.*" Standards are challenging to develop, but once the standards are agreed to, their use can make things much easier for the user.

Parallel design is an effective method in the UCD process. The design requires several people to create an initial design based on the same requirements. Before they complete their plans and share with the group, each designer should have worked independently. Then all the solutions will be considered by the design team, after which each designer will be allowed to further improve the ideas. The main tasks of designers include: (1) define layouts, (2) clarify the expectations on design fidelity, (3) if using a team approach, make sure team members have equivalent skills, (4) set up the evaluation criteria [32].

Prototyping is a widely used method, based on "a draft version of a product, allowing researchers to explore ideas and demonstrate the intention of a feature prior to the investment of time and money into real design" [33]. There is no limit for the prototype format which can be a paper draft or even a functional website. Using the prototyping method can significantly reduce the cost when changes need to be made before the final product is finished. Usability issues are already addressed since the feedback from users is gathered while researchers or companies are still planning and designing the product.

An individual interview is a direct way to gather information from users. This method allows researchers to probe the users' attitudes, beliefs, desires, and experiences to get a more comprehensive understanding about the requirements of potential users. Such an interview can be a face-to-face meeting, a phone call, or a video conference, or even a chat via instant messaging systems [34]. Surveys such as rating or ranking choices for the product content can also be processed during the interviews. During an individual talk, the interviewer can give the interviewee his full attention and adjust the interviewing style according to the interviewee's needs without being worried about the group dynamics. Individual interviews typically involve five to ten participants. Since the interviewers only talk to one person at a time, too many interviewees could extend the overall time, which may influence the quality of the discussion.

4.2.2 Create Approaches for Sharing CDS Knowledge, Modules and Services

To improve CDS research and development, there is an urgent need to establish approaches for sharing the practices and experiences. The primary task is to standardize the taxonomy of CDS interventions and outcomes which allows different systems and organizations to display and compare their practices and outcomes. With a goal of providing a platform for such sharing purposes, Sittig et al. suggest that "a set of standards-based interfaces to externally maintained clinical decision support services that any EHR could "subscribe to", in such a way that healthcare

organizations and practices can implement new state of the art clinical decision support interventions with little or no extra effort on their part." [12]. Imagine a system where CDS knowledge modules can be executed everywhere because the modules are designed to be compatible with the local clinical system based on the standardized interface. In the near future, all novel CDS applications could be proposed collectively with standards-based, sharable CDS modules. It is also necessary to create Internet-accessible CDS repositories which could be easily shared by all the products using the standards-based interface [12]. Such a repository would provide an accurate source of knowledge and would allow individual healthcare facilities to avoid the arduous task of creating their own rules.

4.2.3 Enhance Quality of Knowledge Base to Support Multimorbidity Decisions

The multimorbidity issue is becoming a great challenge in healthcare [12]. Multimorbidity is defined as "any combination of chronic disease with at least one other acute or chronic disease, bio-psychosocial factor or somatic risk factor" [35]. Elderly patients almost always have multiple co-morbidities and a wide spectrum of medication prescriptions [36]. Studies have found that the following disease groups are likely to co-occur: cardiovascular diseases, diabetes mellitus, chronic kidney disease, chronic musculoskeletal disorders, chronic lung disorders, and mental health problems [37–39]. It is estimated that 84 % of total health expenditures involve patients with more than one condition in the United States [40]. The impact on public health and the economy of multimorbidity is significantly increasing [41].

To identify a technological approach for managing multimorbidity, evidence-based practice and involvement from both health professionals and patients are essential. As Sittig et al. argued, "the challenge is to create mechanisms to identify and eliminate redundant, contraindicated, potentially discordant, or mutually exclusive guideline-based recommendations for patients presenting with co-morbid conditions" [12]. Reviews on multimorbidity from the perspective of informatics indicate that CDSS can potentially improve patient safety for patients with multimorbidity [42, 43]. However, clinical guidelines are still far away from being fully utilized since they do not sufficiently address the multimorbidity issue, which may lead to the requirement of developing new strategies using computer science methods, such as logical and semantic approaches. To date, the most effective solution for the combination of clinical practice guidelines is to create ontologies including the criteria provided by experts [44].

As defined by Carter, "Knowledge bases are collections of facts about the real world, encoded in a manner that allows them to be used computationally" [45]. In fact, more sophisticated CDSS require a knowledge base for accessing facts and key concepts that underlie the domain. An ontology can provide structure to that

knowledge. Communication, computational inference and reuse, and knowledge management are the three basic purposes when using ontologies [45]. In regard to communication, the information extracted and aggregated from different sources can be used to answer user queries or be regarded as input data to other applications, if all the terms are shared and published using the same underlying ontology [46]. The hierarchical structure of ontologies is helpful for functional and computational inference and data reuse in the investigated domains [47], which may consequently enhance the application value of the system. Ontologies are widely accepted in the next generation knowledge management systems focusing on conceptual models because they are an essential technology for activating semantic knowledge [48]. Thus, the use of ontologies can significantly enhance the quality of CDSSknowledge bases, especially in supporting multimorbidity decisions.

4.2.4 Integrate CDSS with the EHR

In a review of the effectiveness of CDSS, Moja et al. cite studies that show that CDSS "increase the use of preventive care in hospitalized patients, facilitate communication between providers and patients, enable faster and more accurate access to medical record data, improve the quality and safety of medication prescribing, and decrease the rate of prescription errors" [49]. CDSS should be integrated with the EHR so as to further improve the effectiveness.

Although EHR adoption is gaining momentum in healthcare systems, issues related to usability, workflow, and cognitive support are barriers to EHR meaningful use. Some of these barriers can be addressed by integrating the CDSS with the hospital information systems including but not limited to EHRs [1]. There are a number of commercial CDSS that are successful in narrowly defined domains, for instance, diagnostic decision support systems built into electrocardiograms (EKGs). However, they are still far from being well-integrated with the EHR. Similar to the process of knowledge standardization, EHRs also need uniform definitions prior to integrating CDSS. In addition, standardization is considered a priority to optimization. The Armed Forces Health Longitudinal Technology Application (AHLTA), the only EHR system used by healthcare providers of the U.S. Department of Defense (DoD) since 2004, allows central storage of standardized EHR data and shares patient information worldwide. Although this system is not immune to common issues shared with other EHR systems, AHLTA has been proven to be effective because of its standardization. Despite its strengths, the system is not as interoperable as it needs to be. In July 2015, the DoD announced that AHLTA will be replaced by a commercial system that is able to interact more effectively with civilian EHR systems [50]. This change reflects the inexorable trend of EHR standardization. The impact and benefit of CDSS linked to EHR will not be fully realized until the standardization of EHRs is further developed.

4.2.5 Reduce Errors by Learning from Previous Experience

Each year in the United States, 650,000 cancer outpatients receiving chemotherapy are at high-risk of developing infections [51]. The infections may lead to hospitalization, disruptions in chemotherapy schedules, or even death. This is just a fraction of preventable patient safety events which are highly repetitive and could be reduced. To learn from the recurring events, an event reporting system is regarded as an effective way to analyze accumulated events and similarities at a collective level. An ideal reporting system would generate actionable knowledge based upon patient safety event repository, and even suggest common solutions for similar events under investigation. Unfortunately, current reporting systems still remain in the primary stage transitioning from paper forms, lacking a logic-based organizational knowledge structure for comparison and analysis, and suffering from poor usability—all of which impede the development of the systems towards the ideal. Therefore, there is an urgent need for learning from patient safety event reporting systems. Based on structural knowledge, the learning mechanism can dynamically measure the similarities of patient safety events and thus promote a learning effect. By integrating semantic searching algorithms into a patient safety event reporting system, the system should have the ability to learn from previous events and provide hints or common solutions for current events. With this innovative idea, reporting systems will have more useful functions and potentially trigger a revolution for data management and analysis in the field of patient safety, and then become an important approach to enhance the usability of CDSS [52].

4.3 Safety-Enhanced Design and Usability Assessment

CDSS have the potential to dramatically improve healthcare quality and safety. To reach this goal, systems must be designed, developed, and implemented with a focus on usability and safe use [53]. In the last decade, considerable attention from both researchers and vendors has been directed towards usability and integration into the clinical setting. Usability assessment aims to measure the satisfaction of users when they learn or use a product to achieve their goals. The degree of satisfaction is based on user feedback which reflects a combination of various factors including intuitive design, ease of learning, efficiency of use, memorability, error frequency and severity, subjective satisfaction, etc. In order to collect and assess such feedback, there are plenty of competent methods such as safety-enhanced design (SED), rapid usability assessment (RUA), usability testing, heuristic evaluation, card sorting, first click testing, individual interviews, online surveys, and system usability scales (SUS), etc. Some of these methods can be used for both design and assessment. This section provides an overview of usability evaluation and presents several of these commonly used approaches.

4.3.1 Safety-Enhanced Design (SED)

Aiming at accommodating users rather than forcing users to adapt, there are six key principles of user-centered design (UCD) according to Usability.gov [54].

1. Design is based upon an explicit understanding of users, tasks and environments.
2. Users are involved throughout design and development.
3. Design is driven and refined by user-centered evaluation.
4. The process is iterative.
5. The design addresses the whole user experience.
6. The design team includes multidisciplinary skills and perspectives.

Safety-enhanced design (SED) is a design process to reduce design-based errors within EHR interfaces, thereby improving the quality and safety of EHR systems [55]. As part of the certification criteria for meaningful use [26] vendors are required to use a formal, user-centered design (UCD) process during EHR system development and perform summative usability testing for portions of their EHR products. The testing includes CPOE, drug-drug, drug-allergy interaction check, medication list, medication allergy list, CDS, electronic medication administration record, electronic prescribing, and clinical information reconciliation. To fulfill certification requirements, vendors must submit documentation specifying the UCD processes used, which allows for significant flexibility in achieving SED. However, few summative tests or UCD experience reports are available at the current stage. Growing the literature on UCD implementation is considered necessary [56].

4.3.2 Rapid Usability Assessment (RUA)

Rapid Usability Assessment (RUA) is a laboratory-based, analytical usability process which was proposed to identify usability challenges and estimate the efficiency in performing routine meaningful use related tasks [57]. As described by Walji et al., there are three main stages in RUA [57]:

1. Selection of meaningful use objectives. The National Institute of Standards and Technology (NIST) developed meaningful use test procedures which contain specific instructions and sample data to determine if a system has met a meaningful use objective. The test specified data must be recorded in a structured format using either ICD-10-CM or SNOMED-CT.
2. Use of a modeling tool to predict task completion times as an indicator of productivity. Specifically, predict an expert's routine task completion times using a modeling tool, then use these results as performance benchmarks for laboratory evaluations [58]. There are several cognitively grounded approaches that can be used to predict task completion times, such as Goals, Operators, Methods and Selection (GOMS) technique [59].

3. Identifying usability challenges through expert review. Expert review can be conducted rapidly, and has been found to be effective in identifying gross usability problems [60]. A typical type of expert review is Heuristic Evaluation which was initially proposed by Nielsen and modified for use in clinical settings, and has been successfully applied to health IT, including practice management, computerized provider order entry (CPOE), telemedicine, and medical devices [61–65]. It has also been successfully used for predicting usability issues that impact end user involvement [66–68].

4.3.3 Usability Testing

"Usability testing refers to evaluating a product or service by testing it with representative users" [69]. In the context of CDSS, usability testing refers to evaluating CDSS and the associated heath information system with clinicians or other types of users. During a typical usability test, participants will be asked to complete typical tasks (e.g. prescribe an order) while observers watch, listen with minimum interruption, and take notes or record the entire test session. The purpose of usability testing is to make sure the usability issues of products are identified and fixed before they go into production. The process of usability testing typically includes three main steps: develop a plan, recruit participants, choose a moderating technique and proceed to the testing. In order to make the whole schema more tangible, below is an example to further demonstrate the implementation of usability testing. The examples come from a description of the design of a voluntary patient safety reporting system [70].

1. Develop a plan. The plan should be made according to the purpose of the testing, such as what type of data you are going to collect. In the example, the researchers wanted to assess the usability of their user-centered voluntary patient safety reporting system. The problem of patient falls, a major patient safety event, was selected as the research target. The data to be captured from testing was execution times on five subtasks (answer initial questions, rate a harm score, enter patient related information, answer case-dependent multiple-choice questions, and document further comments). Further, the testing plan was designed to ask participants to report three patient fall events using the system and then complete the five subtasks.
2. Recruit participants. The participants should be a representative sample of the potential users of the product. The number of participants depends on the testing purpose. Although normally five participants will be able to generate the majority of the usability problems in most usability tests, ten subjects were recruited for the test in the example case because the tasks they needed to do were fairly complex.

3. Choose a moderating technique and proceed to the testing. A moderating technique should be chosen according to the goals once the plan and participants of the test are determined. Retrospective think aloud (RTA) was used in the study. This technique involved gathering the user's verbalizations of attitudes when the reporting session was completed instead of during the session. The obtrusive disturbances to users' cognition, which would happen when the thinking aloud were done concurrently with task performance, can be significantly reduced or even completely eliminated when using RTA. There are also several other methods that could have been used, such as concurrent think aloud (CTA), concurrent probing (CP), and retrospective probing (RP).

Card Sorting

Card sorting is applied to help design or assess the information architecture of a product [71]. Topics are organized in the form of cards and provided to participants who may help researchers label the groups according to whether the topics make sense to them. Rather than the actual cards, researchers can also choose other forms such as pieces of paper or even online card-sorting tools. Open card sort and closed card sort are two widely used sorting strategies based on different requirements. The only difference is whether the categories of topics are pre-defined prior to sorting. The open and closed card sort can also be used in a combination way that initially implements an open card sort to identify content categories and then applies a closed card sort to see how well the category labels work.

Online Surveys

Online surveys provide researchers a more flexible and low-cost way to learn from users' feedback, such as the potential user group, the purpose of users when using the product, and what kind of information users expect to gain [72]. Online surveys can be used at any stage of the development process according to the goal. A study on identifying the user requirements of UCD demonstrated a successful example of using online surveys to screen interview candidates and train the follow-up interview [34]. Aiming at figuring out both benefits and barriers of a voluntary patient safety event reporting system toward UCD, the investigators organized an online survey in the form of a questionnaire including questions about participant's role, assessment, and preference of the proposed UCD features in e-reporting. A Likert scale was used to measure the level of agreement for the questions. The online survey form and the easy-to-use scale made the survey more understandable and easy to complete [34].

4.4 Summary

While it is becoming increasingly clear that CDSS are effective in improving clinical processes when integrated with the clinical workflow, it may take some time to fully realize CDSS' potential in improving healthcare quality and outcomes. As Osheroff and colleagues state in the preface to their book, *Improving OutcomeswithClinical Decision Support*, "The challenge of improving healthcare has never been primarily due to a lack of innovations, but in failure to implement, evaluate, and disseminate the myriad promising innovations awaiting our attention" [73]. Fortunately, more researchers have been involved in this field over the past decade, especially those from other disciplines. As the researchers bring more innovative ideas, we hope to witness the revolution of CDSS with enhanced usability in the near future.

References

1. Berner ES, La Lande TJ. Overview of clinical decision support systems. In: Berner ES, editor. Clinical decision support systems. Theory and practice. 2nd ed. New York: Springer; 2007. p. 3–22.
2. Curtain C, Peterson GM. Review of computerized clinical decision support in community pharmacy. J Clin Pharm Ther. 2014;39:343–8.
3. Armijo D, McDonnell C, Werner K. Electronic health record usability: interface design considerations, AHRQ Publication No. 09(10)–0091-2-EF. Rockville: Agency for Healthcare Research and Quality; 2009. October 2009. Available from: https://healthit.ahrq.gov/sites/default/files/docs/citation/09-10-0091-2-EF.pdf.
4. Johnson CM, Johnson TR, Zhang J. A user-centered framework for redesigning health care interfaces. J Biomed Inform. 2005;38:75–87.
5. Kushniruk AW, Patel VL. Cognitive and usability engineering methods for the evaluation of clinical information systems. J Biomed Inform. 2004;37:56–76.
6. Patel VL, Zhang J. Cognition and patient safety. In: Durso FT, editor. Handbook of applied cognition. New York: Wiley; 2007. p. 307–31.
7. Zhang J. Human-centered computing in health information systems. Part 1: Analysis and design. J Biomed Inform. 2005;38:1–3.
8. Zhang J. Human-centered computing in health information systems part 2: evaluation. J Biomed Inform. 2005;38:173–5.
9. Zhang J, Walji MF. TURF unified framework of EHR usability. In: Zhang J, Walji MF, editors. Better EHR: usability, workflow and cognitive support in electronic health records. National Center for Cognitive Informatics and Decision Making in Healthcare; 2014. pp. 29–56. Available from: http://www.researchgate.net/publication/269400453_Better_EHR_Usability_Workflow_and_Cognitive_Support_in_Electronic_Health_Records.
10. Zhang J, Walji MF. TURF: toward a unified framework of EHR usability. J Biomed Inform. 2011;44:1056–67.
11. Jansvier WA, Ghaoui C. Replicating human interactin to support E-Learning. In: Ghaoui C, editor. Encyclopedia of human computer interaction. Hershey: Idea Group; 2006. p. 503.
12. Sittig DF, Wright A, Osheroff JA, Middleton B, Teich JM, Ash JS, et al. Grand challenges in clinical decision support. J Biomed Inform. 2008;41:387–92.

13. AHRQ Patient Safety Network. Patient safety primers: alert fatigue. 2015. Agency for Healthcare Research and Quality (AHRQ). Available at: http://www.psnet.ahrq.gov/primer.aspx?primerID=28.
14. Slight SP, Seger DL, Nanji KC, Cho I, Maniam N, Dykes PC, et al. Are we heeding the warning signs? Examining providers' overrides of computerized drug-drug interaction alerts in primary care. PLoS One. 2013;8(12):e85071.
15. Cadet JV. Clinical decision support: workflow integration is vital for optimizing care. Cardiovascular Business. 2011. http://www.cardiovascularbusiness.com/topics/health-it/clinical-decision-support-workflow-integration-vital-optimizing-care.
16. Karsh B-T. Clinical practice improvement and redesign: how change in workflow can be supported by clinical decision support, AHRQ Publication No. 09-0054-EF. Rockville: Agency for Healthcare Research and Quality; 2009. Available from: https://healthit.ahrq.gov/sites/default/files/docs/page/09-0054-EF-Updated_0.pdf.
17. Gluud C, Nikolova D. Likely country of origin in publications on randomised controlled trials and controlled clinical trials during the last 60 years. Trials. 2007;8:7.
18. Gardner RM. Computerized clinical decision-support in respiratory care. Respir Care. 2004;49:378–86. discussion 386–378.
19. Petersen LA, Orav EJ, Teich JM, O'Neill AC, Brennan TA. Using a computerized sign-out program to improve continuity of inpatient care and prevent adverse events. Jt Comm J Qual Improv. 1998;24:77–87.
20. Zeng Q, Cimino JJ. A knowledge-based, concept-oriented view generation system for clinical data. J Biomed Inform. 2001;34:112–28.
21. Koppel R, Wetterneck T, Telles JL, Karsh B-T. Workarounds to barcode medication administration systems: their occurrences, causes, and threats to patient safety. J Am Med Inform Assoc. 2008;15:408–23.
22. Kowalczyk L. Patient alarms often unheard, unheeded. Boston Globe. Boston. 2011. 13 Feb 2011. Available from: http://www.boston.com/lifestyle/health/articles/2011/02/13/patient_alarms_often_unheard_unheeded/.
23. Baysari M. Finding fault with the default alert. AHRQ Web M&M. October 2013. Available at: http://webmm.ahrq.gov/case.aspx?caseID=310.
24. Shah NR, Seger AC, Seger DL, Fiskio JM, Kuperman GJ, Blumenfeld B, et al. Improving acceptance of computerized prescribing alerts in ambulatory care. J Am Med Inform Assoc. 2006;13(1):5–11.
25. Yuan MJ, Finley GM, Long J, Mills C, Johnson RK. Evaluation of user interface and workflow design of a bedside nursing clinical decision support system. Interact J Med Res. 2013;2:e4.
26. Blumenthal D. Stimulating the adoption of health information technology. N Engl J Med. 2009;360:1477–9.
27. Demiris G, Rantz M, Aud M, Marek T, Tyrer H, Skubic M, et al. Older adults' attitudes towards and perceptions of "smart home" technologies: a pilot study. Med Inform Internet Med. 2004;29:87–94.
28. Rantz MJ, Marek T, Aud M, Tyrer HW, Skubic M, Demiris G, et al. A technology and nursing collaboration to help older adults age in place. Nurs Outlook. 2005;53:40–5.
29. Dowding D, Spilsbury K, Thompson C, Brownlow R, Pattenden J. Nurses' use of computerised clinical decision support systems: a case site analysis. J Clin Nurs. 2009;18:1159–67.
30. Sears A, Jacko JA. Human-computer interaction: designing for diverse users and domains. Boca Raton: CRC; 2009.
31. Norman DA, Draper SW. User-centered system design: new perspectives on human-computer interaction. Hillsdale: Lawrence Earlbaum Associates; 1986.
32. Norman DA, Draper SW. Parallel design. Usability Net. 2015. Available from: http://www.usabilitynet.org/tools/parallel.htm.
33. Bailey B. Paper prototypes work as well as software prototypes. Usability.gov. 2005. Available from: http://www.usability.gov/get-involved/blog/2005/06/paper-prototypes-and-software-prototypes.html.

34. Gong Y, Song H-Y, Wu X, Hua L. Identifying barriers and benefits of patient safety event reporting toward user-centered design. Saf Health. 2015;1:7.
35. Le Reste JY, Nabbe P, Rivet C, Lygidakis C, Doerr C, Czachowski S, et al. The European General Practice Research Network presents a comprehensive definition of multimorbidity in family medicine and long term care, following a systematic review of relevant literature. J Am Med Dir Assoc. 2013;14:319–25.
36. Boyd CM, Darer J, Yu Q, Wolff JL, Leff B. Clinical practice guidelines and quality of care for older patients with multiple comorbid diseases: implications for pay for performance. JAMA. 2005;294:716–24.
37. Stevens LA, Li S, Wang C, Huang C, Becker BN, Bomback AS, et al. Prevalence of CKD and comorbid illness in elderly patients in the United States: results from the Kidney Early Evaluation Program (KEEP). Am J Kidney Dis. 2010;55:S23–33.
38. Yaffe K, Ackerson L, Kurella Tamura M, le Blanc P, Kusek JW, Sehgal AR, et al. Chronic kidney disease and cognitive function in older adults: findings from the chronic renal insufficiency cohort cognitive study. J Am Geriatr Soc. 2010;58:338–45.
39. Zhang X, Decker FH, Luo H, Geiss LS, Pearson WS, Saaddine JB, et al. Trends in the prevalence and comorbidities of diabetes mellitus in nursing home residents in the United States: 1995–2004. J Am Geriatr Soc. 2010;58:724–30.
40. Anderson G. Chronic care: making the case for ongoing care. Princeton: Robert Wood Johnson Foundation; 2010.
41. Taylor AW, et al. Multimorbidity – not just an older person's issue. Results from an Australian biomedical study. BMC Publ Health. 2010;10:718.
42. Roshanov PS, Misra S, Gerstein HC, Garg AX, Sebaldt RJ, Mackay JA, et al. Computerized clinical decision support systems for chronic disease management: a decision-maker-researcher partnership systematic review. Implement Sci. 2011;6:92.
43. Yourman L, Concato J, Agostini JV. Use of computer decision support interventions to improve medication prescribing in older adults: a systematic review. Am J Geriatr Pharmacother. 2008;6:119–29.
44. Jafarpour B, Abidi S. Merging disease-specific clinical guidelines to handle comorbidities in a clinical decision support setting. In: Artificial intelligence in medicine. Murcia, Spain: Springer; 2013 pp. 28–32.
45. Carter JH. Design and implementation issues. In: Berner ES, editor. Clinical decision support systems. New York: Springer; 2007. p. 64–98.
46. Gruber TR. A translation approach to portable ontology specifications. Knowl Acquis. 1993;5:199–220.
47. Kanehisa M, Goto S, Hatori M, Aoki-Kinoshita KF, Itoh M, Kawashima S, et al. From genomics to chemical genomics: new developments in KEGG. Nucleic Acids Res. 2006;34:D354–7.
48. Maedche A, Motik B, Stojanovic L, Studer R, Volz R. Ontologies for enterprise knowledge management. IEEE Intell Syst. 2003;18:26–33.
49. Moja L, Kwag KH, Lytras T, Bertizzolo L, Brandt L, Pecoraro V, et al. Effectiveness of computerized decision support systems linked to electronic health records: a systematic review and meta-analysis. Am J Public Health. 2014;104:e12–22.
50. Noble Z. DoD awards massive health records contract. 29 July 2015. FCW. Available at: https://fcw.com/articles/2015/07/29/dod-dhmsm-award.aspx.
51. Centers for Disease Control and Prevention. Preventing infections in cancer patients. Available at: http://www.cdc.gov/cancer/preventinfections/.
52. Kang H, Gong Y. Developing a self-learning patient safety event reporting system. Innovations in cancer prevention and research conference. Austin; 2015.
53. Karsh BT. Beyond usability: designing effective technology implementation systems to promote patient safety. Qual Saf Health Care. 2004;13:388–94.
54. Visual Design Glossary Terms. Usability.gov. Available at: http://www.usability.gov/what-and-why/glossary/tag/visual-design/index.html.

55. Lowry SZ. Technical evaluation, testing, and validation of the usability of electronic health records. Gaithersburg: National Institute of Standards and Technology; 2012.
56. Ratwani R, et al. EHR vendor usability practices. In: Zhang J, Walji MF, editors. Better EHR: usability, workflow and cognitive support in electronic health records. Houston, TX: National Center for Cognitive Informatics and Decision Making in Healthcare; 2014. pp. 103.
57. Walji MF, Franklin A, Kannampallil T, Zhang Z, Graves K, Li Y, et al. Rapid usability assessment of commercial EHRs. In: Zhang J, Walji MF, editors, Better EHR: usability, workflow and cognitive support in electronic health records. Houston, TX: National Center for Cognitive Informatics and Decision Making in Healthcare; 2014. pp. 91–109.
58. Gong Y, Zhang J. Toward a human-centered hyperlipidemia management system: the interaction between internal and external information on relational data search. J Med Syst. 2011;35:169–77.
59. John BE, Kieras DE. The GOMS family of user interface analysis techniques: comparison and contrast. ACM Trans Comput Hum Interact (TOCHI). 1996;3:320–51.
60. Nielsen J. Guerilla HCI: discount usability engineering to penetrate intimidation barrier. In: Bias RG, Mayhew DJ, editors. Cost-justifying usability. San Diego: Academic; 1994.
61. Zhang J, et al. Using usability heuristics to evaluate patient safety of medical devices. J Biomed Inform. 2003;36:23–30.
62. Thyvalikakath TP, Schleyer TK, Monaco V. Heuristic evaluation of clinical functions in four practice management systems: a pilot study. J Am Dent Assoc. 2007;138(209–210):212–8.
63. Chan J, et al. Usability evaluation of order sets in a computerised provider order entry system. BMJ Qual Saf. 2011;20:932–40.
64. Tang Z, et al. Applying heuristic evaluation to improve the usability of a telemedicine system. Telemed J E Health. 2006;12:24–34.
65. Graham MJ, et al. Heuristic evaluation of infusion pumps: implications for patient safety in Intensive Care Units. Int J Med Inform. 2004;73:771–9.
66. Gong Y, Zhang J. A human-centered design and evaluation framework for information search. AMIA Annual Symposium proceedings. 2005. pp. 281–5. http://www.ncbi.nlm.nih.gov/pubmed/16779046.
67. Johnson CM, et al. Can prospective usability evaluation predict data errors? AMIA Annu Symp Proc. 2010;2010:346–50.
68. Thyvalikakath TP, et al. Comparative study of heuristic evaluation and usability testing methods. Stud Health Technol Inform. 2009;143:322–7.
69. Usability.gov. Usability testing. Available at: http://www.usability.gov/how-to-and-tools/methods/usability-testing.html. 2015.
70. Hua L, Gong Y. Design of a user-centered voluntary patient safety reporting system: understanding the time and response variances by retrospective think-aloud protocols. Stud Health Technol Informat. 2013;192:729–33.
71. Usability.gov. Card sorting. Available at: http://www.usability.gov/how-to-and-tools/methods/card-sorting.html. 2015.
72. Usability.gov. Online surveys. Available at: http://www.usability.gov/how-to-and-tools/methods/online-surveys.html. 2015.
73. Osheroff JA, et al. Improving outcomes with clinical decision support-an implementer's guide. Chicago: HIMSS; 2012.