Usability evaluation of the medication ordering CPOE system in the AMC hospital

An evaluation of usability issues related to Medicator CPOE



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June 2008

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Preface

This master thesis consists of the usability evaluation of a medication prescription system concerning the prescription of cytostatic therapy in the AMC hospital. This thesis is the final product of the master degree in medical informatics at the University of Amsterdam.

I would like to express my appreciation and thanks to the following people and for their help and support during this scientific research project (SRP).

Martijn ten Harpe, Marie-Jose Kerstens, Liane ten Boome, Anette Coumou, Koen de Heer, Boelo Poppema, My fellow master students.

I owe very special thanks to Monique and Reza, my tutor and mentor, for supporting and guiding me during the entire project. Thank you so much for challenging, encouraging, guiding and pushing me to make my work even better.

Amsterdam, August 2008 Dennis de Jongh

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Abstract

From conversation with end-users and the evaluation documents (vision documents) of the implementation of Medicator it was clear that the Medicator Computerized Physician Order Entry system (CPOE) suffers from usability flaws which could potentially lead to medication errors. In order to optimize its design our objective was to evaluate the usability of the Medicator CPOE system and the influence of its design aspects on usability and potential for medication errors. The Medicator CPOE was tested at the hematology and oncology department of the AMC hospital.

The Medicator CPOE was evaluated by using two usability evaluation methods: The Cognitive Walkthrough (CW) evaluation method performed by two researchers from the field of medical informatics and the Think Aloud (TA) evaluation method conducted by users. Four users, a system expert, two residents from the hematology and oncology department of the AMC and a domain expert participated in TA sessions. After the TA sessions end-users were asked to fill out a questionnaire. Data from questionnaires was used during the analysis to see how user satisfaction holds to the outcome of the usability analyses.

A total of 31 usability problems were detected through use of the CW methods. The TA end-user testing revealed an additional 14 usability problems not detected by the CW. At least 14 of the total number of identified usability problems could lead to severe errors, e.g. prescription of wrong medication, rigidity against canceling or editing wrong medication orders and drug overdosing or drug underdosing.

The overall questionnaire results confirmed the usability evaluation results that user satisfaction with the system is very low. All end-users agreed on the fact that the system is very rigid, difficult to use and therefore very frustrating. Furthermore they felt the Medicator system hardly offers any guidance through (help) messages and Mediator's errors messages were often ambiguous. On the basis of this usability study and the outcome of the questionnaire and the revealed usability problems it is shown that a revision of the implemented Medicator CPOE is strongly suggested. Furthermore the study shows that conducting a TA as well as a CW evaluation improved the outcome of and the validity of results of the usability evaluation considerably.

Keywords: CPOE, Medicator, usability evaluation, medication errors

Samenvatting

Zowel uit visie documenten van de implementatie van het medicatie doseersysteem, Medicator, als uit gespreken met eindgebruikers is gebleken dat Medicator gebukt gaat onder bruikbaarheidsfouten welke potentieel tot medicatie fouten kunnen leiden.

Het doel van dit onderzoek was zowel de bruikbaarheid te evalueren van Medicator tijdens het voorschrijven van cytostatica alsmede de invloed van ontwerp aspecten van Medicator gerelateerd aan bruikbaarheid op potentiële medicatie fouten. De evaluatie van het Medicator systeem vond plaats op de hematologie en oncologie afdeling van het AMC te Amsterdam.

Twee analyse methodes werden toegepast: De Cognitive Walkthrough (CW) uitgevoerd door twee medische informatiekundige en de Think Aloud (TA) uitgevoerd met behulp van eindgebruikers. Vier personen werkte mee aan de TA sessies: Een systeem expert, een domein expert en twee afdelingsartsen van de hematologie en oncologie.

Na de TA sessies werden deze personen gevraagd een vragenlijst in te vullen. Deze gegevens zijn gebruikt tijdens de analyse om te zien hoe de tevredenheid van de systeemgebruikers zich verhoudt tot de resultaten van de bruikbaarheids analyse.

In totaal zijn er 31 bruikbaarheids problemen ontdenkt via de CW evaluatie methode. De TA evaluatie methode vond nog eens 14 bruikbaarheids problemen welke niet eerder ontdekt waren met de CW. Zeker 14 van dit totaal aantal geïdentificeerde bruikbaarheids problemen (45) kunnen leiden tot ernstige fouten zoals het voorschrijven van verkeerde medicatie, aanpassen van verkeerde medicatie en medicatie over-, en onderdosering.

De deelnemers waren unaniem in het oordeel dat Medicator zeer rigide is, moeilijk te leren en daardoor erg frustrerend in het gebruik. Verder biedt Medicator weinig sturing d.m.v. helpberichten en de enkele berichten die getoond worden zijn vaak onduidelijk of niet geheel juist.

Deze studie toont, met de uitkomsten van de vragenlijsten en de geïdentificeerde bruikbaarheids problemen, dat een herziening van het huidige Medicator systeem sterk aan te raden is. Verder suggereert de studie dat het uitvoeren van een TA alsmede een CW een positief resultaat heeft op de hoeveelheid geïdentificeerde bruikbaarheids problemen.

trefwoorden: CPOE, Medicator, bruikbaarheids evaluatie, medicatie fouten

General introduction

1.1. Introduction

One of the major impacts of information management technology on modern society is the way it is changing the manner and ease in which we communicate. Computer-based, direct physician order entry (CPOE) which stands for the process of electronic entry of physician instructions for the treatment of patients under his or her care, has been put forth as a potential way to improve communication within the health care process (e.g. entering medication orders directly into the computer) and ultimately for improving patient outcomes^{[1].}

This thesis describes the evaluation study which was performed in the period of September '07 till June '08. The study focuses on the Medicator CPOE which has been introduced in the AMC hospital in 2005. From conversation with end-users and the evaluation documents (vision documents) of the implementation of Medicator it was clear that the Medicator CPOE suffers from usability flaws which could potentially lead to medication errors. From conversations with specialists of the hematology department it was clear that due to the complicated medication prescription process it takes lots of time to order medication overdoses and drug-drug interactions. Therefore the ICT and TIPP decided to order a usability evaluation of the Study was to evaluate the usability of the Medicator CPOE system in ordering cytostatics and the influence of its design aspects on usability and potential for medication errors. The ultimate goal was to write an evidence based report which could be used as input for the optimization of the Medicator CPOE in the AMC hospital.

1.2. Research questions

The research questions we posed in this study are:

- 1. What is the role of CPOE in healthcare and what are the potential benefits and potential negative side-effects of a CPOE implementation?
- 2. What kind of usability issues are related to CPOE in general and what methods exist/ are suitable for a usability evaluation?

- 3. To what extent does the MEDICATOR CPOE system for ordering drugs support the (cognitive) task behavior of their end-users?
- 4. What is the potential effect on type and frequency of errors?
- 5. To what extent do the various usability methods differ in their potential for detecting usability flaws?

1.3. Outline of thesis

The research questions were answered in different stages of the scientific research project (SRP). We can therefore roughly divide the SRP into four different stages. Figure 1 shows an activity diagram of the SRP setup with all processes together with their inputs and outputs and how these processes are interrelated.

To be able to answer the first two research questions literature was to be studied. The next two chapters will describe the results of two literature studies in which chapter two provides a description of "the role of CPOE in healthcare and the potential benefits and potential negative side-effects of a CPOE implementation" and chapter three describes "usability issues related to CPOE and methods suitable for evaluation of usability".

In the second stage of the SRP the Cognitive Walkthrough (CW) was to be conducted. In order to perform the CW a number of activities were to be performed:

A mobile test environment was required for testing the system and was also used by the two usability experts to get acquainted with the Medicator CPOE. A description of the Medicator CPOE is given in Chapter 4. Second, patient scenario's were to be developed which were used in performing the CW and in a later stage of the SRP, the Think Aloud (TA). Before performing the CW the scenario's were to be validated by a hematological expert. Chapter five provides a description of the methods used, the setup in which the methods were used as well as the materials used.

The third stage of the SPR started by preparing instructions for the end-users that were asked to perform the TA. Two groups of end-users were created: A first group of expert users which performed the TA first and a second group of end-users new to the system. After performing the TA, users were asked to fill in a questionnaire concerning there

satisfaction about the Medicator CPOE. Chapter six of this thesis provides the results of the CW and the TA and the questionnaires.

The last stage of the SRP was the analysis of all the collected data in order to find answers to the remaining research questions. Chapter seven contains the discussion in which the results and answers are described.



Figure 1. - Activity diagram

1.3. References

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Chapter 2

Computer-based Physician Order Entry Systems for Medication Ordering in Healthcare

A review of the potential benefits and potential negative side-effects of implementing CPOE systems

2.1 Computer-based physician order entry: The state of the art

CPOE is defined as a process which allows a person (physician) with the licensure and privileges to do so to use a computer to directly enter medical orders. CPOE holds the potential for improving the order communication process and ultimately for improving patient outcomes ^{[2].} Because of this potential, implementation of CPOE seems inevitable and many healthcare institutions world wide have tried to implement a CPOE system in their organization. All these institutions faced difficulties with smooth implementation and organizational upheaval control during the organizational transformation resulting from CPOE implementation. Successful implementation of CPOE systems can be achieved by recognizing and skillfully managing the complexity of the implementation process of CPOE systems ^{[3].} Literature however shows that a significant part of healthcare institutions that have tried to implement CPOE over the past 20 years have failed ^{[1, 4, 5].}

2.2. Reasons for implementing CPOE

From literature it is evident that there are many reasons for implementing CPOE in order to improve the medication ordering process. Profits that can be gained by implementing CPOE add up to an impressive list of assumed improvements ^{[1, 6, 7].}

2.2.1. Ambiguities caused by illegibility of hand-written orders

Rob Shulman et. al ^[8] proved in his study that over 56% of medication errors occur during the prescribing stage due to the misinterpretation of hand-written orders. Ordering medication using CPOE has proven to eliminate any ambiguities caused by the illegibility of hand-written orders by providing methods for standardization of data entry, the use of approved medication names, legibility and full audit trail of actions performed by the physicians ^{[1, 8].}

2.2.2. Enhancement of communication

Sittig et al. found that communication between physicians and other departments like pharmacy or nursing wards is advanced by implementing CPOE for medication ordering: When medication is ordered by a physician using CPOE, the system handles the rest of the communication to the nursing staff and laboratory. Furthermore the CPOE system is also able to generate related orders automatically without intervention of clinicians.

Also, CPOE systems offering decision support are able to reduce the number of redundant tests ordered by means of communicating previous test results to clinicians before they intend to submit new tests ^{[1].}

2.2.3. Reduction of total healthcare cost

Costs of implementing CPOE in healthcare institutions are strongly depended on the size of the institution and the existing hardware and software systems ^{[9].} Adoption of CPOE may be financially infeasible for smaller healthcare institutions with absence of increases in hospital payments or ongoing subsidies for third parties ^{[10].} Healthcare institutions which are big enough to bare the financial weight of implementing CPOE can eventually save millions a year due to optimization of several processes ^[11]:

During the medication ordering process the CPOE system can supply the physician with information about his medication ordering behavior in relation to the hospital's standards: Information can be giving about alternative medication from the hospital's formulary, which contains medication that is equivalent to other medication the physician tried to order but costs less. By instructing physicians which medication to order, money can be saved. Furthermore the reduction of medication errors through real-time decision support and the elimination of ambiguities caused by illegibility of hand-written orders save money because wrong medication most of the time implies more patient care ^{[1].}

2.2.4. Increasing patient safety and decreasing medication errors

Medications are powerful and commonly used in modern therapies yielding many benefits to patients. While the medication can improve patient's health it can also cause considerable harm. The process of prescribing medication is complex and error-prone, especially if a prescribing physician fails to consider relevant patient characteristics. Errors in the prescribing process can cause many preventable medication conflicts. For

example, renal insufficiency and advanced patient age call for lower than usual [12]. medication lethal doses. and drug-drug interactions are sometimes CPOE systems, especially with clinical decision support modules operate in real-time. This makes these CPOE systems perfectly suitable for generating response messages to the physician about medication prescriptions for a certain patient. When prescribing medication using a CPOE system with a decision support module, the CPOE system will supply the physician with a warning message if a hazardous situation arises. These warning messages given by the CPOE system can contain information about the drug dosage, medication history and possible drug-drug interaction^{[13].} If the correct action is taken upon these error messages by a physician, reliability, quality, and safety of medication use is enhanced ^{[14].} Bates et al. also proved in their study that implementing CPOE can reduce medication errors up to 55%^{[15].} Furthermore a review study on evaluation studies of CPOE implementations performed by Aarts, Ash and Berg in 2006 showed that patient outcomes can be improved in terms of reduction in length of stay ^{[16].}

2.3. Possible downsides of the described benefits

In literature extensive lists of benefits of CPOE implementations can be found. This section describes only the top few to be gained from implementing CPOE. But from literature it's also evident that all of these possible benefits can have its downsides too.

2.3.1. Elimination of ambiguities caused by illegibility of hand-written orders

Elimination of ambiguities caused by illegibility of hand-written orders is one of the most obvious and straightforward advantages from implementing a CPOE system to support the medication ordering process. The only downside mentioned in the literature is that while data entry is standardized, data entry is also limited ^{[1, 17].} The physician is not able to enter free text anymore or use abbreviations which are not recognized by the CPOE system. This forces physicians to alter their normal working pattern which could lead to negative emotions and abandonment of the system.

2.3.2. Decrease of communication

CPOE systems often alter traditional communication patterns dramatically among care providers, ancillary services and clinical departments. Whereas before interpersonal conversations were the basis regarding the provision of care, the introduction of CPOE changed this basis.

Beuscart et al. looked at the impact of CPOE on doctor-nurse cooperation for the medication ordering and administration process and found that due to CPOE nurses did no longer participate in the decision making phase of the ordering process. The cooperation between the nurse and the physician was altered into an asynchronous and sequential cooperation in action, in which the coordination in the medication ordering and administration process was supported mainly by the CPOE system. Because of this central coordination, the communication between nurses and physicians lacked of face to face information exchange which resulted in misinterpretation of orders ^{[18].}

Dijkstra ^[19] pointed out that CPOE provides an "illusion of communication" because it promotes the belief that entry of an order into the system ensures that the right people will see the order and act accordingly upon it. This belief can be unfound and can potentially lead to dangerous situations especially with emergency orders because their timely execution is depended on interpersonal communication. Hence there is often redundancy in communicating information because clinicians are uncertain of the speed in which orders are being handled through the use of a CPOE system. (E.g. calling in emergency orders as well as computerized ordering entry to make sure action is taken timely upon). Indeed literature proves that physicians, nurses and other providers report that CPOE can cause an unsatisfactory reduction of face-to-face communication regarding patient care^{[20].}

2.3.3. CPOE investments

CPOE is said to decrease total healthcare costs by instructing physicians how to use CPOE systems and streamlining their workflows, medication errors are reduced and ambiguities caused by illegibility of hand-written are eliminated which saves money. The downside is that the implementation of CPOE is very expensive.

Kuperman and Gibson considered three major areas of costs associated with implementing CPOE in healthcare institutions ^[24]: the technical costs, which include hardware, software, technical support and integration with existing systems, the costs of process- and workflow redesign and the costs of implementation and support. The total costs of these areas are so high that only the larger healthcare institutions will be capable

of compensating for these investments with the benefits CPOE offers. Therefore it is very important to conduct a cost and benefit evaluation before starting implementation of CPOE systems in healthcare.

2.3.4. Increasing patient safety and decreasing medication errors

If CPOE for ordering medication is correctly implemented medication errors due to errors in the ordering process can be decreased and sometimes even reduced to almost zero ^{[21].} If the physician orders medication that could lead to an Adverse Drug Event (ADE) the decision support module if present, will provide the physician with a warning and information about alternative medication options. If action is taken correctly upon these warnings, patient safety can be increased. The downside is that when ordering medication through CPOE becomes part of the daily working routine, physicians can get accustomed to the warnings the system generates. This habituation of warning messages to physicians can result in decreased attention for the content of the messages or even in automatically overriding the message^{[14, 22].} At this point the decision support function of the CPOE system can lose parts of the positive impact it has on avoiding medication errors.

Despite the high costs of implementing CPOE, CPOE seems a perfect way of standardizing certain work flow and communication patterns but from literature it becomes clear that this standardization process can also lead to an increased likelihood of errors due to miscommunication, delayed initiation and execution of orders, and fewer team-wide discussions regarding planning and coordination of medication ordering ^{[23].} Furthermore the habituation of warning messages can result in a decrease of the positive impact the system has on avoiding medication errors.

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Chapter 3

Usability evaluation of CPOE systems in healthcare

A review of usability issues related to CPOE and methods for evaluating usability

3.1. CPOE systems in healthcare

As the adoption of information technology in healthcare has increased, so too has the demand that these systems become more adapted to the physicians and nurses environments to make access and management of information easier ^{[1].} Computerized Physician Order Entry (CPOE) systems have become a primary focus of time and monetary investment in the healthcare arena.

The success or failure of a CPOE system is however highly dependent on the acceptance by its users which is in its turn related to user satisfaction. CPOE systems are often hard to learn to use and they often lead to user frustrations and abandonment ^{[2].} As it seems the implementation and adoption of a CPOE system is often complicated due to changes in the interaction with such a new system and guidance in the use of the new system offered by the system itself ^{[3].} In medication ordering CPOE systems, cumbersome interfaces may slow end-users down but above all may introduce a new class of errors.

These errors occur because end-users often interact with the system in a different way than the developers had meant for. This can lead to dangerous situations resulting in medical errors due to usability flaws in the system interfaces design ^{[4].} So the recognition is growing that this new class of errors introduced by implementing CPOE systems is neither solely attributable to lapses in human performance nor to flawed technology, but developed as a product of their interaction.

3.2. Usability errors due to CPOE

CPOE systems are widely regarded as the technical solution to medication ordering errors which is the largest identified source of preventable hospital medical error ^{[5].} Recent studies however focused on the emergence of CPOE related types of medication errors:

Horsky et al. found that medication errors are related to the confluence of several factors. Errors made in the medication dosing process by physicians who did not receive adequate training in prescribing medication using CPOE, the absence of automated safeguards in the system that help prevent these errors during the medication ordering process, and uncertainty on the part of physicians about how to manage unusual ordering scenarios are examples of the factors influencing the medication process ^{[6].} Horsky et al. also found that screen layout and visual representation of information may critically affect the way it is interpreted by users: the study showed that some medications orders were falsely identified as erroneous and that some real erroneous medication orders were interpreted as correct. This was a direct result of the manner in which information was represented on the screen.

Koppel et al. performed a study with the objective to identify and quantify the role of CPOE in facilitating prescription error risks ^{[7].} They found that a widely used CPOE system facilitated 22 types of medication error risks where several of the errors occurred weekly or more. All 22 types of medication error risks can be divided in two groups:

"Information errors generated by fragmentation of data" and the "hospital's information systems and their human-machine interface flaws reflecting machine rules that do not correspond to end-users' work organization or usual behaviors". There are several examples of information errors generated by fragmentation of data:

When physicians order medication using a CPOE system the antibiotic renewal notices can be missed because the notices are placed on the paper charts instead of in the CPOE system leading to a delayed medication continuation which results in gaps in the patient's therapy.

Procedures and certain tests are often accompanied by medication treatments. If procedures are canceled, there is no system linked to the medication ordering module that automatically cancels the medication prescription that has become obsolete. This means that medication is still being ordered and prepared for a patient while the test or procedure that required the medication has been canceled.

The CPOE system provided feedback on drug allergies after medication has been ordered by a physician. Furthermore clinicians appeared to miss allergy notices due to rapid scrolling and haste during the ordering process because of the time pressure to order many different medication for many patients.

Examples of human-machine interface flaws reflecting machine rules that do not correspond to work organization or usual behaviors are:

In the particular CPOE system investigated, the patient's medication was seldom synthesized on one screen. The patient information was strongly fragmented and up to 20 screens were needed to see all of the patient's medication increasing the likelihood of selecting a wrong medication.

Also the names of patients and drugs were represented closely together on the screen, the system font was small and patient names were not visible on all screens increasing the possibility of selecting the wrong patient or medication.

Furthermore different CPOE system screens offered different colors and typefaces for the same information, enhancing misinterpretations as physicians switch among screens which also led to errors in selecting patient names or drugs.

In 2007, Peute and Jaspers conducted a usability assessment of an emerging CPOE system for computer-supported ordering of laboratory tests. They conducted a cognitive walkthrough where after the think aloud method was used to verify the outcomes. Their analyses revealed a total of 33 usability problems and they found that interface design flaws were, among other things, related to misallocation of buttons on the screen, incomprehensibility of button labels and feedback containing no relevant information to the user about the cause of errors made and consequences of a user's action^{[8].} These interface design flaws led to inefficient ordering behavior due to the lack of information concerning the cause and effects of the action taken in error messages. Furthermore tests were wrongly selected or not selected at all because of differences in terminology used in paper forms and system terminology automatically abstracted from the resources catalogue of the Laboratory Hospital Information System.

Beuscart et al. conducted a usability assessment of the CPOE system which showed several problems^[9]:

Due to a suboptimal graphical representation of standardized schedules only 8 items of a medication list which consisted of 22 items could be seen. No indication was given by the CPOE system that scrolling the window was necessary to view other items and therefore related items were not noticed by clinicians. Beuscart el al. also reported on problems with the use of colors in the user interface. By using colors for highlighting which are by

usual convention associated with exclusion of options, several options were overlooked by clinicians. (E.g. available times and dates were highlighted in grey, resulting in a highly inefficient patient planning because the grey was associated with the state "not available"). A further problem concerned the user's control of the application. In several cases where global pre-set schedules were used by clinicians, exact times were automatically registered by the CPOE system. This led to confusion with the nurses who had no means of determining the initial provider's intentions as to whether these specific times were critical, or rather whether the physicians were intended them to be approximate or flexible.

3.3. Usability of CPOE systems in healthcare

In order to optimally support physicians in the medication ordering process, CPOE systems must support clinical workflows and have user interfaces that are easy to understand and navigate. A CPOE system's usability should be more at the focus if we want CPOE systems to be adopted by its users and their implementation to be successful. The International Standards Organization (ISO) defined usability as the effectiveness and efficiency related to user satisfaction with which users can achieve specific sets of tasks in a particular environment ^{[10].} The ease with which system functions can be learned and memorized influences user satisfaction and is related to the frequency of errors that users make in performing tasks while using CPOE in the medication ordering process.

Good interface design requires a thorough understanding of working practices in the context of the task that will be computer-supported to adequately represent these practices in the user interface design ^{[11].} From literature review it is clear that the evaluation of these work practices can provide detailed insight into potential usability flaws in a CPOE system's design that can be used in redesigning for improving its usability ^{[7, 8, 9, 12].} There are two types of evaluation assessments: summative assessment which is often carried out towards the end of a project and focuses on grading the functionalities of the system, and second the formative assessment which is generally carried out throughout a project and focuses on the assessment for learning, providing feedback to the developers for optimization of the system. Several studies used a range of summative approaches to evaluate a healthcare system on it's usability in order to assess

how a final system meets a set of pre-defined goals regarding issues of functionality, safety, and impact on outcome measures such as cost of health care and work efficiency^{[13, 14, 15].} A formative evaluation method can however better be used in the iterative evaluation of systems during their development. The objective is to improve the design of information systems as well as ensuring that the process of design of healthcare systems leads to effective systems ^{[16].}

From the literature reviewed it's evident that there are several highly effective usability evaluation methods which can be used:

3.3.1. Heuristic evaluation

The heuristic evaluation is one of the most common and most popular of usability evaluation methods. In a heuristic evaluation, a small set of evaluators inspects a system and evaluates its interface using a list of recognized usability principles- the heuristics. Typically, these heuristics are general principles, which refer to common properties of usable systems. Heuristic evaluation is in its most common form based on the following set of usability principles: 1) use simple and natural dialogue, 2) speak the user's language, 3) minimize memory load, 4) be consistent, 5) provide feedback, 6) provide clearly marked exits, 7) provide shortcuts, 8) provide good error messages, 9) prevent errors, and 10) provide help and documentation ^{[17].}

During a heuristic evaluation, the evaluator steps through the interface twice. Once to get acquainted with the interface, navigation structure and the scope of the system. The second time focusing on the screen lay out and interaction structure in more detail, evaluating their design and implementation against the pre-defined heuristics resulting in a list of usability flaws with reference to the heuristic violated and an estimation of the severity of the error.

Once all evaluations have been conducted, the outcomes of the different evaluators are compared and compiled in a report summarizing the findings. This report describes the usability flaws in the context of the heuristics violated and assists system designers in revising the design in accordance to what is prescribed by the heuristics. Heuristic evaluation is an efficient usability evaluation method with a high benefit-cost ratio. The downside of the heuristic evaluation is that the evaluators inspecting the system are often not experts. Therefore the amount of usability problems found is directly dependent of the expertise level of the evaluators. Furthermore the heuristic evaluations is a powerful tool for detecting low priority usability problems but less effective in detecting sever and potentially dangerous usability problems.

3.3.2. Cognitive Walkthrough

The cognitive walkthrough method is a design evaluation methodology which aims to provide a tool for assessing the usability of a system. The cognitive walkthrough differs form the heuristic evaluation in that the cognitive walkthrough is highly structured and explicitly guided by user's tasks. During the usability assessment by a cognitive walkthrough causes are assigned to usability problems early in the design process. The cognitive walkthrough is partially based on Norman's theory of action. The theory specifies a model of cyclical interaction in which the user recognizes a state of the system, initiates a goal, brings about a change in the system through action (e.g., a new screen display), and evaluates the new state, which subsequently leads to the next iteration of this action-and-reaction cycle ^{[18].} In practice the cognitive walkthrough is performed by an analyst, preferably an usability expert, evaluating a user interface by analyzing the cognitive processes required to accomplish a task that users would typically carry out by using the computer: The analyst performs a hand simulation of the cognitive processes of a potential end-user who would successfully execute an action sequence to complete a task. In executing the cognitive walkthrough, for each action involved in accomplishing a certain task, the analyst tries to answer four questions. These questions are related to the user's intent to achieve the correct effect, the user's awareness of the availability of the correct action, the user's association of the correct action with the desired effect and the user's awareness after performing the correct action that progress is made towards accomplishing the goal set ^{[8].} If answers to all four questions are positive, the execution of the specified action is found to be without usability flaws. Hence the fact that if one of the questions is answered negatively, the specified action is not free of usability problems [19].

From the reviewed literature on usability evaluation methods it's clear that the cognitive walkthrough evaluation method is less expensive than other usability evaluation methods but requires more expertise than the heuristic evaluation and is also more time consuming. It's also clear that although the cognitive walkthrough reveals much less

usability problems in comparison to the heuristic evaluation, it does reveal proportionally more severe usability problems than less severe cosmetic problems. Furthermore the cognitive walkthrough gives the designers the ability to anticipate some learnability problems before an implementation or even a mock-up of the design is available.

3.3.3. Think aloud end-user testing

The Think Aloud method belongs to the verbal report methods and is often used to gather information in usability testing of computer systems with potential end-users. this method traditionally had applications in psychological and educational research on cognitive processes, but also for the knowledge acquisition in the context of building knowledge base computer systems. Analyzing the usability of a CPOE system via thinking aloud generates direct data on the ongoing thought processes during task performance which makes the Think Aloud methods a very direct method to gain insight in the way humans solve problems^{[20].} Think Aloud testing starts with a usability session in which a minimum of four end-users are involved that "walk through" the system or prototype interface according to a predetermined set of tasks while verbalizing their thoughts. This method is based on the assumption that verbal behavior is a type of recordable behavior that can be analyzed like any other behavior^{[21, 22].} Very important and crucial for generating valid usability data using the think aloud method is the identification and selection of a representative sample of the end-users. The subject sample should consist of persons whom are representative of those end-users who will actually use the system in the future.

From the reviewed literature on usability evaluation methods it's evident that although very expensive in resources needed and the requirement of at least a running prototype, user testing is the best way to find recurring severe usability problems related to users' tasks and experience and is an effective means of identifying serious usability problems and avoiding low priority problems.

After reviewing the different evaluation methods the choice was made to use the CW and the TA for the evaluation of the Medicator CPOE. The TA was chosen for the above mentioned reason that end-user testing is the best way to find recurring usability problems related to users' tasks and experience and is an effective means of identifying serious usability problems and avoiding low priority problems.

The CW was chosen above the heuristic evaluation because although the heuristic evaluation is very powerful in discovering errors in the system, these errors found are mainly low level errors. The CW walkthrough is performed by usability experts using test scenario's to guide them through the system in order to exploit all system functionalities and although the CW discovers much less problems than the heuristic evaluation, the usability problems that are discovered are often of a more severe nature and potentially dangerous.

3.4 References

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Description of the MEDICATOR CPOE

4.1 Medicator CPOE system

In the AMC hospital, which is a 1050-bed teaching hospital, the implementation of the CPOE system Medicator was successfully completed in July 2001. Thereby the AMC was the first centre in the Netherlands using such a hospital wide medication ordering system. At the start of the implementation in 1997 only a character-based version of the program, named Medicatie (Hiscom BV, Leiden, The Netherlands), was available. Currently, the AMC uses a Windows based version of this program, called Medicator, that was introduced in 2000. This CPOE system consists of several components. A locally installed Windows client communicates with the central hospital information system and retrieves its data from several databases. Drug identification and medication control is performed based on the pharmacy drug database together and on the national drug database (the Z-index of the Royal Dutch Association of Pharmacists (KNMP)), which contains data on overdose, interactions and (pseudo) double medication. This database is updated every month. Medicator generates safety alerts concerning overdose, (pseudo)duplicate medication and drug-drug interactions, based on the data in the Zindex. Links are programmed to relevant drug information sources such as the (paediatric) drug formulary, the antibiotic drug formulary, drug handbooks, acute care protocols, therapeutic drug monitoring protocols, Micromedex, PubMed, etc so that the information in the safety alerts is always up to date according the latest standards.

Medication can be selected from the local department stock (default) or the pharmacy drug database. Standardized prescriptions (a single medication order with fixed dose, route, frequency, duration etc.) and medication protocols (several prescriptions belonging to one pharmacotherapeutic protocol) can be programmed within the Medicator CPOE. Standardized prescriptions and protocols can be linked to a ward and can be subdivided into groups (e.g., lung cancer) and subgroups (e.g., specific type of lung cancer). Within protocols a link to patient specific the relevant laboratory values can be programmed.

The physician enters the prescription in Medicator. A patient can be selected in two ways. By selecting a ward (pull-down menu) followed by the patient name, or by entering the patient's name and either patient number or date of birth. After a patient is selected, the current medication of that patient is presented and several buttons are shown. New medication can be started, current medication can be changed, stopped or cancelled (See figure 4.2). After clicking the 'nieuw' button (new medication order) several options are available of which the most important are: selection of a drug on drug name (brand or generic name), selection of a protocol or standard medication order, entering of a 'free text' medication order. If the option to select a new medication is selected, the drug can be selected from the local stock on the ward or the database of the pharmacy stock. The medication order is finished by clicking the 'OK' button. The system then checks for interactions, (pseudo) duplicate medications and overdose. An explanatory text is shown, which helps the physician to decide whether to accept or ignore the alert. Ignored safety alerts are seen by the consulting pharmacist the next morning.

The 'Standard medication' is a useful option for drugs that are prescribed frequently and are always ordered in the same dosage and with the same duration. In that case all fields (frequency, dose, time, etc) are filled in, in advance, with default values. If the physician selects a medication protocol for a certain treatment, Medicator shows the programmed prescriptions related to this protocol one-by-one and, if needed, calculates the dose based on the height and weight of the patient. If necessary, the dose of every prescription can be adapted to the condition of the patient. Every single medication order of the protocol is confirmed with the 'OK' button, resulting in medication control. When exiting Medicator, cardex labels are printed ^{[1].}

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Figure 4.1- example of an Medicator screen

4.2 References

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Methods & materials

5.1 Setting

The Medicator CPOE was tested at the hematology and oncology department of the AMC hospital. This department focus is on diseases of blood cells and blood forming organs and performs clinical activities like bone marrow transplantation, stem cell transplantation, outpatient cytostatic management, blood transfusion and hemaferese treatments. Chemotherapy is a very important component of cancer treatment. Due to the intensity of this therapy an error in calculating the dosage of cytostatic drugs or discontinuation of cytostatic drug therapy would have severe consequences for the patient. Furthermore scheduling cytostatic drug therapy is a complex process and therefore it is very important that the CPOE system used for prescribing cytostatic drugs supports and guides the physician in doing so and checks if errors in these processes are being made. Because of the importance and complexity of the drug therapies prescribed by the hematology department all scenario's developed for testing the Medicator CPOE concerned chemotherapy.

5.2 Participants

Residents from the hematology and oncology department of the AMC were asked to cooperate in the study of which two accepted to participate. The residents were ask to cooperate because they are responsible for the biggest portion of medication ordered in the hematology and oncology departments. The fact that the clinical scenario was based on hematology patients posed no problems because oncology physicians work in a similar field of medicine and therefore have the domain knowledge to prescribe these kinds of therapies. Besides residents of hematology and oncology, two experts were asked to perform a Think Aloud: One system expert whose responsibility was the development of the clinical scenario to be used in the TA and one domain expert. The system expert works with the Medicator CPOE daily and is responsible for the implementation of new drug protocols in the system. Therefore he has extensive knowledge of the Medicator system and of the optimal way to interact with the system. The domain expert is head of the hematology department and therefore has extensive knowledge about treatments and medication protocols that are to be prescribed.

5.3 Materials

5.3.1. Clinical scenario

A clinical scenario, based on a real life patient case, was developed (see appendix A). The scenario was designed so that it could be used for the CW as well as the TA in order to compare the results of the CW and the TA as posed in research question five.

The scenario was based on a chemotherapy protocol used at the hematology department in the AMC. The protocol used to develop the patient scenario was the Hovon 79 study protocol. The Hovon 79 protocol was chosen because of the complexity of this protocol and the fact that it covers all important system functionalities of Medicator which endusers encounter in daily use.

The Hovon 79 study protocol is a protocol in which leukemia patients are admitted for treatment. This protocol always starts by admitting a patient into an "induction phase". The patient receives medication for a short period and is send home. After two weeks the patient returns to the hospital and the patient's vital signs are measured, e.g. Blood pressure, hemoglobin level. Based on these results a patient is placed into one of the consolidation phases of chemotherapy of the Hovon 79 protocol: low risk, medium risk and high risk consolidation phase. Patients who are admitted to a higher risk phase need to receive less medication then patients in lower risk phases.

To ensure that the scenario covered all possible facets of the Medicator system, a system expert working at the hospitals pharmacy was asked to develop this scenario. This expert is responsible for implementing all medication protocols in the Medicator CPOE and therefore very familiar with the CPOE system. To prevent interpretation problems by the end-users which would perform the TA, the scenario was also reviewed by a hematology expert clinician.

5.3.2. Morae

Morae is a software application for usability testing to assess how usable certain software is, for pinpointing specific problem areas, and for easily sharing important information with end-users and software developers.

Morae's effectiveness lies in the fact that it reduces the amount of work required to conduct usability testing, not only at setup, but also during the data logging, analysis and

presentation stages. Morae enables the recording of user experiences, observation and logging of important moments, the analysis and visualization of results.

The Morae software package consist of three programs: the Manager, recorder and the observer. These three programs together provide the ability to capture video, audio and screen sequences in one project file which ensures that information about physical, temporal and social data (how the participants behave during the TA test) can be linked to the verbalized thought processes of the user. Furthermore it's possible to mark important interaction moments after which statistical analyses can be conducted.



figure 5.3.2 example of a Morae manager screen

5.4 Methods

5.4.1. Cognitive Walkthrough

Two researchers from the field of medical informatics performed the CW of the Medicator CPOE according to the description of the CW inspection method^{[1].}

These two evaluators stepped through the system using a clinical scenario for prescribing consolidation phase of chemotherapy for a leukemia patient once using protocol functions of Medicator and once without protocol functions. All possible action sequences to accomplish this specific task and system responses after execution of the actions were described in detail, resulting in a framework of user action sequences and system reactions.

Every execution of an action and resulting system state were analyzed according to the 4 specific "guiding" questions of the CW. For each possible user action and system response, the state of the system and the initial goal of the user in performing the action was described. Potential usability and learnability problems were identified by answering the 4 CW questions for each user action and system response set. These analyses resulted in a list of user interaction problems associated with the execution of the specific tasks in the system, to potentially be encountered by end-users in real practice. All user-interaction problems, which were identified in the CW and described in the list, were coded. This led to a coding scheme of potential user interaction problems with the Medicator CPOE. The framework of user action sequences and system response developed for conducting the CW was also used afterwards to analyze and code the usability problems the end-users actually encountered by analyzing the video recordings of the end-users in interaction with the Medicator CPOE.

5.4.2. Think Aloud

The participating subjects were asked to perform the clinical scenario simulating medication-ordering tasks supported by the Medicator CPOE. In accordance with the TA method, before performing the actual tasks, the users were instructed to verbalize their thoughts while performing the tasks ^{[2].} To let the end-users practice with thinking aloud, they were given a mathematical problem which they had to solve step by step while verbalization their thoughts.

The end-user testing of the Medicator CPOE took place in a test environment for which a laptop running Windows XP with 17' inch screen was used with external keyboard, mouse and also the usability evaluation software from Morae was installed. The laptop was equipped with a internal camera and microphone so every verbal and non-verbal behavior of the end-user could be captured.

The testing lasted approximately 40 to 70 minutes, depending on the experience of the end-user. The users were asked to verbalized their thoughts during task performance. During testing subjects were reminded to keep thinking aloud if the stopped talking, according to Ericsson's description of how to conduct a proper TA ^{[3].} If system errors occurred during testing that were not caused by actions of the subjects, the evaluator would interrupt and correct the problem. The subjects could also decide to stop a (sub)task if they felt they were not able to complete the task. Since Morae software runs as a process in the background, users never noticed they were being recorded in any way.

5.4.3 Questionnaire

After all task scenarios were performed, the users were asked to fill out a short survey concerning the subjects' personal information (age, education, function, overall computer experience, system usages, etc). This information was used during the analysis to group subject into clusters, to compare for example the experienced users with novice users. The users were also given a questionnaire. The questionnaire can be found in Appendix B and comprised of 27 questions divided over five topics:

- 1) Overall reaction to the software,
- 2) Visual presentation on screen,
- 3) Terminology and system information,
- 4) Learnability of the system,
- 5) System capabilities.

The questions of all five topics were presented as a 10-point Likert scale(0-9 with 0 very difficult and 9 very easy) which gives a global insight into each subject's subjective assessment of the CPOE system's usability. Besides the posed questions the questionnaire also gave the respondents the possibility to sum up additional positive/negative points which might not have been revealed by the questions. During the analyses this information was used to assess the physician's subjective assessment of the TA sessions.

After all TA sessions were performed by the participants the recordings were analyzed by two usability experts. At first both experts analyzed the parts of two TA session (ordering two types of medication by hand and ordering medication first phase by protocol) separately and independently developed a coding scheme of the encountered usability problems. Afterward these two coding schemes were compared to evaluate the similarity in the coding of usability problems and interobserver agreement was calculated. This resulted in a validated coding scheme which was used for the analysis of the remaining recordings of the TA sessions.

5.5 References

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Results

6.1 Results

In this chapter, we present three sets of results: the results of the CW, the results of the TA and the results of the user questionnaire for the evaluation of the user satisfaction with the Medicator system. The CW inspection of the Medicator CPOE identified potential usability problems related to this system. The TA end-user testing focused on the number of actual encounters of the usability problems we identified with the CW method, on additional usability problems revealed only by TA and on the effects of the usability problems on the thinking process and working patterns of end-users leading to errors in prescribing chemotherapies.

6.2 Cognitive Walkthrough

The CW identified 3 tasks, 3 subtasks and 34 associated actions to accomplish the admittance of a patient in the Hovon 79 protocol with the use of a specific protocol function. The admission of a patient in the Hovon79 protocol without using the protocol function of Medicator required 3 tasks, 2 subtasks and 43 actions of the user, some of them more then once . The 3 tasks included: (A) log into the system, (B) select a patient, (C) prescribe consolidation phase. The subtasks included: (1) enter a medication type 1, (2) enter a medication type 2, (3) enter a medication type 3. Table 6.2.1 shows the entire CW walkthrough scheme as identified by two evaluators stepping through the system:

Goal A: log into the system

- a. Double click "Isoft-medicatie" (user action)
- **b.** Enter "User identificatie nr" + "wachtwoord" (user action)
- **c.** Click button "ok" (user action)
 - Screen "Medicatie Registratie klinisch-geen patient" is shown. This screen is inactive. (system response) and
 - Screen "selecteren patient" pops up on the first screen (system response)

Goal B: selecting a patient

- a. Click tabblad "Indev. Pat." (user action)
- **b.** Search for the patient entering patient information (user action)
 - o Patient number
 - o Date of birth
 - o Gender
 - o Name
- **c.** Click button "zoeken" (user action)
 - Patient information is shown in this screen (system response)
- d. Check patient data (user action)
- e. Select correct patient record (user action)
 - Patient information is highlighted (system response)
- **f.** Click button "selecteren" (user action)

Screen"selecteren patient" is disappeared and Screen "patient dossier" becomes active (system response) Goal C: Prescribing consolidation schema C-1: Entering medication data using protocols *C*-1-1: find the the list of protocols **a.** (1) Click menu button "protocollen" (user action) **b.** (2) Click button "MO nieuw" (user action) c. (3) Click menubutton "medicatie-opdrachten" (useraction) **d.** Click submenubutton "registreren" (user action) e. Click subsubmenubutton "nieuw.." (user action) **f.** (4) Click men button "Nieuwe opdracht" (under the menues) (user action) Screen "selecteren verzorgingseenheid" is shown (system response) 0 g. Click one of the options "Klinisch" or "poliKlinisch" (user action) **h.** Type the code of the ward or choose from the list of wards (user action) Click button "OK" (user action) i. Screen "nieuwe medicatie opdrachten" is shown (system response) 0 *C-1-2: find the appropriate protocol* **a.** Select tick box "prorocollen en groepen ..." (user action) List of protocols is shown in the pane below options and the first one is highlighted 0 (system response) **b.** Select suitable protocol (user action) Click button "niveau down" (user action) c. A list of Selected protocols is shown (system response) 0 **d.** Double click related protocol or "Niveau down" (user action) 0 A list of protocol 79 is shown for "induction <70", and "consolidation, low, intermediate, and high risk" labeling 1, 2, and 3. "inductie AIDA" is highlighted. (system response) e. Click "OK" (user action) Screen "gegevens van protocol" is shown including a list of medications and days. 0 (system response) C-1-3: Order medications using protocol **a.** Select start date for protocol (user action) Select start time (user action) b. **c.** Click "ok" (user action) Screen "dosis berekening" for medication type 1 is shown (system response) 0 **d.** Check medication, patient parameters and calculation (user action) Click "ok" (user action) e. Main screen is shown with medication information and protocol information in the 0 "niewe medicatie-opdracht" part (system response) Check information and click "OK" (user action) f. Medication information disappears from main screen and again screen "dosis 0 berekening" is shown (system response) This cycle (6 steps above) repeats several times (4) for medication type 1 0 (idarubicin) Screen "doseringsinstructie" for medication type 2 (vesanoid) is shown (system 0 response) (1) enter total dosage of medication per time and Click "ok" (user action) g. (2) enter dosage according to instruction and Click "M2" (user action) h. • Screen "geneesmiddel informatie" is shown (system response) i. click "ok" (user action) Open tab "motivatietext" In last third part of main screen "Extra informatie ..." (user action) j. click "ok" (user action) k. o alert "geneesmiddel is niet deelbaar" is shown (system response) click "ok" (user action) 1.

	o screen "dosis berekening" for medication type 3 (dexamethason) is shown (system
	response)
m.	Check medication, patient parameters and calculation (user action)
n.	Click "ok" (user action)
	• alert "geneesmiddel is niet deelbaar" is shown (system response)
0.	click "ok" (user action)
	• Main screen is shown with medication (type 4) information and protocol
	information in the "niewe medicatie-opdracht" part (system response)
р.	click "ok" (user action)
-	• Main screen is shown with medication (type 5) information and protocol
	information in the "niewe medicatie-opdracht" part (system response)
q.	click "ok" (user action)
-	• Main screen is shown with medication (type 6) information and protocol
	information in the "niewe medicatie-opdracht" part (system response)
r.	click "ok" (user action)

Table 6.2.1 – CW walkthrough scheme for admitting a patient into the Hovon 79 protocol by hand

The in-depth CW analysis of the Medicator CPOE user interface revealed 31 potential usability problems associated with actions to be performed in executing the described tasks for admitting a patient into the Hovon 79 protocol with or without using the protocol function. These problems were coded based on CW steps and action sequence and categorized by the two evaluators independently(e.g. problem code A.c1 indicates problem 1 encountered while performing action c to achieve goal A). Final decisions about categories and the assignment of usability problems to each category was made by both evaluators. Any disagreements were resolved through discussion. The total of 31 usability problems were categorized into 8 clusters. Sixty-one percent of these usability problems identified by the CW was not encountered by users during TA testing.

6.3 Think aloud

A total of 4 end-users testers performed the tasks presented for the TA study. All tests were performed at mobile test environments within the AMC. Table 6.3.1 shows the characteristics of all the participants.

	User 1	User 2	User 3	User 4
Age	27	28	46	29
Gender	М	F	F	М
Specialty	Pharmacy,	Resident,	Hematology	Resident,
	system expert	hematology	expert	oncology
Comp. experience	> 3 years	> 3 years	> 3 years	> 3 years
Medicator experience	6 - 13 months	< 6 months	6 - 13 months	1-3 years
Weekly use Medicator	1-2 hours	2-4 hours	> 8 hours	2-4 hours

Table 6.3.1: Characteristics of end-user testers

The testing session took around 45 minutes to complete. Some TA sessions lasted over one hour due to the fact that the TA session had to be interrupted several times. The recordings were not paused during this period to make sure no information was lost when stopping and continuing the TA. The usability testers expressed little difficulty with thinking aloud, although some of the users needed to be reminded to keep talking on multiple occasions during the session.

In the total of four scenarios performed with and without the use of the protocol function by the four end-user testers a total of 45 usability problems were identified by the two evaluators. In 87% of all cases the usability problem was detected by both evaluators. The total number of encountered usability problems during the TA sessions was 33 which means that the CW discovered about 57% of the encountered usability problems.

Table 6.3.2. shows how many kinds of severe, less severe and great impact usability problems were encountered by the end-users separately during the TA. E.g. user one encountered six different usability problems that could lead to severe medication errors, six less severe problems that could lead to some extend to user frustration and inefficiency and one great impact problem which lead to a lot of frustration an was very time consuming. In total 13 different kinds of problems were encountered. However the

total amount of encounters is much higher because all problems could be encountered more than once.

	User 1	User 2	User 3	User 4	Total
Severe	6	3	8	5	22
Less severe	6	1	12	6	25
Great impact	1	4	5	2	12
Total	13	8	25	13	59

Table 6.3.2: amount of severe, less severe and great impact errors per user

CW	Category	Usability problems	# user	#	Results	Severe,
coue			miA	rs in TA	problems)	GI
A.c1	Ambiguous information	In the first pane of the computer screen it is written that "for this patient no medication is prescribed" while no patient is chosen.	-	-	User confusion	LS
B.a1	Lack of information, lack of visibility	Function of tabloid "VZE-identificatie" unclear, tabloid "Indev. Pat." Poorly visible	2/4	3	User confusion, Time consuming	LS
B.b1	divergent from normal flow	Not all patient selection criteria are usable for searching	-	-	User confusion, Wrong patient selection	S
B.c1	Ambiguous information	Clicking "enter" while searching for a patient a dossier seems to be opened but in fact isn't.	-	-	User confusion, time consuming	LS
B.c2	Divergent from normal flow	The first record in the patient list is automatically selected. When clicking the Enter button on the keyboard the first dossier is automatically opened.	-	-	Wrong patient selection	S
B.d1	Poor design	Physician needs to scroll to the right too see patient credentials. The information does not fit the window.	4	4	Increase workload	LS
B.e1	Poor design	The list of patient records is 'tightly' represented. Increased chance of wrong selection	-	-	Wrong patient selection	S
C1.a1	Poor design	Users might not notice the buttons located at upper right hand side of the screen	3/4	>15	Time consuming	GI
C1.g1	Lack of information	Selecting ward from dropdown only possible based on codes	4/4	8	Selection wrong ward	LS
C1.h1	Lack of information	Definitions of tick boxes unclear	-	-	Time consuming	LS
C1.i1	Divergent from normal flow	A minimal of 6 letters is required to searched for medication	2/4	3	User confusion, Time consuming	LS
C1.j1	Lack of information	Definitions used in medication list are unclear	4/4	>15	Time consuming, Wrong medication selection	S
C1.k1	Ambiguous information	Medication list is full of unusable medication entries	4/4	>15	User confusion, time consuming	GI
C1.m1	Ambiguous information	Function of button "niveau down" unclear	3/4	3	User confusion, Time consuming	LS
C2.a1	Lack of warning and guidance	No checks on "toedieningsweg"	-	-	Medication wrongly administered	S

		•				
C2.c1	Lack of visibility	Buttons for automatic calculation of medication dose "M2" and "KG" are poorly visible, functions not clear and too close together.	-	-	Selection wrong button, user confusion, time consuming	LS
C2.e1	Lack of warning and guidance	entering numbers outside the body parameters range(e.g. 1 in box "lengte" instead of 100cm=1m) is possible without warning	-	-	Wrong medication dose calculation	S
C3.b1	Ambiguous information	Tick box accepts letters(e.g. two times per day), but still results in "no dosage is entered"	-	-	User confusion, Time consuming	LS
C4.b1	Ambiguous information	Independent of start time and date entered, in the "Doseringstabel" administration time starts from 8:00	4/4	>15	Confusion about correct administration time	LS
C4.c1	Lack of warning and guidance	System accepts start and stop date up till three days in the past.	-	-	Medication not administered	LS
C4.c2	Lack of warning and guidance	If stop date is forgotten, system proceeds without warning	2/4	2	Medication period to short	S
C2.g1	Ambiguous information	Information in this warning is the same as in main screen under tabloid "geneesmiddel informatie". The information in this screen is very difficult to understand	3/4	3	Ignorance of important system messages	LS
C2.5.a1	Lack of visibility, lack of warning and guidance	End users may miss the "motivation tabloid", system does not alert the user that motivation is forgotten. Pharmacy has to check every prescription with the physician for the motivation.	3/4	>15	User forgets or skips the motivation, time consuming	GI
C2.5.d1	Lack of information	Drop-down menu gives only 10 and 20 which may mislead physician and induce him to choose one of these dosages.	2/4	5	user confusion, Wrong medication dose selection	S
C12.b1	divergent from normal flow	Inefficient use of protocol list: not alphabetic ordered	4/4	4	Increased workload, time consuming	LS
C12.d1	Lack of information	Consolidation high risk is related to <60 years which is confusing because when <70 is selected the period 60><70 is unclear	-	-	wrong protocol selection	S
C1-2e1	Poor design	The button 'protocol geraleteerde uitslagen' is always active but does not contain any information. This is misleading.	1/4	1	Ignoring this button in the future, drug drug interaction	S
C1-2e2	Ambiguous and non reliable info	Definition "percentage dosering" unclear	4/4	4	User confusion, ignoring of potential useful system function	LS
C1-3.c1	inflexibility and lack of efficiency	In order to alter/cancel a step in the protocol you first have to complete it	4/4	>15	Increased workload, confusion	GI
C1-3.f1	Poor visibility of system status	System gives no information about which step in the protocol is active	4/4	4	User confusion	LS
C1-3.j1	inflexibility and lack of efficiency	While entering medication during protocol function motivation can not be filled in, but is requested. Motivation has to be checked by pharmacy so the physicians needs to be called before completing the order medication.	4/4	>15	User frustration/conf usion, ignoring motivation text, time consuming	GI

Table 6.3.3. – Coding scheme of usability problems detected by the Cognitive Walkthrough

Table 6.3.3 shows all the usability problems identified by the CW. The table also indicate per identified usability problem how many of the end-user testers encountered this problems and the total frequency of problem encounters. Also the severity of the usability problem is given: S for a usability problem that could lead to severe medication problems, LS for a usability problem that cost time and lead to some extent to inefficiency and GI for problems that often occur and thus have great impact on the medication ordering process.

In the next section, all usability problems identified by the CW are described. Eleven of the usability problems were marked as severe meaning the problem could lead to wrong medication selection, false medication order cancellation, drug under- or overdosing or wrong administration period selection. The other 20 identified usability problems referred to less severe problems of which 7 occurred that often that the impact was significant on the medication ordering process leading to user frustration, user confusion, ignorance of system functionalities and increased workload. From the 11 potential severe usability problems detected by the CW, 4 were encountered during the TA session and from the 20 less severe problems 15 were encountered during the TA sessions.

A.cj1: Ambiguous information when the system is first started: When the Medicator system is started for the first time and a user logs in, the first computer screen shows a message "for this patient no medication is prescribed". This message could confuse an end-user because there is actually no patient selected at all. Although this problem was identified by the CW it was not encountered during the TA session. This was probably because all end-users worked with the Medicator system before en completely ignored the first screen.

B.a1: Lack of information while selecting a patient: First a patient has to be selected in order to prescribe medication. The system's screen for selecting a patient shows "VZE identification' which was identified by the CW as an unclear abbreviation. These findings were supported by the TA in which two end-users were confused because of the

abbreviation and also did not notice the correct tabloid that needed to be selected which resulted in inefficiency in the search for a patient.

B.b1: Divergent from normal flow when searching a patient: The system provides several criteria which can be used for searching a patient. However some of the criteria only seem to work when they are used in combination with other criteria. E.g. The CW identified a potential problem in circumstances that only a name is available and gender is not know. The system has the function gender: "n.v.t." (unknown/not applicable) which can be used in such cases. Entering the name in combination with gender: "n.v.t." may result in no patients found. Searching for the same patient name in combination with gender: "male" or female" instead of gender: "n.v.t." however does show patient records. Because of the fact that end-users were given patient identification numbers during the TA sessions these problems was not encountered.

B.c1: Ambiguous information while searching for a patient: If a physician searches for a patient by entering patient identifying criteria and clicks the "enter" button instead of the "search" button in the screen, the search window is closed and a patient record **seems** to be opened. The fact that the search window is closed and still no patient information is shown can confuse the end-user which could leads to inefficiency in the medication ordering process. This potential problem was not encountered by end-users during TA sessions.

B.c2: Divergent from normal flow when selecting a patient from the patient list: If a patient is searched by criteria other than patient number it is possible that the system responds with a list of possibilities which match the search term. From this list the first record is automatically selected. Clicking the "enter" button on the keyboard directly opens this record. If the end-user notices the problem the search process has to be repeated which leads to user frustration and is time consuming. If the end-users did not notice the selection of the wrong patient, medication will be ordered for another patient. During TA sessions patients were found through patient identification numbers so this potential problem could not be encountered.

B.d1: poor representation of patient information while searching for patient: When the search function is used to lookup information about a patient, the system can respond with a list of results matching the criteria searched for. The CW revealed that the windows in which the patient information is presented is to small to fit all information in. In some cases two patients are that similar that the end-user needs to scroll from left to right to be able to see all patients data in order to select the right patient. During TA sessions patients were found through patient identification numbers so this potential problem could not be encountered.

B.e1: Poor representation of patient information while searching for patient: When the search function is used to lookup information about a patient the system can respond with a list of results matching the criteria searched for. The CW revealed that this list of patient records is very "tightly" represented which increases the chance of selecting the wrong patient. During TA sessions patients were found through patient identification numbers so this potential problem could not be encountered.

C1.a1: Wrong location of buttons on the screen: The CW revealed that when a patient record is opened several buttons become active which provide function like "New medication", "Cancel medication" and "Alter medication" which are located wrongly on the screen. This could potentially lead to inefficiency in the use of the system. The TA confirmed that due to the location of the buttons in the upper right corner of the screen these functionalities were not noticed by all users and they tried to find different and more time consuming routes to prescribe new, cancel or alter medication.

C1.g1: Lack of information while selecting the correct ward: If medication is prescribed for a patient who is not admitted to a specific ward yet, the end-user first needs to enter this information. The system provides a textbox with drop-down menu in case the user does not know the ward by heart. The CW identified a potential usability problem that he drop-down menu only consists of codes (e.g. F6ZU) which also confused several end-users in the TA because the could not recall which code belonged to which ward.

C1.h1: Lack of information while searching for medication: The Medicator screen for searching medication provides several search methods: Protocol, medication by name, frequently used medication, etc. The CW indicated that several of these search options are not clear and there is no information available about the options. Moreover the search for "medication by name" is automatically selected increasing the possibility that this function will always be used. This could lead to inefficiency in the medication ordering process because the end-user is not aware of the potential of the other search options. During the TA sessions the end-users indeed never tried one of the other functions.

C1.i1: Divergent from normal flow while searching for medication by name: It is possible to search for a medication by name. The system shows a screen in which the end-user can type a medication name or a part of it. During the CW a potential usability problem was revealed that entering a too short criteria results in no matches found. Two end-users encountered this problem during the TA session that there was no search result when searched for "Dexam" which are the first letters from Dexamethason. After some time and trial and error behavior they found out that a minimum of six letters needs to be given, otherwise the system responds with "no results". This trial and error process proved to be time consuming leading to inefficiency in the medication ordering process.

C1.j1: Lack of information in the medication list: In order to prescribe medication for a patient, the search function in Medicator can be used to find the correct medication. By entering the first 6 characters the system replies, if found, with a list of possible medications. This list contains all kinds of unclear abbreviations. The TA revealed this as a very frequent usability flaw, as all four end-users encountered this problem each time they tried to prescribe a new medication. This resulted in a high inefficiency in ordering and the possibility of selection wrong kinds of medication.

C1.k1: Lack of information in the medication list: If medication has to be prescribed the Medicator system offers a function to search for the correct type. When a medication name is entered the system replies with a list of matches. The TA showed that all users encountered great difficulty with finding the correct medication because the lists always

consisted of a lot of "dummy" medications. The system expert who participated in the TA sessions marked these as "dummy" because these medication names in the list could never be selected. The reason why the dummy items exits in the medication list is still unclear. This usability problem was also identified during the CW.

C1.11: Ambiguous information while selecting a medication: If a medication is searched for the system responds with a list of possibilities. The CW showed a potential problem that selecting one entry in the medication list does not always activate the "Selecteren" button. Only after clicking a different button with an unclear label "niveau down" a new (sub)list of possible medications is shown. When one of these medications in the sub list is selected the button "Selecteren" does become active. Three out of four end-users encountered problems with this.

C2.a1: Lack of warning when altering "toedieningsweg": After a medication name is found in the system and correctly selected, the search windows closed down and some additional information about the medication administration had to be filled in. The "toedieningsweg" always has a default value but still can be changed. When changed the system does not check or warn the end-user if this administration type could cause any problems for a particular drug. Therefore it could well be possible to prescribe an intravenous medication in a patient's eye. During the TA sessions not one of the users looked at the "toedieninsweg" or tried to alter it and because the system correctly fill in this information no problems were encountered.

C2.c1: Wrong proximity of button for calculating dose: For medication dose calculation the Medicator system offers several options. "M2" for calculating medication dose per body surface and "KG" for calculating medication dose per bodyweight. The CW identified the allocation of the button as a potential usability problem, Although the TA showed not encounters of this problems the possibility to click the wrong button is present because both buttons are located very near each other. Clicking the wrong button could result in the incorrect calculation of the medication dose.

C2.e1: Lack of warning while entering patient parameters: If the "M2" or "KG" function is used for the calculation of the correct medication dose the system uses the body parameters that are entered in the system. The end-user first needs to fill in this information or make sure that this information is correct. While filling in this information it is possible to enter numbers outside the body parameter range, e.g. 1 in the box for "length" instead of 100 which means 1 meter. The CW identified this as a potential usability flaw because entering wrong patient parameters could cause severe medication errors due to wrong dose calculations. Because this information for the test patients was correctly filled in, no end-users encountered problems during the TA.

C3.b1: Ambiguous information while entering medication rhythm: The text box for entering medication rhythm accepts letters to be entered, e.g. "Two times per day". Entering this information however results in "No dosage is entered" and the system will not accept this information. The CW showed that this could lead to inefficiency in the medication ordering process and user ignorance of these system functionalities. During the TA sessions this problem was not encountered.

C4.b1: Ambiguous information while entering administration times: The CW identified a potential usability problem that occurred during all TA sessions with end-users which related to the discrepancy between start time of the medication order and the administration time although not all end-users noticed this problem themselves. When selecting a medication rhythm the **medication administration time** is automatically set to 08:00. The end-user can decide to start a **medication order** at 12:00 which means that the first day the patient will not receive any medication because the start time of the medication.

C4.c1: Lack of warning while entering a start and stop date in the past: The CW identified that it is possible to start and stop a medication order up till three days in the pas. It is completely unclear this is possible and that also no warning is given when done. If a medication order is indeed started in the past this could lead to a too short medication period.

C4.c2: Lack of warning while entering start/stop date/time: For the prescription of medication it is required to enter a start and stop date/time. If an error is made in one of these (e.g. stop data before start date) the system will raise an alert but also resets all dates and times to 00:00. Two of the end-users encountered this problem during the TA and did not notice that the stop time also was reset to 00:00 which means that this patient would not received medication for the last day because the stop time had to be 23.59

C2.g1: Ambiguous information for entering "geneesmiddel information": When prescribing some medication the system shows a messages with the request to fill in additional medication information. The information posed in this system message however was very unclear formulated and all kinds of strange abbreviations were used. The message also lack information about why this additional information is required which lead during the TA sessions to the ignorance of this message. All end-users showed frustration because of this message and comments were made like: "I never look at system messages, they never make sense. **** the system"

C2-5.a1: Lack of warning and visibility when entering medication motivation: Some medication types require a motivation text for the pharmacy to explain why this type of medication is needed. After selection of this type of medication, Medicator shows a message with the request for a motivation. The CW identified this message as a potential usability problem because the text in the message is very unclear and the importance of the motivation text is also complete unclear. During the TA session three of the end-users never read the message or attempted to fill in a motivation. After being asked to fill in a motivation all three end-users showed great difficulty in finding the correct data-entry form to do so. Each time a motivation is not given the pharmacy has to check with the end-user who prescribed the medication what the reason for ordering the medication was which is highly inefficient.

C2-5.d1: Lack of / misleading information changing medication dose: After selecting a medication and calculating the correct dose, the system can respond with a message that

the medication dose cannot be given due to capsules that cannot be divided. (e.g. 45mg, only 10mg capsules are available which cannot be split into 5mg parts) In the message presented by the Medicator system, a dropdown menu was available which gave several options for the overall medication dose: 10mg and 20mg. This potential problem was identified by the CW and indeed two of the end-users were confused several times during the TA sessions because the total medication dose they wanted to prescribed was 45mg and they interpreted the numbers in the drop-down as a recommended dose while in fact these were just standard examples which was a time consuming process to figure out. Also it lead to wrong medication dose selection and also

C1-2.b1: divergent from normal flow while selection protocol: The CW showed that the list of available protocols provided by the Medicator system is not alphabetically ordered which was supported by the results of the TA sessions were users had problems in quickly finding the correct protocol. This time consuming process of finding the right protocol from a long list lead to inefficiency in the medication ordering process.

C1-2.d1: Lack of information about therapy differences: Some of the study protocols required patients to be admitted into several groups. The patients in these groups need to receive different kinds of medication of different drugs doses. For the Hovon 79 protocol for example a patient has to be admitted in: A consolidation phase related to patients <60 or a group for patients <70 which also seem to contain patients <60. The CW showed that because of this confusing information the wrong kind of consolidation phase could be chosen which could lead to wrong medication prescription and wrong medication dosing. During TA sessions no end-users encountered this problem.

C1-2.e1: "gerelateerde uitslagen" button always active: While ordering medication using the protocol function there is at the start of the protocol function always an active button *"gerelateerde uitslagen*". The CW showed that this buttons is always active and users first have to click on it to see if there in fact are any other results available. This is very inefficient and could lead to the ignorance of this function in the future if the end-users is every time frustrated by an empty screen. Also the lack of information of other

medical results could influence the medication ordering process and could lead to wrong medication selection.

C1-2:e2: Non reliable information while prescribing medication using protocol function: The first step in the protocol function shows a lists of medications to be prescribed and the possibility to fill in a percentage per medication. The CW identified this first step as a possible usability problem because the function of the percentages are completely unclear. The TA sessions also showed that end-users never noticed this option or ignored it due to lack of information about how to use it.

4 C1-3.c1: Inflexibility while altering medication step during protocol prescription: A patient can be admitted in a study protocol by using the specially designed protocol function. The Medicator CPOE leads the end-user through a series of sequential steps so all medication is ordered for that patient. All TA session confirmed the usability problem identified by the CW that all as soon end-users wanted to cancel a certain medication in a part of the protocol or they wanted to return to a previous step to alter a medication as both actions were not supported by the Medicator protocol function. Instead, users first have to complete all separate steps in the protocol after which the user had to manually edit or cancel one of the entered medications. This led to severe user confusion and increased the workload.

C1-3.f1: Poor visibility of system status while using protocol function: The protocol function of the Medicator systems guides the end-user through a series of step in order to prescribe a complete protocol. The CW identified the fact that the system gives no information about the status of the protocol function as a potential usability problem: The user is not able to see how many medications already have been prescribed and how many steps he still has to complete which could increase user frustration. Although no end-users encountered real problems with this during the TA sessions two end-users did comment on this as annoying.

C1-3.j1: Inflexibility while entering medication while using protocol function: For several types of medications a motivation is required. The problem while entering medication with the use of the protocol function is that this option is not available. The CW identified that for every time the motivation needs to be given the end-user has to manually edit a medication in order to fill in the motivation text. The TA shows that the users do not understand this workaround or get very annoyed and ignore the requested for motivation completely. This leads to a high inefficiency because the pharmacy will need to check the motivation for every medication it was not filled in for with the end-user.

ТА	Category	Usability problems	#	#	Results (potential	Severe:
not			user	counter	problems)	S, LS,
code			in TA	s in TA		GI
1	inflexibility and lack of efficiency	Inactive button ("selecteren") when it is needed.	3/4	3	User confusion, Time consuming	LS
2	inflexibility and lack of efficiency	Rigidity of protocol steps does not allow to skip the already ordered medication user have to cancel medications and start again	2/4	2	User confusion, Time consuming	LS
3	inflexibility and lack of efficiency	Inflexibility of protocol function for medication dosage does not allow user to prescribe different dosages	4/4	>15	Prescription of wrong medication dose, Manual prescription of medication resulting in increased workload	S
4	divergent from normal flow	Clicking "Enter" does not work as usual	1/4	1	User confusion, Time consuming	LS
5	lack of information	lack of information about the number of days the medication is administered when a user has selected a start and stop date	4/4	>15	Too short/long prescribed medication period	S
6	Lack of warning and guidance	Lack of warning for skipping induction phase	4/4	4	Patient is admitted into a consolidation therapy without first being admitted in a induction phase	S
7	Lack of warning and guidance	Lack of warning when user selects wrong kind of consolidation therapy	1/4	1	Patient is admitted in a high risk study group where he should be admitted in a low risk group.	S
8	Poor design	Poor design of field for administration time omits time after selecting it from drop down menu while time shows in "doseringstabel" and the field still remains active	1/4	4	User confusion, Time consuming	LS
9	Lack of support to undo or redo	There is no support for user to cancel ordering of a medication. Clicking on cancel button cancels the rest of protocol	2/4	2	Increased workload, User confusion/frustration	LS
10	Lack of color coding and categorization	Lack of color coding and categorization of last medications and new medications confuse users	1/4	1	User confusion, Selecting wrong medication	S
11	inflexibility and lack of efficiency	Because of inflexibility of the system to order different dosages of the same medication for different administration time stripes, a user has	4/4	>15	Increasing work load and consuming time, Unnecessary repetition	GI

		to prescribe the drugs many times for different time strips			of the same task, which results in receiving duplicate medication alert	
12	lack of information	System reply (medication list) completely different then the searched criteria	1/4	4	User confusion, Selection wrong medication	S
13	Lack of warning and guidance	Wrong alert ("geen doseringen aanwezig" instead of "no rhythm filled in")	1/4	1	Long and exhausting effort for correcting the problem	LS
14	Lack of warning and guidance	System does not check if altering the dose due to "deelbaarheids probleem" is correct	4/4	8	Over/ under dosing the patient	S

Table 6.3.4. – Coding scheme of usability problems only revealed by the Think Aloud

Table 6.3.4 gives an overview of 14 usability problems additionally encountered during the TA usability testing and the number of actual user encounters. The usability problems described in table 6.3.4 were thus not identified by the CW.

In the next section, all these usability problems are described. Seven of the 14 usability problems were marked as severe, the remaining seven problems were less severe leading to some extent to inefficiency and user confusions. One of these less severe problems (TA Not Coded[11]) potentially could lead to a "wrong medication selection" which is a severe error. This is because the list of returned medication is completely different than the criteria used during the medication search. However we can assume that end-users licensed to prescribe medication are familiar with duplicate or alternative names for medications.

TA Not Coded[1]: Inflexibility while using "enter" button on the keyboard: For most data entry forms the "enter" button on the keyboard has the same function as clicking the "Selecteren" button in the screen. Three end-users encountered the problem that the button "Selecteren" was still inactive so clicking "enter" on the keyboard was required to complete a data entry. This was time consuming because it was not clear why this buttons was not active and finding the solution by trail and error took some time.

TA Not Coded[2]: inflexibility in continuing medication protocol function: Two of the end-users tried to alter a medication while prescribing a protocol using the specific Medicator function. Afterwards they tried to continue with the protocol function which

was not possible. The users had to cancel all prescribed medications and start over with the whole protocol. This was highly inefficient and very time consuming.

TA Not Coded[3]: Inflexibility of protocol function for prescribing medication dosage: Some patients need to be admitted into a study protocol. For several protocols Medicator offers a special function which (should) ensure that the end-user does not need to prescribe all medications by hand. All end-users encountered problems during the TA: It was not possible to divide one medication over several administrations a day. In order to do this the medication first had to be prescribed as one administration whereafter the user needed to delete that medication and manually prescribe the administration of the drugs over several administrations a day. This process took a lot of time and was very frustrating for all end-users during the TA sessions.

TA Not Coded[4]: divergent from normal flow while using "enter" button on the keyboard: For most data entry forms the "enter" button on the keyboard has the same function as clicking the "Selecteren" button in the screen. one end-users encountered the problem that the sometimes the "enter" button does not work and the end-user is forced to use the mouse to click on the button on the screen. This end-user was used to clicking enter after entering information in a text box and therefore it took some time before figuring out the "enter" button did not work.

TA Not Coded[5]: *lack of information and visibility of medication period:* Patients often need to receive medication over several continuous days. When ordering medication, Medicator sets the medication period always to one day. To change this period Medicator offers dropdown menus which show a calendar to select a different start/stop date. All four end-users experienced severe difficulties in ordering medication for more than one day because the days have to be counted manually for the system provided no feedback about the number of selected days which was highly inefficient, time consuming and several time led to the selection of the wrong medication period.

TA Not Coded[6]: Lack of warning when planning protocols steps: If a patient is to be

admitted into a study protocol it is often required to plan several steps. The TA showed that the Medicator system lacks any kind of warning when admitting a patient into a study protocol: The end-users were asked to admit a patient into the Hovon 79 study protocol. In order to find out in which group (low risk, medium risk, high risk consolidation) a patient had to be admitted first an induction phase of chemotherapy had to be scheduled. The outcome of this phase would determine the patient's risk group. All end-users admitted a patient in a consolidation phase without Medicator providing any warning that there was no induction phase planned which could mean that a patient is admitted in a wrong consolidation phase and receives all the medication in wrong dosages.

TA Not Coded[7]: Lack of warning when continuing a protocol: One of the end-users encountered a problem which forced him to stop the protocol. Afterwards the user searched for a way to continue the protocol. While doing so the end-user selected a different type of consolidation therapy. As a result the patient was first admitted in the low risk group and afterwards in the high risk group. No alerts or warning were raised by the system which meant the patient would receive wrong medication and different medication doses.

TA Not Coded[8]:Poor design of administration time: When prescribing medication a medication rhythm has to be given. This can be done by using the drop-down menu presented by Medicator. One of the end-users showed great difficulties with the fact that after selecting an entry from the drop-down menu closes and it seems the Medicator system did not select an administration time. While in fact the "doseringstabel" has been altered and the drop-down menu is reset to it's initial state which is a blank field making the end-users believe that he made a mistake because no administration time is shown.

TA Not Coded[9]: Lack of support while canceling medication using the protocol function: If medication is ordered using the protocol function of Medicator the system guides the user step by step through the ordering process. If an error is made however it is not possible to undo that one mistake. If the "cancel" button is clicked the complete

protocol is canceled and the users needs to start over again which is inefficient en time consuming.

TA Not Coded[10]:Lack of color coding and categorization of medication groups: The top part of the main Medicator screen (figure 4.1) gives an overview of all the medications ordered for a patient. The list of medications very tightly presents a lot of information on one line. One of the end-users encountered problems with this resulting in the cancellation of a prescribed medication that did not had to be cancelled instead of the medication that needed to be cancelled.

TA Not Coded[11]: Inflexibility of support when ordering same medication: Some protocols required a planning of the same medication in a lot of different time stripes. Not one of the end-users found a way to replicate an existing medication order which made it very time consuming to repeat the same task over and over again, thus increasing the workload.

TA Not Coded[12]: Lack of information while searching for medication: If medication is searched for using the Medicator function the system returns a list of possible medications. In some cases however the returned list of medications is completely different than the criteria used for the search. This could lead to user confusing as shown during the TA session with one of the end-users and possibly wrong medication selection.

TA Not Coded[13]: wrong warning while changing medication rhythm: One end-user took a long and exhausting effort to correct a problem due to a wrong system alert which stated "No medication dose selected" instead of "no rhythm filled in". Because of this message the user constantly tried to correct the medication dose while the rhythm had to be filled in which lead to inefficiency.

TA Not Coded[14]:Lack of guidance when altering medication dose after alert: When entering medication the Medicator CPOE can calculate the correct dose. At the end of the ordering process the system could raise a "deelbaarheids probleem "alert which means that the dose has to be altered. All end-users encountered problems that the system did not check the altered medication dose which eventually resulted in the administration of a wrong medication dose.

6.4 Questionnaire

In this section the results are presented based on data from the Questionnaire for User Interface Satisfaction(QUIS) which the participants of the TA usability testing filled out. Questions of this questionnaire should be answered based on a 10 point scale from 0 to 9. All four end-user responded to all 27 questions although 7 questions were marked as not applicable (NA) by at least 1 user and 2 questions were not understood by 1 user. The overall mean score was 4.22. Table 6.4.1 gives an overview of the overall mean user responses for the individual categories.

Individual category	Mean user responses
Overall reaction to the software	3
Screen	4.5
Terminology and system information	4.3
Learning	3.3
System capabilities	6

 Table 6.4.1 - overall mean user responses on QUIS questionnaire with a Likert scale from 0-9, 0: worst, 9:best.

Table 6.4.1 also shows that for all individual categories the mean user response was low except for 'system capabilities' which shows a slightly higher mean (6).

Further analysis of the questionnaire show that 21 of the in total 27 posed questions were scored lower than 5 as can be seen in figure 6.4.2.



Figure 6.4.2 - mean user responses per question

In only 6 of the 27 posed questions the mean score was above 5 (1 questions had a measure of 5). Table 6.4.2 shows these 6 questions with their means score.

All four users agree on the fact that the system works fast enough and that no waiting is necessary when a request or an action is initiated. Also the system proves to be quiet when using it. In case of the four other questions the scores per user varied from three to nine but still resulting in a positive mean.

QUIS question	Mean user responses
system speed	8.75
system tends to be noisy /quiet	8.7
exploring new features by trail and error	7.25
use of terms throughout system	6.25
Remembering names and use of commands	6
reading characters on the screen	5.25

Table 6.4.3 – highest scoring QUIS questions.

Table 6.4.4 shows the QUIS questions for which the mean user response was the lowest. All users agreed on the fact that the system is very rigid and there are few help messages and the ones that are present are not very meaningful. Also error messages as well as the position of messages were rated very low. Overall the users agreed on the fact that the system is difficult to use which leads to a lot of frustration. For all of the mentioned questions goes that not one user gave a positive score.

QUIS question	Mean user responses
Is the system: Rigid - flexible	1.5
Does the system: offer: Help messages on screen	1.7
Does the system: Error messages	2.25
Is the system: frustration- satisfying	2.25
Is the system: difficult - easy	3.5
How is the position of messages on screen	3.75

Table 6.4.4 – lowest scoring QUIS questions.

Appendix D shows the total questionnaire with all the mean user responses per questions, per category and overall score.

Besides the 27 questions, the questionnaire also provided the users the opportunity to give a list of positive and negative comments about the Medicator system which might not have been revealed by the questions themselves. Table 6.4.5 gives an overview of the positive and negative comments. Because of the low number of end-users who filled in the questionnaire it is not possible to calculate some statistics about the list of positive and negative comments although some comments are odd:

- The questionnaire showed that all users agreed on the fact that the system is very rigid and it is difficult to use. Nevertheless the list of comments shows that one user did call the system quick and another user called the system user friendly which is not in term with the other comments and the results of the TA sessions.
- The TA showed that all users experienced great difficulty in selecting medications from the medication list due to unknown abbreviations and inconsistent items in the list. One user nevertheless commented that the medication list was summarized in a good way and that it is easy to use.
- On the other hand the comment was given that the system tend to crash a lot. Both evaluators never experienced a system crash during the TA and also the TA sessions never showed a system crash.

Positive comments	Negative comments
Quick (2 users)	Not every protocol is in the system (2 users)
Good summary of medication list (1 user)	System does not recognize every medication (1 user)
Printing receipt is easy (1 users)	System crashed a lot (2 users)
Medication information available at all times (1 user)	Inflexible (1 user)
System basics are easy to learn (1 user)	Advanced option very complex to learn (1 user)
User friendly (1 user)	Medication period very unclear (1 user)

Table 6.4.4 – User comments about Medicator

<u>Chapter 7</u>

Discussion

7.1 Discussion

Literature has shown that when successful implementation of CPOE is achieved by recognizing and skillfully managing the complexity of the implementation process of CPOE systems^[1], CPOE holds the potential for improving the order communication process and ultimately for improving patient outcomes ^{[2].} Literature has also shown that implementing CPOE is a very difficult process^[3] and implementing CPOE can cause errors due to among others, usability problems with the system (interface)^{[4, 5].}

In this study we performed a usability evaluation of the Medicator CPOE for ordering cytostatic drugs for hematology patients in the AMC by means of a CW, performed by two experts in the field of medical informatics, combined with the TA method with four end-users of the system.

Literature shows that the CW appears to be more effective in finding severe than less severe problems and that detailed task descriptions rather than shorter ones can significantly increase the number of usability problems found by a CW^[6]. It was therefore that we made use of the most recent version of the CW which requires detailed descriptions of how users should accomplish tasks as input: We indeed created per task a complete description of the correct action sequences and interface states along these sequences before a cognitive walkthrough was conducted.

The resulting framework of user action sequences and system responses developed for the CW could be adequately applied for the analysis of the Medicator interaction problems encountered during the TA test sessions, providing us with details on the underlying causes of usability problems encountered by end-users.

Fifteen of the total 31 usability problems identified by the CW, actually resulted in inefficiency of ordering, omissions and factual errors in ordering medication as well as canceled medication orders during the TA sessions: 18 of the usability problems identified by the CW were also confirmed by the TA sessions.

The CW thus did not reveal all usability problems encountered by end-users in interaction with the Medicator system. The total number of different usability problems encountered by end-users during the TA sessions was 32. The CW only discovered 18 of the usability problems actually encountered by the four end-users. These results indicate
that the CW method does not predict all usability problems which can be explained by the fact that the latest version of the CW (used in this thesis) which for each task required detailed descriptions of correct action sequences caused the evaluators to analyze predefined action sequences instead of discovering solutions through exploration. This might have limited the evaluators' ability to find certain types of problems not directly related to these action sequences. However, the CW has proven to be a very effective method in situations where, because of time or financial constraints, the focus is on detecting the more severe usability problems^{[7].}

Thinking Aloud is a very good technique as a way to gain insight into users' thought processes and plays an important role in the end-user ability testing of systems. Think Aloud is said to provide a rich source of data where a small sample of subject (approx. 8 subjects) suffices to gain a thorough understanding to identify the main usability problems with as computer system. Although the number of end-users used for the TA sessions of the evaluations of the Medicator CPOE was limited to only four, the results still seem to be representative for the end-user population of the Medicator system: Given the user profiles (table 6.3.1) it was to be expected that the end-users with the least Medicator experience (<6 months and 6-13 months) would have encountered the most usability problems. In these circumstances including more novice users might have increased the number of encountered usability problems. Table 6.3.2 shows however that novice users (E.g. user 2) in fact encountered the least usability problems. It also shows that the most experience user (user 3) encountered almost four times more problems. This seems to suggest that age and overall experience with computers and screen layouts of applications is more important for working optimally with the Medicator computer system then system knowledge. It also seems to suggest that performing additional TA sessions with more end-users would not have influenced the amount of encountered usability problems drastically.

Literature also shows that TA sessions reveal more major and recurring problems than minor, cosmetic problems ^[8, 9, 10] in comparison to the CW. Because end-users participating in the TA testing are not limited to the analyses of predefined solutions but instead try to discover solutions through exploration which is supported by our results: The TA analysis revealed fourteen additional usability problems. These identified

usability problems influenced the way physicians interacted with the system by increasing the workload and causing a lot of user frustration and at least six of these usability problems could have lead to severe medication errors. In total (CW and TA together) more than fourteen encountered usability problems could cause severe medication errors and more than ten encountered usability problems were recurring problems directly impacting the workload. The results of our study support the findings reported in literature^[12] that certain types of usability problems are closely associated with the occurrence of specific types of errors in the prescription process of medications. Furthermore our result showed that due to the usability flaws end-users do not optimally make use of automated function (e.g. protocol function) which supports finding reported in literature^{[13].}

The results of the QUIS indicated that the end-users of the Medicator system were unanimous in rating the system as very rigid, difficult to learn and frustrating and the relative low user rating for the QUIS also reflects this. In fact only the "system capabilities" showed a slightly positive rating (6) the rest were all very low. These findings are in line with the results of the TA sessions in which all users made several remarks about the system and the frustrating problems they encountered while prescribing medication.

However certain comments provided by the participants showed some discrepancy with the results of the TA sessions. E.g. the system is called user friendly, quick and easy to learn which is out of line with the results of the QUIS and TA sessions. It need to be mentioned that except for high system speed, these remarks were never made by more than one end-user and due to the low number of participants these remarks may not be that significant.

A limitation of this study could be that the end-users only performed one scenario twice, once using the protocol function and once by hand. An explanation for the fact that potential usability problems detected by the CW were not encountered by end-users during the TA sessions could simply be that the "window of opportunity" to encounter certain usability problems was very small: Several usability problems which could lead to severe medication errors could therefore not have been encountered, e.g. usability problem C1.2.d1 could lead to admitting a patient into a wrong study protocol meaning

the patient would receive a wrong medication dose for a long period of time. End-users could have encountered this usability problem which could lead to a severe medication error, only once per TA session and therefore the risk of selection the wrong option was limited. Furthermore all the end-users had no time pressure while performing the TA and were not interrupted very often so all end-users were very alert on not making major mistakes. In the normal workflow the workload is very high, end-users are interrupted very often and the pressure of ordering medication quickly between visits is also high. Meaning that in view of the high number of medication orders set out each day at the hematology department, the usability flaws detected in our study could indeed result in a high percentage of encountered usability problems that could lead to (severe) medication errors during normal practice.

Also several potential usability problems were not encountered during the TA sessions because certain system functionalities were never used. Most of these potential problems were related to the functionality for searching patient records in the system: The endusers were given patient identification number which they used to search the system. This way the end-users were ensured to select special test-patients and no real patient data.

A further limitation of this study was that every protocol in the Medicator system has to be implemented one by one, manually which means that every protocol could have a different interface and therefore introduce new potential usability problems. Because only one scenario was used for this study, potential usability flaws in other protocols could not be detected.

The usability evaluation of the Medicator system is meant to be continued so more information will be available for further analysis. The aim is to finish all TA sessions within the next months so that there will be enough data available to finalize the ultimate goal: Presenting an evidence based report which will be used in the discussion which is currently held in the AMC: What kind of revision of the Medicator system is necessary in order to suffice the needs of the AMC hospital or is it better to look for CPOE solutions among other suppliers of CPOE.

7.2 References

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Conclusion

8.1 Conclusion

Computerized Physician Order Entry is an inherently complex process, but the way in which the system is designed can either increase or minimize its complexity and prevent or cause usability problems and (medical) errors. The medication prescription CPOE, Medicator is a tool which is meant to minimize the complexity and decrease medication errors while ordering medication for admitted patients by leading the end-user step by step through the ordering process. For this SRP the Medicator CPOE was analyzed with the focus on its usability to evaluate whether physicians encountered usability problems during the medication ordering process. Usability evaluation was performed by Cognitive Walkthrough and Think Aloud end-user testing. Both evaluation methods revealed a limited number of minor usability problems (cosmetic problems) that lead to inefficient use of the system and a large number of major usability problems which potentially could lead to severe medication errors.

From the analysis of the TA session the conclusion can be drawn that the Medicator CPOE is difficult to use and therefore very time consuming which is supported by the results of the usability survey: All end-users expressed great frustration about the rigidness and complexity of the system and the difficulty of using the system and the lack of correct guidance slows down the ordering process and could even cause severe medication errors.

This leads to the conclusion that Medicator is a good basis for standardizing the medication process but redesign is strongly recommended to simplify and optimize the medication ordering process. Also decision support functions need to be revised so the risk of medication errors through faults in the medication process can be adequately prevented.

Appendices

Appendices

Abbreviations

- SRP scientific research project
- AMC academic medical centre
- TA Think Aloud (end-user testing)
- CW Cognitive Walkthrough
- HE Heuristic evaluation
- CPOE Computerized Physicians Order Entry
- ADE Adverse Drug Event
- ISO International Standards Organization

Appendix A: Clinical scenario

Situatie

Patiënt Man, 19 jaar, 185 cm, 86 kilo met acute promyelocyten leukemie.

Behandelplan:

Hovon 79 studieprotocol, bestaande uit 3 fasen:

- Inductiefase
- Consolidatie
- Onderhoud

Opdrachten

- Schrijf patiënt het inductieschema (AIDA) voor met bijbehorende supportive care, startend volgende week.
- Schrijf vervolgens de consolidatietherapie voor (Low Risk) en plan alle drie de kuren in.
- Annuleer na het aanvragen van de 3 kuren de tussenliggende kuur (kuur 2)

(bij het uitschrijven van deze volledige opdracht moeten hier een aantal user interface specifieke

Verwachte problemen

- Vergeten SDD medicatie voor te schrijven
- Doseringsaanpassing vesanoid (ATRA) voor patiënten onder de 20 jaar
- Frequentie Idarubicine afhankelijk van leeftijd
- Dosering vesanoid afronden op 10 mg capsules (afronding omlaag of omhoog?)
- Anti-emetica voorschrijven
- Allopurinol voorschrijven

Appendix B: Questionnaire

Date of birth:					
Gender:	male	female			
Specialty:				since:	•••••
Comp. exp.	<6 months	6-12 months	1-3 years	>3	years
Medicator exp.	<6 months	6-12 months	1-3 years	>3	years
Weekly use Medicator	<1 hours	1-2 hours	2-4 hours	>8	hours

#	QUIS question	Scoring		
	Overall reaction to the software			
1		terrible - wonderfull		
2		difficult - easy		
3		frustrating - satisfying		
4		inadequate power - adequate power		
5		dull - stimulating		
6		rigid - flexible		
	Screen			
7	reading characters on the screen	Hard - easy		
8	highlighting simplifies task	Not al all – very much		
9	organization of information	Confusing – very clear		
10	sequence of screens	Confusing – very clear		
	Terminology and system information			
11	user of terms throughout system	Inconsistent – consistent		
12	terminology related to task	Never – always		
13	position of messages on screen	Inconsistent – consistent		
14	prompts for input	Confusing – clear		
15	computer informs about its progress	Never – always		
16	error messages	Unhelpful – helpful		
	Learning			
17	learning to operate system	Difficult – easy		
18	exploring new features by trail and error	Difficult – easy		
10	remembering names and use of			
19	commands	Difficult – easy		
20	performing tasks is straightforward	Never – always		
21	help messages on the screen	Unhelptul – helptul		
22	supplemental reference materials	Confusing – clear		
~~~	System capabilities	<b>-</b>		
23	system speed	I OO SIOW – TAST ENOUGH		
24	system reliability			
25	system tends to be noisy - quiet	Noisy – quiet		
26	correcting your mistakes	Difficult – easy		
27	designed for all levels of users	Never - always		

Appendix C: QUIS	questionnaire results
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#	QUIS question	mean	Comments
	Overall reaction to the software		
1	terrible - wonderfull	4	
2	difficult - easy	3.5	
3	frustrating - satisfying	2.25	
4	inadequate power - adequate power	4	
5	dull - stimulating	2.7	1 user filled in NA
6	rigid - flexible	1.5	
	mean score per category	3	
	Screen		
7	reading characters on the screen	7.25	
8	highlighting simplifies task	2.3	1 user filled in NA
9	organization of information	4.5	
10	sequence of screens	4	
	mean score per category	4.5	
	Terminology and system information		
11	use of terms throughout system	6.25	
12	terminology related to task	4.25	
13	position of messages on screen	3.75	
14	prompts for input	4.5	
15	computer informs about its progress	4.7	1 user filled in NA
16	error messages	2.25	
	mean score per category	4.3	
	l earning		
17	learning to operate system	4	
18	exploring new features by trail and error	5.25	
	remembering names and use of	0.20	
19	commands	6	
20	performing tasks is straightforward	4.5	
21	help messages on the screen	1.7	1 user did not understand question
22	supplemental reference materials	3	1 user did not understand question, 2 users filled in NA
	mean score per category	3.3	
	System capabilities		
23	system speed	8.75	
24	system reliability	5	
25	system tends to be noisy - quiet	8.7	1 user filled in NA
26	correcting your mistakes	4.75	
27	designed for all levels of users	2.75	
	mean score per category	6	
Tot	al mean for the QUIS questionnaire	4.2	