

User Centered Design of E-Health Applications for Remote Patient Management

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ABSTRACT

Researchers investigating Human Computer Interaction(HCI) issues in the domain of e-health specially emphasize the need for following a holistic framework to design interactive and user-centered mobile e-health applications. In this context, “conservative environments” – commonly experienced in rural areas of developing countries – pose a unique challenge for designing, developing and deploying e-health applications. In this paper, we present a four step framework to engineer usability for conservative environments:(1) background analysis, (2) design conceptualization, (3) iterative prototype implementation, and (4) usability evaluation. The main contribution of the paper is following a multifaceted integrated approach for conducting an in-context usability evaluation during the development phase of an application’s life cycle. We have evaluated the proposed framework on our project “Remote Patient Monitoring System with Focus on Antenatal Care” that aims to revamp the existing medical infrastructure of Pakistan by providing basic health care facilities to the remote village population – the majority lives in a conservative culture – of Pakistan. The findings of our case study also validates our thesis: adopting a number of usability evaluation approaches – focus groups, heuristic based expert evaluation and field observation study – prove useful in achieving desired goals for our mobile e-health application in the conservative environments.

Categories and Subject Descriptors

H.5.2 [Information Systems]: Information Interfaces and Presentation—*User Interfaces*

General Terms

Design, Performance, Human Factors

Keywords

User-Centered Design, e-health, Conservative Environments

1. INTRODUCTION

In recent years, the advances in Information and Communication Technology (ICT) has resulted in developing electronic medical record systems that facilitate reliable storage and retrieval of clinical data of patients; as a result, the physicians are enabled to perform an informed diagnosis. Consequently, the quality of health care has significantly improved. Varshney has envisioned the concept of “Pervasive Health care” to realize ‘*health care to anyone, anytime and anywhere by removing geographic, time and other restraints while increasing both the coverage and the quality*’ [1]. In contrast to traditional health care systems, the pervasive health systems not only keep track of clinical data of the patients but also share it in a ubiquitously fashion with interested parties through wired and wireless networks [2]. Recent advancements in mobile networks and smart phones can be instrumental in realizing the dream of a true ubiquitous health care information system. It is disappointing to note – even with ICT revolution – ubiquitous e-health applications are virtually non-existent for providing health care and services [3]. An important reason for this scenario is the incompatibility of most of the e-health applications with their work environments.

In this context, we do not need to emphasize the challenges posed by conservative environments – prevailing in rural areas of many developing countries. We define the concept of “conservative environment” as *an environment in which the majority of population adheres to the culture, social norms and religion of their ancestors – leaving no room to accept change in them*. Consequently, the environment is invariant in time and space. Its users show significant amount of resistance to advancements in the society. Their cognitive faculties are not evolved to formulate their requirements or expectations from a given system – a nightmare for an HCI project. In such an environment, introducing an e-health system has to overcome a number of challenges: (1) winning hearts and minds of its users, (2) taking into account the cultural issues such as the use of language and illustrations, (3) user processes, (4) reliable data collection, (5) setting up and configuring the devices, and doing their calibration and maintenance, (5) interactivity of physicians with the diagnostic systems, (6) accessibility issues, and (7) the presentation medium [4]. It is very difficult – if not altogether impossible – to develop stable and systematic relationship between the system and human users; as a result, the interaction mostly remains ad hoc – leading to dissatisfied and frustrated users – that becomes an impediment in its diffu-

sion within the environment.

Researchers clearly identify poor usability as one of the potential barriers in adopting e-health applications [2][5] by medical experts. Only a small number of mobile e-health systems – having a limited scope of creating health awareness through messaging and maintaining electronic medical records – are reported in the literature [6][7]. To the best of our knowledge, none of them gave attention to usability engineering as an important process in the development life cycle of the system. Hesse and Shneiderman have observed that a number of potential errors in e-health applications can be reduced and their effectiveness can be maximized by simply incorporating users’ perspectives – how individuals interact with technologies and health care systems – into interaction paradigms of e-health systems [8].

E-health researchers have empirically evaluated the effectiveness of using diverse User Centered Design (UCD) approaches in developing user interfaces for health care applications. Gao et al. in [11] have demonstrated the use of an iterative, user centered design process to create an electronic triage system for mass casualty events. Constance et al. through a case study have presented a user centered design framework, specifically for redesigning the health interfaces [5]. The strategies adopted in their framework have shown a definite improvement in usefulness of the system and its interface quality. Their major focus is on redesigning health care interfaces, and do not address the challenges pertaining to the interaction design for interfaces of e-health systems for conservative environments [12].

In this paper, we propose a UCD framework for mobile e-health applications with a special focus on their deployment in conservative environments. The goal is to interactively formulate the cognitive abilities of conservative users in the design of e-health applications to ensure maximum usability of the system in the targeted environments. To this end, we have devised a four step UCD framework as shown in Figure 1: (1) background analysis, (2) design conceptualization, (3) iterative prototype implementation, and (4) usability evaluation. We apply our framework as a case study in our project – ‘Remote Patient Monitoring System with Focus on Antenatal Care’ – that aims to revamp the existing medical infrastructure of Pakistan by providing basic health care facilities to the remote village population – the majority lives in a conservative environment – of Pakistan¹.

The remaining paper is organized as follows: The UCD framework is introduced in Section 2 followed by a thorough evaluation of our case study in Section 3. In Section 4, we give the useful insights and conclusions of our usability analysis with an outlook to our main contribution.

2. A UCD FRAMEWORK FOR CONSERVATIVE ENVIRONMENTS

Preece et al. define UCD as ‘an approach which views knowledge about users and their involvement in the design process as a central concern’ [9]. The principles of UCD are formulated on Norman’s theory – using the concept of the Human Action Cycle [10] – of user interaction for computer systems.

¹For details visit: www.rpms.nexginrc.org

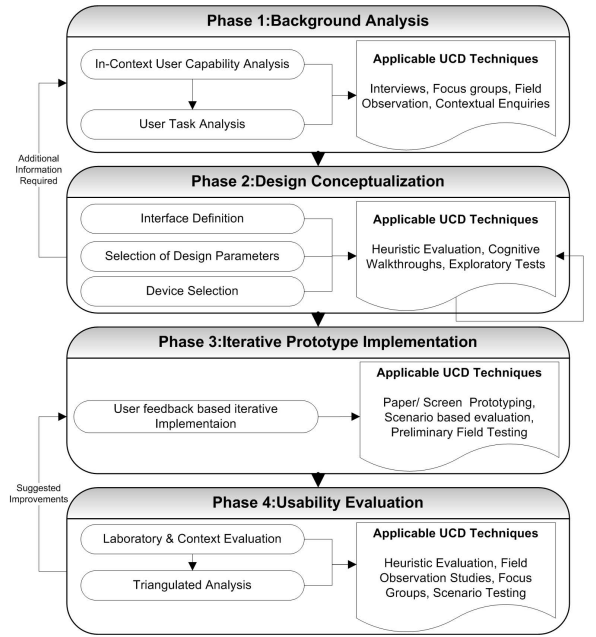


Figure 1: UCD framework for conservative environments.

The Human Action cycle emphasizes the direct impact of an environment on the behavioral aptitude and thinking process of its individuals.

In the context of conservative environments, the user activity model shows a poor correlation between a user’s psychologically expressed objectives and the physical variables of an e-health application. The main challenge is to map the psychological goals of the user – intentions, actions and behavior – into interfaces for e-health applications which users can perceptually process and interpret. This can only be achieved if the user is actively involved during the design and evaluation of the system. Researchers have already emphasized the systemic use of laboratory and real environment UCD methods to develop applications which are usable in their actual context [20]. But to the best of our knowledge, no holistic UCD framework is available that helps in developing mobile e-health applications for conservative environments. Inspired by the work of Constance et al. [5], we present a four step UCD framework to cater for this limitation (see Figure 1): **(1) Background Analysis.** Identify the problem context to get a detailed analysis of user’s capabilities and tasks with in their work context. This phase focuses on analyzing the general in-context capability of the user, gathering information on the workflows and the nature of tasks performed by the target users. **(2) Design Conceptualization.** Map the cognitive abilities and requirements of the target users before initial implementation. This stage further consists of three main steps. First, the ‘Interface Definition’ identifies the optimum interface type to display information to the user according to their respective tasks. Second, the ‘Selection of Design Parameters’ translates the identified requirements into the design principles of the interface by examining the user goals and how the users will reach these goals. Third, the optional ‘Device Selection’ stage is applicable in those contexts where a suitable

device can play a critical role in the overall user experience of performing required tasks. To facilitate the execution of these design conceptualization stages, a number of UCD research techniques – heuristic evaluations, cognitive walkthroughs, scenario based testing and exploratory tests – can be applied. **(3) Iterative Prototype Implementation.** Development of application in accordance with the design principles and improvement by gaining consistent user feedback. The user feedback can be obtained during different stages of the development. During the initial phase, a paper or screen prototype may be developed and then tested with the user. In the intermediate stages, scenario-based evaluations can be useful to identify any discrepancies or missing links in the implementation. Finally, a preliminary field survey may also facilitate identification of any major context-based usability problems. **(4) Usability Evaluation.** Though our framework recommends involvement of users and their context considerations at each stage, a formal usability evaluation phase is still relevant. In our proposed framework, we recommend the use of methodological triangulation for evaluating the usability of the application [19] because of two reasons: (1) the limited usability research in validating e-health systems mandates to look for a number of complementary or congruent methods on primary data [20], and (2) in conservative environments, it is not possible to identify the complete range of usability issues by just relying on laboratory-based methods. The usability techniques – heuristic evaluation and think aloud protocol – may provide valuable insights but they definitely cannot identify the problems faced by a user in the real environment. Consequently, it is very important to take a holistic approach to the usability evaluation – a combination of laboratory evaluation techniques and context evaluation methods like field observation – to accurately measure the usability of an application in conservative environments.

3. CASE STUDY

We now present a systematic analysis of our proposed UCD framework in a real conservative environment – an e-health application to be deployed in remote rural areas of Pakistan.

3.1 Background Analysis

Pakistan is a developing country with the majority of its population residing in rural areas having insufficient health care facilities. Our project “Remote Patient Monitoring System with focus on Antenatal Care” is designed to provide basic health care facilities to the underprivileged population at their doorstep. The current medical statistics clearly justify our cause of targeting antenatal domain: Pakistan has the highest Infant Mortality Rate (IMR) among SAARC countries standing at 70 deaths per 1,000 births and also the highest Maternal Mortality Rate (MMR) in South Asia. The catastrophic situation is aggravated by lack of medical staff as Pakistan has one physician for 1351 people, a nurse for 3225 people, a midwife for every 6666 people while only 31% of the total births are delivered by skilled birth attendants [15].

The main reasons for inefficient – virtual non-existent – antenatal care in Pakistan are: (1) Presently, antenatal care in rural areas is being provided by less-educated Lady Health Workers (LHWs), who manually perform all the steps of the patient care and record this data into printed forms. The

collected forms are then sent to a doctor who scans them for any symptom of abnormality. The cumbersome process practically results in losing useful information being in big registers. (2) The lack of awareness among pregnant women about the importance of visiting basic health centers at early stages. A number of socio-economic constraints – imposed by their family and environment – are responsible for this practise. (3) The women residing in remote villages have to travel great distances over a highly inefficient transportation system in order to reach the nearest health care center just to receive the basic health care services. (4) The influx of pregnant women at tertiary care hospitals – mostly in emergency complicated scenarios – leaves little room for medical experts to do any effective management. The population residing in rural areas of Pakistan – strictly follows their culture and social norms – is a perfect model of our conservative environment. The situation is, however, further complicated because the majority of these areas lack even basic necessities of life. Our goal is to provide ‘point of care’ decision support to the rural women in order to reduce the alarming rates of maternal mortality and infant mortality. Our proposed system has a data gathering module (DGM) consisting of wearable medical sensors and a PDA. The LHW in a remote area uses a PDA to gather the physiological data of the patient and transfer it to a remote web server where it is stored in an Electronic Medical Record (EMR) and is analyzed by an intelligent Clinical Decision Support System (CDSS). The diagnosis and corresponding treatment is then transmitted back along with the feedback of the medical expert to the Lady Health Worker for an immediate implementation of the treatment plan. For our proposed system the role of end users of our system – LHWs – is of prime importance; therefore, it is very important to center the design of our system on their requirements. Luckily, the mobile telephonic networks have been the most dynamic market in Pakistan for last 6 years with an average growth rate of 124.3% as far as the subscribers are concerned. Pakistan’s mobile sector is forecasted to grow at an average rate of 31.6% to reach 124.6 million users by the end of June 2010 [16]. Therefore, our vision is to utilize the high penetration rate of this technology – mostly used to stay connected with family and friends – to provide a ubiquitous and pervasive e-health system in rural conservative environments. We are using the setup of a US based non-government organization – Human Development Foundation (HDF) – that covers seven rural centers throughout Pakistan. Over 30 million people are receiving services from the LHW system in their villages at an average cost of PKR 26,500 per LHW per year. The case study, presented in this paper, is the story of one such rural center which covers 1000 households with the help of 6 LHWs. The medical expertise and domain knowledge is being provided by two leading tertiary care hospitals of Pakistan – Benazir Bhutto Hospital (BBH) and Pakistan Institute of Medical Sciences (PIMS). An interested reader can find more details in [14].

3.1.1 Context based User Capability Analysis

We conducted field interviews and contextual enquiries with LHWs and rural village population to analyze the skills and capabilities of our users. LHWs are responsible for providing preventive, curative and rehabilitative services to the community. The selection criteria for LHWs is that they should have passed 8th grade school examination and be the local resi-

dents of their targeted villages. The average age of LHWs is 22 years and most of them are not married. They have the basic domain knowledge required to interact with the patients. Most LHWs routinely use mobile phones for interacting – using voice calls or Short Message Service (SMS) – with their family and friends. The LHWs being the residents of the targeted village, understand the jargon, used in the local community for pregnancy related issues, and the socio-economic status of their patients. The residents LHWs are a blessing for the local population because they do not allow nonresident women into their houses – a typical practise that prevails in the population of a conservative environment.

3.1.2 User Task Analysis

The main job of LHWs is to do periodic checkups of patients – residing in their area of responsibility – and maintain their medical records. The checkups are classified into two categories: Booking Visit and Routine Visit. In a booking visit, the LHW registers a new household by logging basic medical history of the women. The medical history is further categorized into personal information, past medical history, family history, social history, previous pregnancies, gynecological history and general examination. In a routine visit, they physically examine the antenatal patients to determine the weeks of gestation, fundal height, presentation, edema, anemia and measure physiological data – blood pressure, temperature and pulse. The LHWs record above-mentioned medical data of the patient in their register and report it back to a doctor in the nearest health center. Each LHW visits approximately 14 different households every day; as a result, a particular household is visited only once in a month. The average time spent by a LHW with a patient is about 5 – 8 minutes in which she records the basic information. Each LHW carries about 5 Kg bag that contains registers to record patient information and basic instrumentation devices – blood pressure monitor and temperature sensor. The LHWs have no special training period in which they are trained to conduct these visits. Our observation is that they can adapt to a new system, if they are convinced that it is going to help them in conducting their visits efficiently.

3.2 Design Conceptualization

3.2.1 Interface Definition

The existing registers used by LHWs are poorly designed because the text boxes are simply cluttered on the pages; as a result, it leads to a number of errors during the process of entering patients information. Our first objective is to design simple and user friendly data entry electronic forms, which semi-skilled semi-literate LHWs can enter with a minimum (2 to 3 days) training. To achieve this objective, we have designed a form-filling interface that can be directly manipulated as well. Consequently, the interface guides LHWs through the form-filling process that helps them to enter the data even with their limited domain knowledge.

3.2.2 Selection of Design Parameters

Based on our analysis of the work environment of LHWs and their task flows, we have agreed on essential design parameters – shown in Table 1 – that would align our mobile

Table 1: Key design parameters for PDA application.

Design Parameter	Relevance to PDA Application
Learnability	Interface should provide LHWs with complete guidance to carry out their tasks. Instructions for use of the application should be visible or easily retrievable whenever appropriate.
Natural Mapping	The workflow of the application should be similar to the current practice of LHWs. Familiar terminologies like ‘Booking Visit’, ‘Routine Visit’ would be used. Further the interface should allow them to enter data in the same units in which are used to, for instance, weight in ‘Kgs’ and Height in ‘cm’
Ease of Navigation	Navigation choices and exit points should be clearly marked for the LHWs. The interface should indicate when to store data, when to move next and display confirmation messages where applicable.
Information Visibility	The information should be presented in natural colors following the real-world conventions. For instance, red color to represent an active while black color to show an inactive text box, while bright colors as markers to select the checkboxes or radio buttons
Consistency & Minimilast Design	LHWs should not have to wonder whether different words, situations, or actions mean the same thing. Interface should use consistent language and notations. of LHWs, the interface should be simple without any distracting widgets and choices
Error Prevention	Keeping in view the critical nature of the data being entered, error-prone conditions should be eliminated wherever applicable or be checked and confirmed before the users commit an action. For instance, do not allow LHWs to enter weight as four digit number in ‘Kgs’
Error Detection & Recovery	In case of an error, the error messages should express the problem plainly and precisely with proper solution. For instance, if the LHWs enter age below 10, the error message should clearly indicate the range in which the value of age is valid.

e-health application with the mental model of our target users (LHWs).

3.2.3 Device Selection

We have realized that proper attention must be given to the selection of the mobile phone – housing the data entry module of our e-health application – by taking into view the feedback of LHWs. At this stage, we cannot afford to make an error because it would become an impediment in successful adoption and diffusion of our system in the constrained environment. Therefore, we gathered requirements directly from the user to eliminate interminable arguments (from designers and vendors) about the right device selection [17]. The data sources used for soliciting device requirements are given in Table 2. We have used interviews, exploratory tests along with screening, and the post-test questionnaires to gauge user requirements for device selection [18]. The outcome of our user task analysis is the conclusion that the most critical factor in selecting a device is the user friendly mode of data entry. We have used four different types of hand-held devices with various styles of data entry to gather the LHWs feedback. The analysis of the screening questionnaires clearly reflect that LHWs are novice users of the mobile phones – most using voice call and SMS features –

Table 2: Data sources for soliciting device requirements.

Participant Category	Total Number	Age Group	Experience (Years)	Mobile Users
LHW's	6	18 – 26	1 – 3	4
Medical Specialists	4	27 – 55	2 – 20	4
Mobile Experts	4	22 – 37	3 – 5	4

Table 3: Post test questionnaire data view: TS – Touch Screen, KP – Keypad.

No.	Question	Opt. 1	Opt. 2
1	Do you use Mobile Phone Regularly?	Yes(4)	No(2)
2	Is it easy to fill the data on the mobile than on the register?	Yes(6)	No(0)
3	On which device(s) is it easier to fill in the data?	TS(5)	KP(1)
4	It is easy and quick to add data using numeric keypads	Yes(2)	No(4)
5	Procedure to fill form is easier using touch screen	Yes(5)	No(1)
6	Proceeding to the next window instance is easier in touch screen based PDA's?	Yes(5)	No(1)
7	It is difficult to put the data in the text boxes using stylus?	Yes(2)	No(4)
8	It is helpful to use the color of the enabled text box in determining the actions to be made?	Yes(5)	No(1)
9	It is difficult to select the right option(s) on the choice groups using stylus?	Yes(0)	No(6)
10	With which device more errors are made?	TS(1)	KP(5)
11	I prefer aesthetics and design of which device ?	TS(4)	KP(2)
12	If I am given an option to choose a device to fill the mother care form, my choice will be?	TS(1)	KP(5)

and have little knowledge about advance features available in different mobile phone sets. In the exploratory tests, the LHWs have performed various data entry tasks on a dummy form-based application, which has text fields for patient's name, age, height and weight etc. It also contains few check box and radio buttons based selection fields to analyze their comfort level with the device for different type of form fields. The data collected from this testing activity includes video recordings, hand taken observer's notes and post test questionnaires. The post test questionnaires includes both open ended questions and closed ended questions. We summarize the results obtained from answers of the closed ended questions in Table 3. Moreover, we have also conducted interviews with the medical experts to get an understanding of their views on the capabilities of LHWs and their opinion on the suitability of different types of devices.

Data Analysis. Our first impression is that the LHWs need a self-guiding tour of the data entry process because they need to browse through at least 14 – 20 screen instances to complete one form on PDA/hand-held device. (In comparison, they used to fill the same information on 1 to 2 pages of the manual register.) We have seen that using the numeric keypads for data entry process is cumbersome for the LHWs because they lack the skills to use the hand-held devices for work purposes. The complexity is further aggravated by the fact that they have to enter records of 25 – 30



Figure 2: PDA application: actual and simulator implementation.

patients on a daily basis. The touch-screen enabled device has proven to be more useful in the data entry process because it does not expect them to remember the buttons and the sequences. The user feedback data in Table 3 indicates that LHWs feel more comfortable with the stylus based data entry mode as it aligned more closely with their current register data entry model. The semi-structured interviews with the medical experts also report consensus on the need to select a device that can easily replicate the pen-paper style of the data entry mode to facilitate a smooth transition for LHWs. As a result of these convergent findings, we have selected stylus based touch-screen device (i-mate JAMA) for our e-health application.

3.3 User Feedback Driven Iterative Prototype Implementation

For the prototype implementation, our aim is to follow an application development cycle closely guided by continuous input and feedback from the LHWs. The application is developed using J2ME. As this analysis focuses on the evaluation of the UCD framework; therefore, we skip technical details of the interface design for brevity. We used the results of the background and design analysis to build simulation-based prototype of data entry screen instances. This initial prototype proved useful in outlining high level navigation and presentation of the interface. The LHWs have performed various data entry tasks by using think aloud protocol. We have identified a number of usability issues in an early stage of our development cycle – the wrong sequencing of the fields, lack of familiarity of LHWs with some terminologies, requirements regarding availability of the help messages and need for adequate status messages to guide the navigation process – because of our UCD approach. After the development of first iteration of the prototype with the suggested improvements, we have conducted a field visit to gather the user feedback in their constrained environment. During the field visit, the six LHWs performed data entry tasks by directly interacting with their patients. The findings from the field visit highlighted various usability concerns attributed to the conservative work environment: (1) lack of confidence of the LHWs to use the application while doing a live interaction with real patients, (2) skipping certain fields by the LHWs in order to conclude their visit in a hurry, and (3) mistakenly closing the application by inadequately responding to the warning messages. To elevate the confidence of the LHWs with the interface, we have also

Table 4: Focus groups setup at our research center for duration of one hour.

User Group	Total No.	Key Characteristics	Recording
LHW's	7	Aged 18 – 25 (End Users)	Audio & Video
Physicians	6	Aged 25 – 50 (Domain Experts)	Audio
Usability Experts	6	Aged 20 – 30 (System Designers)	Audio

conducted some in-house training workshops to increase the adaptability of the user with the device and the application. Moreover, we have introduced adequate navigation restrictions – supported by guiding error messages – to avoid the problem of storing incomplete forms.

3.4 Usability Evaluation

We now present our concrete findings acquired by the application of the research techniques that are part of the overall methodological triangulation. The techniques include: (1) focus groups, (2) field observation, and (3) heuristics based expert evaluation. For the purpose of usability evaluation of the PDA interface, we do not combine the obtained data sets; rather, we have triangulated acquired findings to avoid violating any inherent assumptions of each of the selected research techniques.

3.4.1 Focus Groups

The focus groups explored the extent to which the interface meets the expectations and perceptions of the users as well as the domain experts. In addition to this, we also take the designers opinion to identify any potential gaps between the user and designer mental models. Table 4 presents the demographic details of the participants.

The focus group with LHWs have demonstrated a notable confidence and the command of the users of the application. In the discussion session, the participants have expressed their satisfaction on the overall information layout and visibility. Further, the participants also appreciated the error recovery and detection attributes of the interface. Regarding the difficulties and suggestions for improvement, the participants recommended improving the aesthetics by using different background colors for each type of form. They unanimously rejected the idea of taking and storing the photographs of the patients in our e-health application because of the conservative working environment – the male members in the environment consider this as an intrusion into their privacy. The participants suggested that they should be allowed to select from the standard ranges for height and weight instead of asking them to enter them in the text boxes. The opinion of physicians concurred with the opinion of LHWs: diminution of text entry – the data entry is cumbersome – and instead provide options using check boxes and radio buttons. Further, the physicians appreciated the interface for its user friendliness, and adequate exception handling to avoid any errors in data entry. The physicians have also suggested to improve the aesthetics of our e-health application. But their recommendation contradict with that of the LHWs. The designer participant group has also recommended the use of the advanced selection widgets like drop down lists for those fields which have

Type of Form	Screen Transitions	Avg. Time - PDA	Avg. Time-Register
Booking Visit	25	3 minutes	2.4 minutes
Routine Visit	14	2 minutes	1.8 minutes
Previous Pregnancy (per iteration)	10	1 minute	0.8 minutes

Figure 3: Field evaluation results.

large list of selection options. Unlike LHWs, they perceive extensive use of scroll bar not a major usability concern. In general, the focus groups clearly identify close alignment of the designer's and user mental models. However, the user revealed some minor usability gaps – improving aesthetics and the usefulness of text entry.

3.4.2 Field Observation Study

For effective usability evaluation, it is vital to cater for the distinct nature of the conservative working environment of the LHWs. We held a total of 8 test sessions of 50 minutes each in two distinct locations. First at Benazir Bhutto hospital, and second in the vicinity of the LHWs local health center where they visit patients. Six LHWs and six physicians participated in our trials. Our main objective of this field observation is to evaluate the impression of the LHWs and physicians during the data entry process. We primarily focus on LHWs interaction with the PDA application by capturing their facial expressions along with their hand and finger movements. The factors that complicated the overall data collection are – the problematic spatial layouts and noise in the surrounding areas. The LHWs collect data from the patients that visited the health center for their routine checkup. The observations recorded while LHWs performed their tasks: (1) the type of the form that LHWs has to fill, (2) the time to complete the form, and (3) and the videos of LHWs interacting with the patients. Every LHW has attended six patients and entered their data using our e-health application. Figure 4 presents a summary of the average time taken by the LHWs to fill each type of the form – the complexity of the task is indicated by the number of screen instances associated with each form. We can safely conclude that the average time to fill a form manually is only marginally smaller compared with the average time to fill the form using a mobile phone. Moreover, the negligible difference almost diminishes with the decrease in number of screen instances. The macro analysis of the video recordings show great confidence of the LHWs in using the application; however, there are certain minimal barriers that still impede the LHWs abilities to effectively use the system. The notable interface limitations are – narrow scroll bars and limited use of colors to indicate inter-form transition.

The videos and field notes provide a rich record of encounter. But in order to gain further insight into the usability issues of the interface, the participants (6 LHWs and 6 Physicians) have been also given a post-test questionnaire. The questionnaire is a modified version of CSUQ [21] that is customized to evaluate the alignment of the PDA interface with the design principles described in the previous section. For each of the fifteen questions, the user has to select between four options which are assigned weights from 1 to 4 i-e selecting option 'a' has a weighted score of 1 which means lowest from the usability perspective and selecting option



Figure 4: Field Observation: LHW entering patient information using PDA.

Table 5: Post-Observation questionnaire response: I1 – Net usability score in Iteration 1, I2 – Net usability score in Iteration 2.

No.	Question	I1	I2
1	Difficulty level of the interface	28	40
2	Degree of comfort with the interface	28	41
3	Aesthetics of the interface	15	33
4	Interface is fun to use	33	33
5	Characters on the PDA interface	41	41
6	Organization of information on the PDA screen	36	44
7	Sequence of the screens	37	40
8	Learning to operate the application	31	42
9	Remembering names and use of commands	33	43
10	Task can be performed in straight forward manner	33	40
11	Entering numeric values	42	42
12	Writing text using on-screen virtual keyboard	37	40
13	Interface guides you about what to do next	38	40
14	Error messages and warnings	32	42
15	Correcting errors	34	40

‘d’ has a score of 4. The questions² are asked to evaluate the usability of the application in terms of comfort (1-2), aesthetics (3-4), visibility and navigation (5-7), learnability (8-10), data entry (11-12) and context-aware capabilities (13-15). The results are compared with the questionnaire based feedback collected during preliminary field visit (see Table 5). In order to evaluate the statistical significance of the results, we have performed the standard non-parametric Wilcoxon signed ranked test. The test showed a significant difference between the net usability score in the two iterations. The overall sum of signed ranks is equal to the sum of unsigned ranks which suggests that the users tend to rate the usability of this application higher than in the previous case. Mathematically, $W = W_{max} = 78$ for $n = 12$ where W is the net signed score and n is the number of signed ranks.

3.4.3 Heuristic Based Expert Evaluation

The PDA application is examined by three experienced interface and usability engineers against a modified version of Nielsen’s usability heuristics [13]. The analysis of the expert reviews identify the key usability strengths of our e-health applications as: consistency, simplistic navigation and quality of natural mapping. However, the experts also suggest that the “gulf of evaluation” can be further reduced by generating status updates like ‘number of fields left’ to keep the user informed. Further, one of the experts has suggested to

²The numbers within parenthesis indicate the question numbers

increase the default time of display for pop up help messages. The experts have also suggested to enhance the overall aesthetics of our interface by adding attractive images with the text field labels to improve the quality of user experience. Overall the expert reviews validate the UCD approach – with few minor exceptions – adopted for the design of our application.

3.4.4 Triangulated Analysis

This Section presents the triangulated analysis of findings presented in the previous section. On the convergent side of the findings, triangulated analysis confirms that the interface of our e-health application offers a consistent and informed navigation experience to the LHWs who work in a constrained environment. Moreover, the findings also reveal that the users and designers agree to add more status information to improve the overall navigation experience of a user. The triangulation of findings suggest a significant improvement is still possible in the aesthetics of the interface of our e-health application.

On the divergent side of the findings, it transpires from the analysis that the experts do not envisage text field based data entry as cumbersome. On the other side, the users (LHWs) hint on minimizing the text entry fields and preferably replacing them with check boxes and radio buttons. This finding indicates a gap between the designer’s model and the user’s model of the system. The rationale from the user’s perspective can be justified because of their extremely goal oriented nature which urges them to perform their tasks with a minimum effort [23]. Another divergent finding is that the experts want to provide advanced search capability for the locally stored data. But the LHWs do not view the lack of this ability as a usability concern. We can easily justify it from the LHWs perspective because their prime task is to enter data and they seldom have to do any manipulation on it. Therefore, simple search on name and date fulfills their needs. Based on the recommendations from the triangulated analysis, the data entry module of e-health is enhanced by incorporating the suggestions of the users and the experts.

4. CONCLUSIONS AND DISCUSSIONS

This paper demonstrates, with the help of a case study, a UCD based framework for designing mobile e-health applications for conservative environments. We have tried to learn the lesson from the failure of many theoretically elegant interfaces – adaptive interfaces, social agents, expert systems – in the real-world settings. As a consequence, our framework demonstrates the power of using the UCD process to create applications that align user’s mental models and capabilities with their work environment. Our UCD framework not only allows us to understand LHWs workflows but it also enables us to identify the influence of the contextual constraints imposed by their conservative work environment. The initial background analysis guides us in determining the needs of the users which are subsequently translated into the design of the interface. We have gone through a series of prototype demonstrations with LHWs to identify their problems and rectify them before putting the application in operation in the conservative environment.

The important feature of our framework is the integrated

approach towards usability evaluation by combining conventional methods of laboratory-based usability evaluation – heuristics evaluation and focus groups – with context-based usability evaluation methods like field observation. This approach enables us to combine relevant merits of both methods and minimize their limitations. The controlled usability evaluation techniques – heuristic evaluation and focus groups – have allowed us to collect various types of data, which is very difficult to gather from the constrained work environment of a user. For instance, it is not feasible to apply think aloud protocol in the field because the LHWs work in a dynamic and interruption prone environment. We do acknowledge the fact that the collected data set of course lacks realism of the field setting. To overcome this major limitation, we also carry out field observation studies in order to better understand the usability issues specific to the conservative environment. This not only increased the reliability and validity of our evaluation results but also became a source of optimizing the interface design of our e-health application. The results show that the LHWs feel significantly more satisfied in carrying out their tasks in an efficient manner with the final version of our application compared with its first version. Our analysis show that an e-health application can only diffuse into the constrained environments, if its interface does not hinder with the workflow of the users; rather, it should provide quantifiable benefits to them in efficiently executing their tasks.

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