Journal of Biomedical Informatics 44 (2011) 968–977

Contents lists available at SciVerse ScienceDirect

Journal of Biomedical Informatics

journal homepage: www.elsevier.com/locate/yjbin

Design and development of a mobile computer application to reengineer workflows in the hospital and the methodology to evaluate its effectiveness

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A R T I C L E I N F O

Article history:
Received 4 January 2011
Accepted 8 July 2011
Available online 26 July 2011

Keywords:
Evaluation method
Information system
Workflow reengineering
User-computer interface
Software design
Mobile computing

A B S T R A C T

This paper describes a new method of collecting additional data for the purpose of skin cancer research from the patients in the hospital using the system Mobile Computing in Medicine Graz (MoCoMed-Graz). This system departs from the traditional paper-based questionnaire data collection methods and implements a new composition of evaluation methods to demonstrate its effectiveness.

The patients fill out a questionnaire on a Tablet-PC (or iPad Device) and the resulting medical data is integrated into the electronic patient record for display when the patient enters the doctor's examination room. Since the data is now part of the electronic patient record, the doctor can discuss the data together with the patient making corrections or completions where necessary, thus enhancing data quality and patient empowerment. A further advantage is that all questionnaires are in the system at the end of the day – and manual entry is no longer necessary – consequently raising data completeness. The front end was developed using a User Centered Design Process for touch tablet computers and transfers the data in XML to the SAP based enterprise hospital information system. The system was evaluated at the Graz University Hospital – where about 30 outpatients consult the pigmented lesion clinic each day – following Bronfenbrenner's three level perspective: The microlevel, the mesolevel and the macrolevel:

On the microlevel, the questions answered by 194 outpatients, evaluated with the System Usability Scale (SUS) resulted in a median of 97.5 (min: 50, max: 100) which showed that it is easy to use.

On the mesolevel, the time spent by medical doctors was measured before and after the implementation of the system; the medical task performance time of 20 doctors (age median 43 (min: 29; max: 50)) showed a reduction of 90%.

On the macrolevel, a cost model was developed to show how much money can be saved by the hospital management. This showed that, for an average of 30 patients per day, on a 250 day basis per year in this single clinic, the hospital management can save up to 40,000 EUR per annum, proving that mobile computers can successfully contribute to workflow optimization.

1. Introduction and motivation

At the clinical department of Dermatology of the University Hospital in Graz, one of the largest hospitals in Europe, approximately 30 outpatients consult the pigmented lesion clinic each day. They are asked to complete a questionnaire (see Fig. 1) as part of the skin cancer research's Melanoma Pre-care/Prevention Documentation [10,11]. When a patient arrives for the first time, they are asked to fill out a long form version of the questionnaire (referred to as LONG FORM in the results section), on subsequent visits they are asked to fill out a short form version of the questionnaire (referred to as SHORT FORM in the results section).

When the patients arrive at the central administration desk of the outpatient clinic, a medical nurse hands them a paper questionnaire. The patient is asked to complete the questionnaire alone and return it to the nurse, where they are collected together for the doctor. Theoretically, the doctor can peruse the paper questionnaire during the treatment, but concentration is usually limited to the patient and the Electronic Patient Record (EPR) displayed on the clinical workplace monitor. Most often, the ques-

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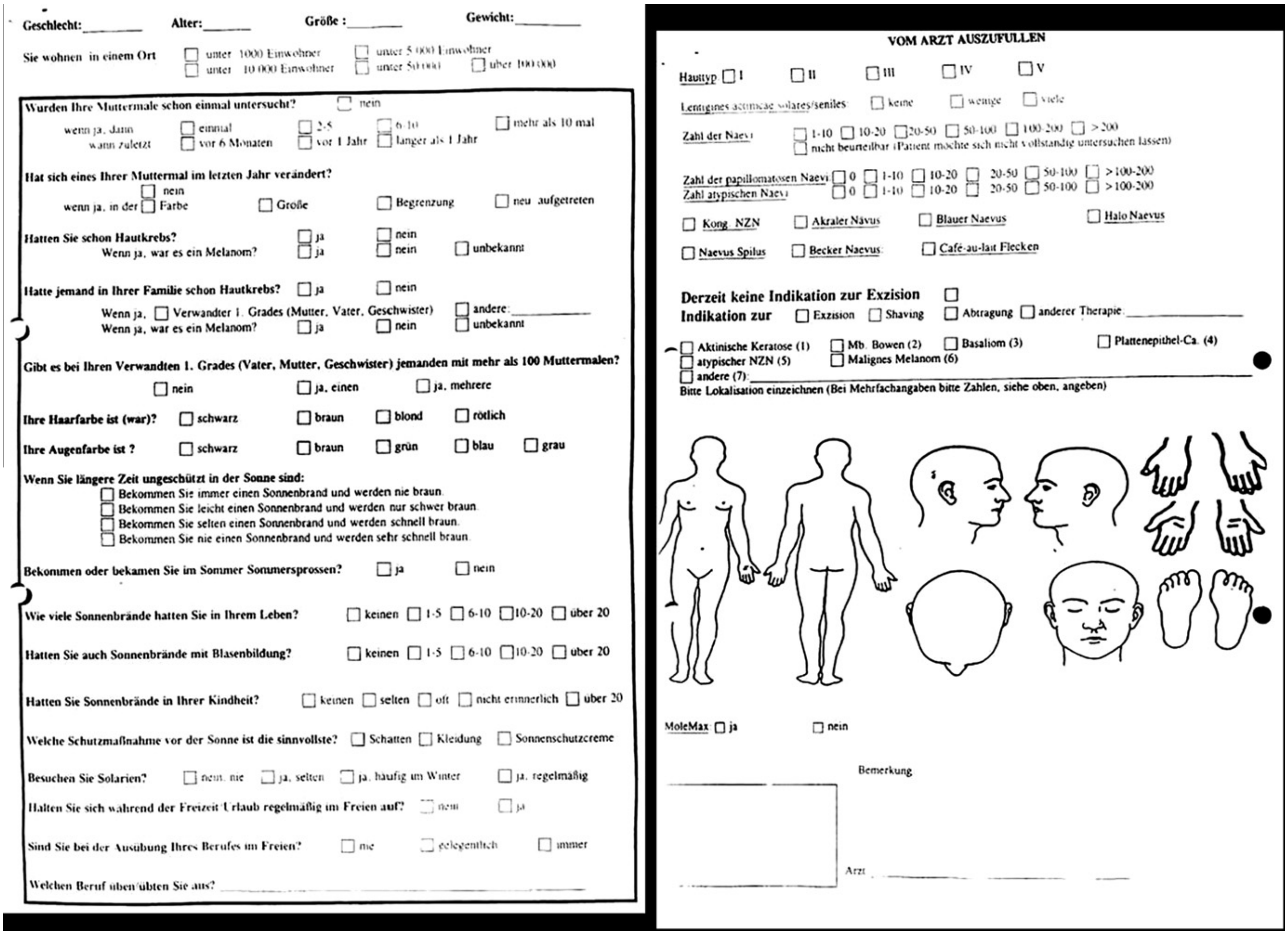
doi:10.1016/j.jbi.2011.07.003



Geschlecht:________ Alter:_______ Größe :________ Gewicht:_________

Sie wohnen in einem Ort ☐ unter 1000 Einwohner ☐ unter 5 000 Einwohner ☐ unter 10 000 Einwohner ☐ unter 50 000 ☐ über 100 000

Wurden Ihre Muttermale schon einmal untersucht? ☐ nein
wenn ja, dann ☐ einmal ☐ 2-5 ☐ 6-10 ☐ mehr als 10 mal
wann zuletzt ☐ vor 6 Monaten ☐ vor 1 Jahr ☐ länger als 1 Jahr

Hat sich eines Ihrer Muttermal im letzten Jahr verändert?
☐ nein
wenn ja, in der ☐ Farbe ☐ Größe ☐ Begrenzung ☐ neu aufgetreten

Hatten Sie schon Hautkrebs? ☐ ja ☐ nein
Wenn ja, war es ein Melanom? ☐ ja ☐ nein ☐ unbekannt

Hatte jemand in Ihrer Familie schon Hautkrebs? ☐ ja ☐ nein
Wenn ja, ☐ Verwandter 1. Grades (Mutter, Vater, Geschwister) ☐ andere:__________
Wenn ja, war es ein Melanom? ☐ ja ☐ nein ☐ unbekannt

Gibt es bei Ihren Verwandten 1. Grades (Vater, Mutter, Geschwister) jemanden mit mehr als 100 Muttermalen?
☐ nein ☐ ja, einen ☐ ja, mehrere

Ihre Haarfarbe ist (war)? ☐ schwarz ☐ braun ☐ blond ☐ rötlich

Ihre Augenfarbe ist ? ☐ schwarz ☐ braun ☐ grün ☐ blau ☐ grau

Wenn Sie längere Zeit ungeschützt in der Sonne sind:
☐ Bekommen Sie immer einen Sonnenbrand und werden nie braun.
☐ Bekommen Sie leicht einen Sonnenbrand und werden nur schwer braun.
☐ Bekommen Sie selten einen Sonnenbrand und werden schnell braun.
☐ Bekommen Sie nie einen Sonnenbrand und werden sehr schnell braun.

Bekommen oder bekamen Sie im Sommer Sommersprossen? ☐ ja ☐ nein

Wie viele Sonnenbrände hatten Sie in Ihrem Leben? ☐ keinen ☐ 1-5 ☐ 6-10 ☐ 10-20 ☐ über 20

Hatten Sie auch Sonnenbrände mit Blasenbildung? ☐ keinen ☐ 1-5 ☐ 6-10 ☐ 10-20 ☐ über 20

Hatten Sie Sonnenbrände in Ihrer Kindheit? ☐ keinen ☐ selten ☐ oft ☐ nicht erinnerlich ☐ über 20

Welche Schutzmaßnahme vor der Sonne ist die sinnvollste? ☐ Schatten ☐ Kleidung ☐ Sonnenschutzcreme

Besuchen Sie Solarien? ☐ nein, nie ☐ ja, selten ☐ ja, häufig im Winter ☐ ja, regelmäßig

Halten Sie sich während der Freizeit/Urlaub regelmäßig im Freien auf? ☐ nein ☐ ja

Sind Sie bei der Ausübung Ihres Berufes im Freien? ☐ nie ☐ gelegentlich ☐ immer

Welchen Beruf üben/übten Sie aus? ____________________

VOM ARZT AUSZUFÜLLEN

Hauttyp ☐ I ☐ II ☐ III ☐ IV ☐ V

Lentigines actinicae solares/seniles: ☐ keine ☐ wenige ☐ viele

Zahl der Naevi ☐ 1-10 ☐ 10-20 ☐ 20-50 ☐ 50-100 ☐ 100-200 ☐ >200
☐ nicht beurteilbar (Patient möchte sich nicht vollständig untersuchen lassen)

Zahl der papillomatosen Naevi ☐ 0 ☐ 1-10 ☐ 10-20 ☐ 20-50 ☐ 50-100 ☐ >100-200
Zahl atypischen Naevi ☐ 0 ☐ 1-10 ☐ 10-20 ☐ 20-50 ☐ 50-100 ☐ >100-200

☐ Kong. NZN ☐ Akraler Nävus ☐ Blauer Naevus ☐ Halo Naevus

☐ Naevus Spilus ☐ Becker Naevus ☐ Café-au-lait Flecken

Derzeit keine Indikation zur Exzision ☐
Indikation zur ☐ Exzision ☐ Shaving ☐ Abtragung ☐ anderer Therapie:__________

☐ Aktinische Keratose (1) ☐ Mb. Bowen (2) ☐ Basaliom (3) ☐ Plattenepithel-Ca. (4)
☐ atypischer NZN (5) ☐ Malignes Melanom (6)
☐ andere (7):__________
Bitte Lokalisation einzeichnen (Bei Mehrfachangaben bitte Zahlen, siehe oben, angeben)

MoleMax: ☐ ja ☐ nein

Bemerkung

Arzt __________

Fig. 1. The layout of the original paper questionnaire used before MoCoMED-Graz was in operation, was unsuitable for elderly patients.

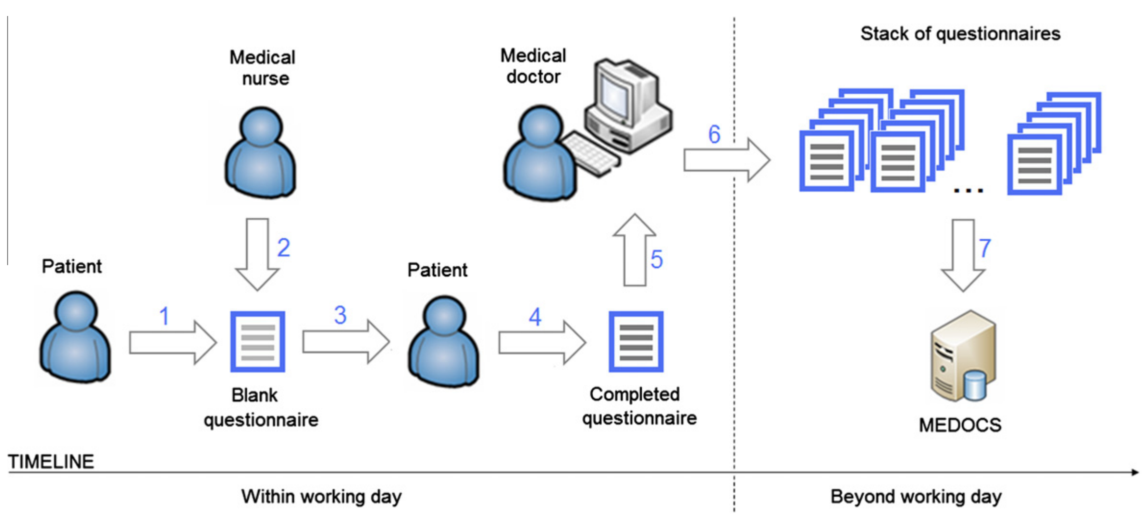


Fig. 2. Original workflow of the paper version before MoCoMED-Graz.

tionnaires are just gathered and manually typed into a separate electronic database after the clinic is closed (see Fig. 2). This data base has no direct connection to the electronic patient record of the Enterprise Hospital Information System (EHIS).

One obvious disadvantage of this workflow is the fact that the data have to be typed in manually, by the doctors, afterwards, wasting valuable medical professional's time, which could be used for more relevant medical core work. Since this information is required for scientific research and is not part of the routine clinical data, there is also the risk that it is sometimes not done. A further disadvantage is the lack of checks on the information given by the patient, and since the paper is often not even read until the patient has left, there is little opportunity for correcting erroneous data.

The Mobile Computing for Medicine Graz (MoCoMED-Graz) system was designed and developed to provide an electronic solution using a mobile touch computer with a specially designed graphical user interface.

The system requirements included:

(a) easy usage for patients – especially for elderly patients;
(b) sufficient data control functionality to minimize invalid input;
(c) transfer of the questions directly into the EHIS (thereby displaying the data as part of the routine patient data within the clinical workplace monitor); and
(d) the possibility of easy manual adaption and administration of the questionnaires by the medical professionals who are, at the same time, the medical researchers.

The system was developed by applying a four stage User Centered Design: paper mock-up studies, low-Fi prototypes, Hi-Fi prototypes and the developed system testing.

2. Background and related work

The usefulness of mobile computing applications in the area of Medicine and Health Care is commonly accepted [13]. Although many computer systems in the past have not paid off, retailers, service providers and content developers are still very interested in mobile applications that are able to facilitate efficient and effective patient care information input and access, thereby improving the quality of services [27]. Since the first mobile health care applications, many different methods have been used to evaluate them, for example:

A study with 153 outpatients, performed by Richter et al. [38], evaluated, the feasibility of electronic data capture of self-administered patient questionnaires using a Tablet PC for the integration in a routine patient management. They also compared these data with results received from corresponding paper–pencil versions and checked quality and validity of the data obtained using the Tablet PC, as well as the capability of disabled patients to handle them. Results showed that scores obtained by direct data entry on the Tablet PC did not differ from the scores obtained by the paper–pencil questionnaires in the complete group and in the disease subgroups. No major difficulties using the Tablet PC occurred, and the authors report on the contribution of the Tablet PC to patient empowerment [38].

A study by Hess et al. (2008) researched the assessment of a self-administered tablet computer based questionnaire in routine clinical care. Between January 2004 and January 2006, the authors asked 10,999 patients in a university-based primary care practice to provide routine screening information using a touch-screen tablet computer-based questionnaire. After completing their first questionnaire, patients reported on their level of difficulty using the tablet computer. They calculated the reported level of difficulty experienced using the tablet computers (no difficulty, some difficulty, a lot of difficulty) based on patient age, sex, race, educational attainment, marital status, and the number of co-morbid medical conditions. However, the majority of primary care patients (84%) reported no difficulty using a self-administered tablet computer-based questionnaire [15], with only 3% reporting a lot of difficulty. Significant predictors of increased difficulty included: increasing age (odds ratio (OR) 1.05, 95% confidence interval (CI) 1.05–1.05); education below high school level (OR 3.0, 95% CI 2.6–3.4); and the presence of co-morbid medical conditions (1–2: OR 1.3, 95% CI 1.2–1.5; $\geqslant$3: OR 1.7 95% CI 1.5–2.1).

Jen et al. [27] reports on an mobile outpatient service system (MOSS) which focuses on illness treatment, illness prevention and patient relation management for outpatient service users within a local hospital in Taiwan, including a study on outpatient satisfaction wherein about 89% of participants indicated that they were satisfied with their system.

A study by Reuss et al. [37] showed that it is essential to obtain empirical insight into the work practices and context in which a mobile system will be used. They investigated how 14 physicians of a Swiss hospital worked with the patient record during their daily round. They reported that physicians show clear preferences for accessing and interacting with the patient record during their daily round. A CPR system, designed to reflect these access frequencies and patterns and improve the efficiency of data entry and retrieval.

In their review on mobile computing in hospitals, Lu et al. [34] identified that usability, security concerns, and lack of technical and organizational support, as well as lack of seamless integration in enterprise hospital information systems, are the major obstacles in the adoption of mobile computing in hospitals.

Finally, one study describes a mobile solution, the COW (computer-on-wheels) system [7]. The two systems, COW and MoCoMED-Graz, share the goal of converting paper-based documents to digital records in order to save time and to cut down redundancy. Both use mobile technology for employment in hospitals and ambulances. Whereas COW has been developed only for use by nursing staff, the MoCoMED-Graz system includes all medical levels: the patient (microsystem), the medical professionals (mesosystem) and the hospital managers (macrosystem).

To achieve the maximum benefit by making useful, usable and enjoyable applications, particularly in light of newly available devices, such as mobile computers, the application of a User-Centered Design (UCD) approach is strongly recommended [35,14,30]. Some key principles of UCD methods include understanding the end users and analyzing their tasks; setting measurable goals and involving the end users in the complete design cycle. Based on previous work [20,16,22,24,21,26,23] we applied a UCD process in the project MoCoMED-Graz.

Despite recommendations that patients should be involved in the design and testing of health technologies, only a few papers in the past reported on how to involve patients in systematic and meaningful ways to ensure that applications are customized to meet their needs [31]. A paper by Dabbs et al. (2009) reports on user-centered design of a Pocket Personal Assistant for Tracking Health [9].

Contrary to usability studies in laboratories (e.g. [39]), we designed and tested our application in the real life hospital. Many projects in the mobile computing area are mainly technology driven, lacking validation and evaluation. Moreover, previous projects had not at this time viewed the development from the three level perspective: patients – doctors – managers, to which we were inspired by Bronfenbrenner's [4] Ecological Systems Theory (EST), which is in the field of child development. Bronfenbrenner postulated four types of nested environmental systems and bi-directional influences within and between these systems: Microsystem: Immediate environments (e.g. peer group), Mesosystem: comprising connections between immediate environments (in Bronfenbrenner's view a child's home and school), Exosystem: external environmental settings which only indirectly affect development (such as parent's workplace) and Macrosystem: The larger cultural context (culture, national economy, political culture, subculture); He later added a fifth system, the Chronosystem: the patterning of environmental events and transitions over the course of life.

Although this theory deals with a different field of study, its basic concepts are applicable and were adapted to our purpose by reduction to three levels:

Microsystem: the patient (Patient–Computer Interaction).
Mesosystem: the medical professionals (Professionals–Computer Interaction and Professionals–Patient interaction).
Macrosystem: the Hospital managers (Managers–Professionals Interaction).

Hospital managers increasingly demand evidence that a new information system will provide an overall benefit to patient and staff, as well as cost-effectiveness, in order to justify investments. In order to provide this data, adequate evaluations of such systems at all three levels is required.

3. The MoCoMED-Graz system

3.1. User Centered Design and development

The first step in this project was to determine the project requirements, clinical context and environment, primary end users, secondary end users and stakeholders.

(1) Technical environment: Our first proposal was the use of touch based Tablet PCs; however, the disadvantages included the possibilities of theft or destruction, potential misuse and end-user difficulty, particularly with regard to the lack of a keyboard, outweighed the advantages of the system. Stakeholders proposed the installation of a solid kiosk station [17]; however, while this would solve some problems, it would have restricted mobility. The solution was a trade-off, which later proved to be an absolute optimum: We decided to build a client–server system with a thin client solution at the front-end using a mobile device. We tested several mobile devices and looked for their advantages and disadvantages before selecting a final device.
(2) Physical surrounding: We proceeded by collecting as much information as possible about the intended workplace and surrounding environment. Actually, the work atmosphere within an outpatient clinic is difficult, hectic and chaotic, with both high and low levels of lighting having an impact on end-users. Our original idea of providing audio feedback proved to be inappropriate due to the high noise level. The infrastructure of the implementation place and the available space and furniture were studied, in order to ensure safe and comfortable operation of the system. This included sitting and standing positions and posture while using the mobile device within a totally mobile setting or with the adjustable wheel table.
(3) Context: The social and organizational context is often neglected but is essential for the success of any system. Factors within our project included general structure: hours of work; team work; job function; working practices; assistance; interruptions; management structure; communications structure and IT policy and organizational aims. Incorporated attitudes towards the system, as well as work characteristics such as job flexibility, valued skills, performance monitoring and feedback, discretion were also taken into account.

It is important to consider the staff and management structures in which the proposed system will operate. In particular, the role of the end users with respect to new procedures associated with the system must be considered, their learning requirements and potential problems. The possibility of offering support should be calculated and suitable support mechanisms should become part of the user requirements specification. In our case, privacy was also a key issue, and the consideration that end users want to feel safe and secure in performing their tasks. If the system does not provide the impression of safety (avoidance of loss of privacy) and security (assurance that only the medical staff is accessing the information provided) users will not perform well.

The effort spent on each phase was as follows:

Conceptual phase: 1 Person Month.
Front End Design phase (Level 1–Level 3 Prototyping): 2 Person Months.
Front End Implementation phase: 1 Person Month.
Back End Implementation phase: 1 Person Month.
Redesign phase: Redesign & Reengineering: 1 Person Month.
Evaluation phase: 1 Person Month.

The complete effort for this project to date was 7 Person Months and a further 0.5 Person Months per year must be calculated for the service phase.

3.1.1. Level 1: Lo-Fi prototyping: paper mock-up

The term paper mock-up means "to prototype the screen designs and dialog elements on paper" [42,36,16], which proved to be an easy and efficient method. With standard office supplies, each interface element, e.g. dialog boxes, menus, error messages, sliders (see Fig. 3) were sketched. This led to an trouble-free creation of alternatives since the ease of alteration encouraged suggestions. We performed the studies at this early level with $N = 10$ different people (see e.g. Figs. 3 and 4), using thinking-aloud and video analysis [24] in order to eliminate possible pitfalls resulting from the average age of the patients. The experiments were repeated until no further findings were gained.

3.1.2. Level 2: Hi-Fi prototyping

As a result of their experiments, Virzi et al. [40] stated that with low-fidelity and high-fidelity prototypes substantially the same set of usability problems can be found. Our experience with this project does not fully confirm this: the difficulties experienced by the users during the paper mock-up studies tended to be more concerned with interaction, while at the Hi-Fi level (Fig. 5), we found the content, i.e. the wording and understanding of the questions, caused more problems. Therefore, we recommend low-fidelity prototypes to encourage the end users inclusion in the design process, while iteration in high fidelity prototyping enables the polishing of all details and the consideration of performance measures.

3.1.3. Level 3: real-life

It is essential to test the final version in full operation within a real-life setting (Fig. 6).

Fig. 3. One of our elderly patients is operating the paper mock-up.

Fig. 4. An elderly patient testing various input possibilities on paper.

Fig. 5. An elderly patient is operating a Hi-Fi prototype with full functionality.

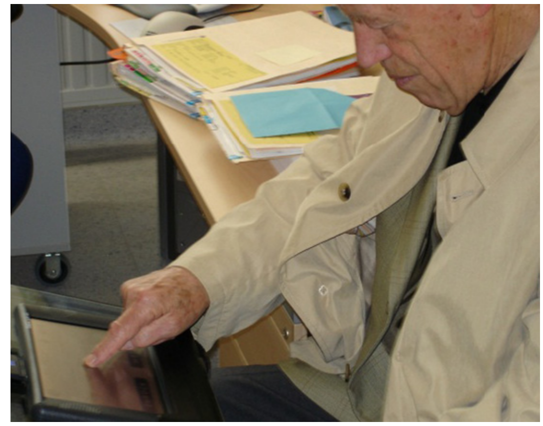


Fig. 6. An elderly patient using the implemented system on the SkeyePad in real-life.

Although developing applications for mobile computers is considered to be different than for desktop computers [41,29,6,18], many of the general guidelines and experiences from desktop interfaces, especially experiences from touch-based interfaces [20,17,16], as well as general usability engineering methods [19] are applicable.

The intensive study of end user methods and requirements by the application of paper mock-ups resulted in a great advantage and clear benefit. Some advantages were that the first sketches allowed an immediate usability feedback and it proved to be inexpensive to produce, with a maximum feedback for minimum effort. At the beginning of our project, we were able to concentrate on abstract interface concepts and not on technological details. Nevertheless some disadvantages also appeared: It was relatively difficult to simulate interface behavior and, in combination with the applied thinking-aloud and video-analysis, it needed far more time than was theoretically predicted because the preparation, post-editing and post-processing time could not always be anticipated accurately, e.g. Beaudouin-Lafon and Mackay [2].

The high-fidelity prototyping had the advantage that the end users could work directly with the interface and be studied in a more realistic setting, however, this scenario still did not adequately represent the final system. At the completion of the final experiments, we had discovered that the primary difficulties experienced by our elderly users were of a semantic nature [25], we therefore implemented iterative improvements in the design of the questionnaire content, including words, phrases and familiar, intuitive concepts.

The feedback from the different groups of elderly patients consulted at each iteration, enabled us to follow an aesthetic and minimalist design: the dialogs contained no irrelevant information whatsoever.

As a result of the insights gained into the end users behavior, we also built a time-out trigger function to activate a graphical hint (red arrow) whenever there is no user input for a certain amount of time encouraging the end users to touch the next button. Initially, we considered audio feedback but the noise within the clinical environment made this inadvisable. The thinking-aloud method revealed – despite a fairly small number of end users ($N = 10$) – why end users preferred certain interactions, consequently, we could optimize both interaction and content. In particular, early clues definitely helped to anticipate and trace the source of problems in the early stage of design in order to avoid later misconceptions and confusion. Disadvantages included: nearly all the people observed perceived this method as strenuous, it took a lot of time and preparation, and 6 out of the 10 people were hesitant to voice negative criticism. With this method, there is always the danger that previously computer illiterate end users generally feel inhibited, which consequently slows down the thought processes, thus increasing mindfulness (which is normally good, but creates a bias because it may prevent errors which otherwise would have occurred in actual use). Generally, these experiments were time consuming since it was necessary to prepare the end user with a careful briefing. Here, it is interesting to note that some elderly end users refused even to take part in the experiments when they heard the word "computer"; however, if we emphasized that we only wanted to test a newly developed questionnaire, the people were more likely to participate. This is possibly due to the fact that elderly people have had less exposure to computers and therefore have a total misconception of the capability of computers. Generally users interact differently with mobile devices than with PCs (see for example [8,28,3]). This does not quite apply to our case, since we used a device with a resolution of 800×600 pixels in our application. However, it is still absolutely necessary to reduce the text input to a minimum, as it is much easier to select values from a list rather than enter text in an input field.

3.2. Systems architecture

We used an XML interface as the technical protocol, because the data collected by MoCoMED-Graz are directly transferred into the countrywide Hospital Information System, openMEDOCS, a customized SAP ISH-Med product [12].

In new workflow (see Fig. 7, and compare with Fig. 2), the patient reports to the central administration desk of the outpatient clinic of the Dermatology department. There, they are registered

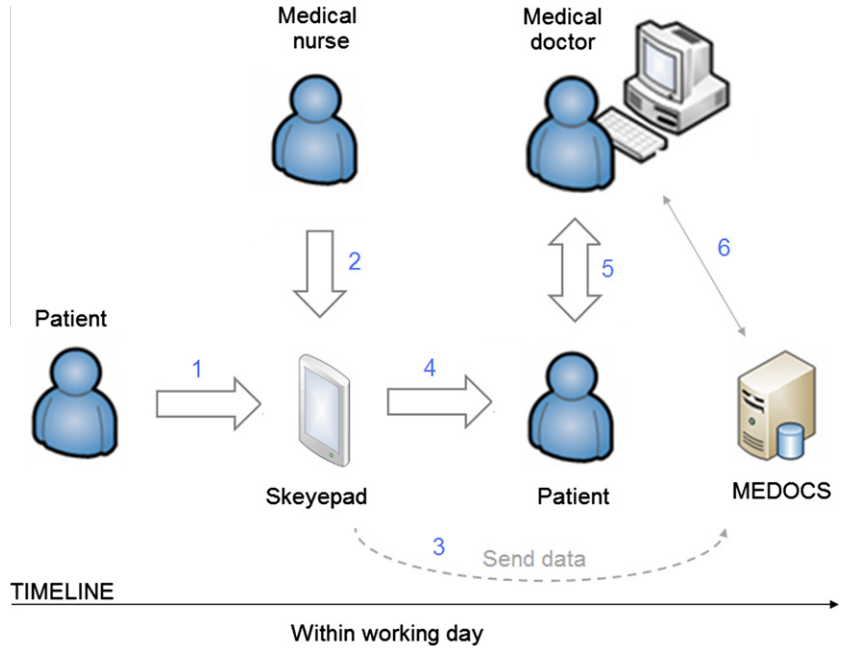


Fig. 7. The workflow after MoCoMED-Graz was developed.

into the pigmented lesion outpatient clinic via the MEDOCS administration program. At the clinical workplace, a list of the waiting patients, who have been registered already in the system but not yet released by a medical doctor, is displayed, flagged to show whether or not they have already filled out a questionnaire. This is indicated by means of text and/or a symbol and differentiates between a questionnaire which has been made available to the patient, a questionnaire filled out on the current day; and a questionnaire, which was completed by the patient during a previous visit (non-current date) and is still available. When no questionnaire is available the flag column remains empty. The medical doctor or the nursing staff of the clinic can decide whether the patient should complete a questionnaire and whether this should be the long or the short version. Clicking on the relevant icon generates the empty questionnaire and registers it in MEDOCS using a unique identification code which identifies the patient unequivocally as the user.

Using an XML communication, the patient identification number (PID), the unique number of the document (document number at the top of the questionnaire) and any further data (e.g. name, date of birth) considered necessary by MoCoMED-Graz, are transmitted.

At the terminal, the patient is equipped with a touch based Tablet PC and a code, with which he/she can login to MoCoMED-Graz and complete the questionnaire following a touch based application. The authentication at MoCoMED-Graz is necessary for data security reasons, so that no patient can access other data and patients avoid mistakes or errors. The code is a unique identification number, generated by and linked with the enterprise hospital information systems patient record MEDOCS, ensuring that the proper patient enters the data. An incorrect code entry prompts an error message and the data is not accepted by the system.

After the questions have been answered and the questionnaire is completed, MoCoMED-Graz transfers the questionnaire into MEDOCS. The corresponding column in MEDOCS now shows the status "questionnaire was filled out on the current day". This process must take place with the minimum possible delay to allow an uninterrupted workflow in the outpatient clinic. As soon as the patient has completed the questionnaire, the XML file containing the answers is stored on the server and subsequently transferred to MEDOCS by using a remote function call (RFC). The XML document containing all answers of a patient includes, of course, the unique identification of each question (see the system architecture in Fig. 8).

The front end software was developed for an 8.4 in. 800 × 600 dots Skeyepad XSL touch tablet running Windows CE.Net 4.2 OS, transferring the data in XML to the SAP based openMEDOCS Hospital Information System (see Fig. 9). The Skeyepad XSL Touch Tablet uses a PXA255 CPU, 400 MHz, 128 MB SD-RAM, 128 MB Flash, 8.4″ SVGA TFT, 800 × 600, Touchscreen, Silicon Motion Graphics accelerator with an 8 MB memory, WLAN IEEE802.11 g, USB Host, USB Device, RS232, PCMCIA Slot Typ II, CF-Slot Typ II, Weight = 900 g, Thickness = 30 mm, Size = 240 mm × 160 mm; Costs in May 2010 were approx. 1.600 EUR per device.

4. Assessment methodology

A wide variety of approaches and methodologies have been applied in assessing the impact of information systems in health care, ranging from standard controlled clinical trials and the application of usability engineering methods [19] to the use of questionnaires and interviews with end users [33,32]. According to [ISO 9241-11] there are three key aspects of usability: *efficiency*, *effectiveness* and *satisfaction*. The last aspect is important to the assessment of how users are getting on with the software. Low satisfaction scores inevitably mean that usage of the product either is or will be attended by feelings of stress in the end users.

Due to the simplicity of the MoCoMED-Graz user interface, we used the System Usability Scale (SUS), developed by Brooke [5] to measure the end user acceptance and general usability. The SUS is a rapid to use and valid tool for capturing end user's subjective rating of a system's usability. Results from the analysis of a large number of SUS scores show that the SUS is a highly robust and versatile tool for usability professionals [1]. We developed a German electronic version of the SUS, which was unobtrusively integrated into the questionnaire, enabling us to complete our microlevel evaluation during the daily clinical routine and automize the administration of the survey.

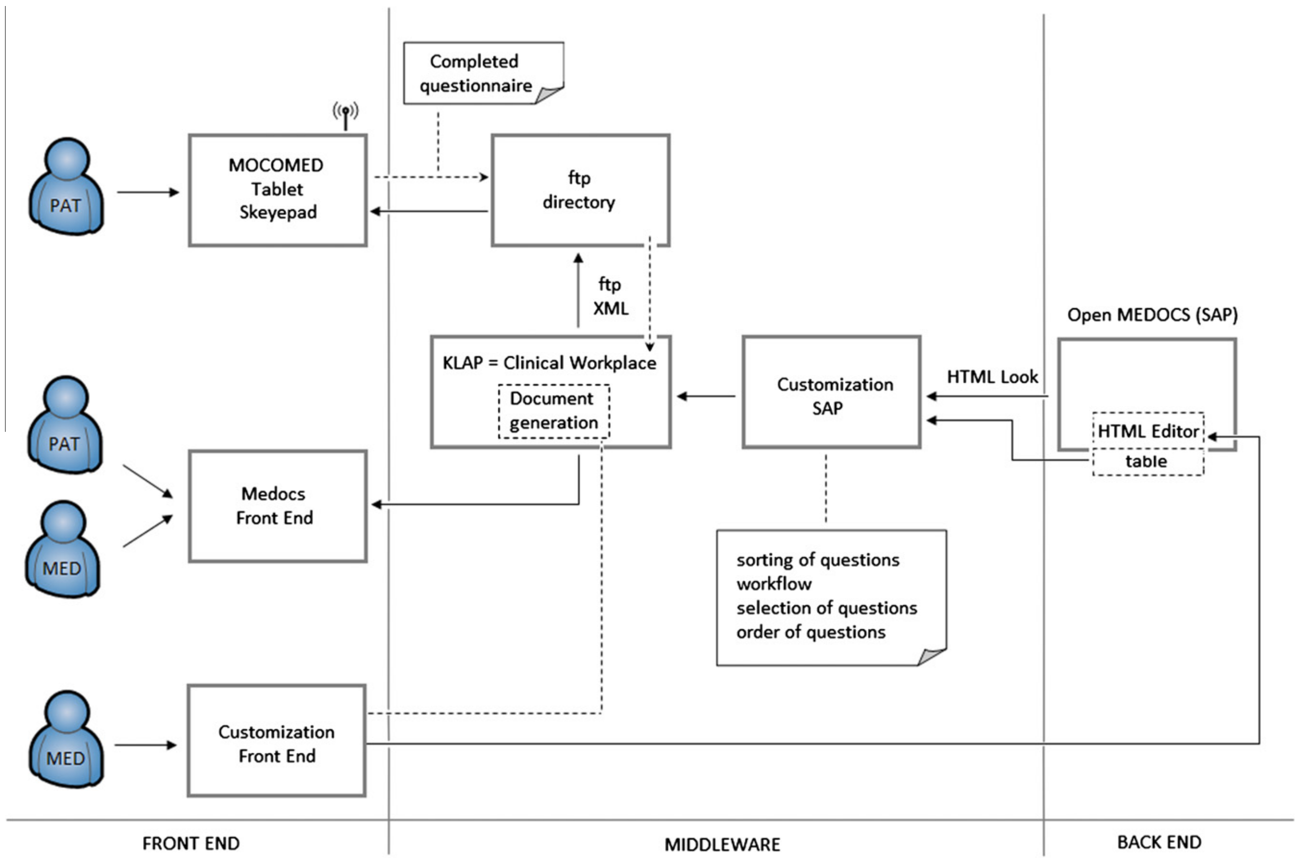


Fig. 8. The system architecture showing the three-tier concept: front end, middleware and back end.

Fig. 9. The application in service at the pigmented lesion clinic, University Hospital Graz.

5. Results and discussion

5.1. Evaluation on microlevel

From 200 completed questionnaires, we used 194, 6 have been discarded, because one had no answer to question 4 (missing value) and five of the patients were below 11 years of age. The user statistics is shown in Table 1.

The results show clearly that the values of the SUS exceeded our expectations (see Table 2).

The Cronbach's alpha showing the internal reliability was $a = 0.843$ for the LONG FORM and $a = 0.735$ for the SHORT FORM, which indicated the valid reliability of the 10 Items SUS. Interestingly, there is no significant correlation between age and the SUS results (see Table 3), which indicated that MoCoMED-Graz is usable independent of age.

5.2. Evaluation on mesolevel

20 Medical doctors (age median 43 years; min: 29 years, max. 50 years) were observed. For the paper questionnaire they needed an average of 10 min (min: 8 min, max: 14 min) to enter the data into a separate database that was not part of the enterprise hospital information system. After the implementation of MoCoMED Graz, the data-entry time was reduced by approximately 90% (median: 1 min, min: 1 min, max: 4 min). One must consider that this questionnaire is for research purposes and not mandatory for routine patient treatment. Since this electronic questionnaire is now part of the routine electronic patient record, it is available on the clinical workplace of the doctors, and already visible to them when the patient enters the ward and there is the opportunity to directly discuss patienttś misunderstandings or problems with data entry. Before MoCoMED, the data was incomplete or simply missing, this project has addressed this problem resulting in a reduction of input errors and an overall enhancement of the quality of the available patient data.

5.3. Evaluation on macrolevel

From the hospital managerś point of view, this method may serve as a valuable tool to achieve extensive surveillance data with limited resources, to reduce human errors to a minimum, and to create standardized data sets for further analyses, thus improving skin cancer prevention and quality of care. As patients

Table 1
Basic statistics of the LONG and SHORT versions of the patient questionnaires.

Form type	Gender	Age (years)					
		N	Mean	SD	Median	Min	Max
LONG and SHORT	Female + Male	194	37.5	13.6	36.6	12.4	78.2
LONG FORM	Female + Male	159	36.4	13.3	35.0	12.4	78.2
	Female	101	35.3	12.5	34.2	12.4	78.2
	Male	58	38.4	14.6	39.1	13.1	70.3
SHORT FORM	Female + Male	35	42.5	13.5	43.6	13.1	68.9
	Female	14	38.3	14.5	37.7	13.07	65.8
	Male	21	45.3	12.4	45.1	17.82	68.9

Table 2
Systems Usability Scale (SUS), min: 0, max: 100 scores; F = Female, M = Male, D = standard deviation, CI = confidence interval, IQR = interquartil range.

Type	Gender	Descriptive statistics SUS									
		N	Mean	95% CI	SD	Median	Min	–	Max	Range	IQR
LONG + SHORT	F + M	194	93.2		10.1	97.5	50.0	–	100.0	50.0	
LONG FORM	F + M	159	93.1	91.5–94.8	10.3	97.5	50.0	–	100.0	50.0	10.0
	F	101	93.8		9.4	97.5	55.0	–	100.0	45.0	
	M	58	92.1		11.7	97.5	50.0	–	100.0	50.0	
SHORT FORM	F + M	35	93.4	90.2–96.6	9.3	97.5	67.5	–	100.0	32.5	10.0
	F	14	93.7		10.4	98.7	67.5	–	100.0	32.5	
	M	21	93.1		8.8	97.5	67.5	–	100.0	32.5	

Table 3
Correlations of age and System Usability Scale (SUS) results.

Correlation method	Type	Correlation coefficient	*p*-Value	*N* (pairs)
Spearman's rho	Total	−.054	.454	194
	LONG FORM	−.074	.357	159
	SHORT FORM	.007	.968	35

were actively integrated into their treatment process and provided with a useful way of spending their waiting time, this may also lead to a substantial improvement in patient care services, and therefore increased patient satisfaction. Apart from the time saving benefit, an important aspect for the health system in general, which is also relevant to the hospital managers in terms of quality of patient treatment is the increased patient empowerment.

For clearly depicting the benefit for the hospital management, a scenario analysis has been made by calculating the facts in this particular outpatient clinic on the basis of $N = 30$ patients a day, 250 days a year.

Scenario 1 (without mobile computers): A doctor costs the hospital approx. 44 EUR per hour = 0.73 EUR per minute. With an average of 10 min per patient, the 300 min of extra effort required by the doctors to transcribe the questionnaires are equivalent to 219 EUR per day = 55 kEUR per year and there is the additional risk of lost and missing data.

We also tested the alternative of letting copy typists transcribe the data: They are faster median = 7 min (min: 5 min; max: 8 min), however, since they are not medical professionals they make more errors, which cannot be corrected without extra costs. Calculating on the basis of their average hourly wages results in a cost of 19 EUR per hour = 0.32 EUR per minute, we have costs of approx. 17 kEUR per annum.

Scenario 2 (using two mobile computers):

Development Costs: 7 Person Months = 28 kEUR.
Hardware Costs: 3.2 kEUR.
Original cost of acquisition = 31.2 kEUR.
Annual service costs: 0.5 Person mpy = 2 kEUR.
The reduction to only 30 min of the medical doctors time per day is equivalent to 22 EUR per day or approx. 5.5 kEUR per year.
Total annual costs = 7.5 kEUR.
Assuming an average life span of 4 years, this amounts to a total of $31.2 + (4 * 7.5) = 61.2$ kEUR, or 15.3 kEUR per annum.
Maximum total possible cost saving per year: 55 kEUR − 15.3 kEUR = 39.7 kEUR.
Minimum total possible cost saving per year: 23.5 kEUR − 15.3 kEUR = 8.2 kEUR.

5.4. Theoretical basis and advantages of our methodological combination

Since the Bronfenbrenner Model could not be applied one-to-one, the adaption of its relevant aspects required us to generate our own interpretation as to how the different levels interacted with each other. The combination of the three levels enabled us to gain insight from the viewpoint of various stakeholders. While this might seem trivial, since consulting all stockholders is a logical step in design, our research uncovered evaluations made on either a technological basis (validation) or on an end user basis (usability evaluation), and (rather rarely) on a process basis (economical validation). This particular combination of methods to form an applicable methodology, following reputable techniques, fulfilled our expectations.

The ecological systems theory by Bronfenbrenner [4] originates from child development theory and describes the interaction between various environments using a layer structure – each having an effect on a child's development. Originally, Bronfenbrenner described five such layers:

(a) The microsystem, which encompasses relationships and interactions within the person's direct environment – from the individual persons' point of view.
(b) The mesosystem, which describes the interaction between the microsystem and
(c) The exosystem, which defines the larger social system in which the person does not function directly.

(d) The macrosystem, which includes the cultural values, customs, and laws.
(e) The chronosystem, which encompasses the dimension of time as it relates to a persons' environment.

The essence is that interactions at outer levels have always impact on the inner structures.

For our purpose, we instrumentalized only three of Bronfenbrenners layers: microsystem, mesosystem and macrosystem and we them into our context:

(1) the microsystem relates to the end user and their immediate environment (end user centered human–computer interaction: user tasks, patient empowerment, ...)
(2) the mesosystem relates to the medical professionals and their environment (professional process centered human–computer interaction: work tasks, medical processes, social context, i.e. discussing the medical data together with the patient – strong influence on patient empowerment, ...)
(3) the macrosystem relates to the hospital environment (economical system centered human–computer interaction: economic issues, quality – finally reputation as enterprise, ...).

By combining these three viewpoints, we are able to determine a common denominator: quality. And exactly this attribute must be ensured when developing a system for such a highly complex environment as a hospital.

6. Conclusion and future outlook

This project serves as an example of how we can benefit all three groups of people: patients, medical professionals and hospital managers. Patients were very satisfied with the front end of the application. Medical professionals could save up to 90% of their formerly wasted time; which ultimately saves money for the hospital manager. Most important, the quality of the medical service is increased, since the newly created workflow brings together patients and doctors in front of the clinical workplace, to check whether all entries are correct.

Since robust, reliable, light and unobtrusive, uncomplicated, appealing hardware is an essential part of the success of such an application in a real-life hospital, the selection of appropriate hardware is an essential success factor. As easy to use as possible, no frills, light weight, with a long running battery (at least 6 h per day) were the primary requirements. To date, only the Skyepad (see Fig. 5) fulfilled this requirement. Preliminary tests with an iPhone showed that this would be a much more robust hardware, however, with a screen too small for most patients. A solution could be to use an Apple iPad. Consequently, further testing should be made with the MoCoMED-Graz implemented on an iPad. Finally, in order to support a wider scope of skin cancer prevention, the usefulness of the devises away from the clinic will be tested, for example during a survey study outside or in an outdoor swimming pool area.

Acknowledgements

We are grateful to Dr. Markus Pedevilla and his team for their technical support.

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