DESIGN OF A PROTOTYPE MOBILE APPLICATION INTERFACE FOR EFFICIENT ACCESSING OF ELECTRONIC LABORATORY RESULTS BY HEALTH CLINICIANS

by

Kumbirai Chigudu

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Supervisor: Assoc. Prof Michelle Kuttel

DECLARATION

I, KUMBIRAI CHIGUDU, hereby declare that the work on which this dissertation/thesis is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

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ABSTRACT

There is a significant increase in demand for rapid laboratory medical diagnoses for various ailments in order for clinicians to make informed medical decisions and prescribe the correct medication within a limited specified time. Since no further informed action can be taken on the patient until the laboratory report reaches the clinician, the delivery of the report to the clinician becomes a critical path in the value chain of the laboratory testing process.

The National Health Laboratory Service (NHLS) currently delivers lab results in three ways: via a physical paper report, and electronically through a web application. The third alternative is for short and high-priority test results, like human immunodeficiency virus (HIV) and tuberculosis (TB), that are delivered via short message service (SMS) printers in remote rural clinics. However, despite its inefficiencies, the paper report remains the most commonly used method. As turnaround times for basic and critical laboratory tests remain a great challenge for NHLS to meet the specified targets; there is need to shift method of final delivery from paper to a paperless secured electronic result delivery system. Accordingly, the recently-implemented centralised TrakCare Lab laboratory information system (LIS) makes provision for delivery of electronic results via a web application, 'TrakCarewebview'. However, the uptake of TrakCarewebview has been very low due to the cumbersomeness of the application; this web application takes users through nine steps to obtain the results and is not designed for mobile devices. In addition, its access in remote rural health care facilities is a great challenge because of lack of supportive infrastructure.

There is therefore an obvious gap and considerable potential in diagnostic result delivery system that calls for an immediate action to design and development of a less complex, cost effective and usable mobile application, for electronic delivery of laboratory results. After obtaining research ethics clearance approval from the University's Faculty of Science Research Ethics Committee a research was sanctioned. A survey of public sector clinicians across South Africa indicated that 98% have access to the internet through smartphones, and 93% of the clinicians indicated that they would use their

mobile devices to access electronic laboratory results. A significant number of clinicians believe that the use of a mobile application in health facilities will improve patient care. This belief, therefore, set a strong basis for designing and developing a mobile application for laboratory results. The study aims to design and develop a mobile application prototype that can demonstrate the capability of delivering electronic laboratory test results to clinicians on their smart devices, via a usable mobile application. The design of the mobile application prototype was driven by user-centred design (UCD) principles in order to develop an effective design. Core and critical to the process is the design step which establishes the user requirements specifications that meet the user expectations. The study substantiated the importance of the design aspect as the initial critical step in obtaining a good final product.

The prototype was developed through an iterative process alternating prototype development and evaluation. The development iterations consisted of a single paper prototyping iteration followed by further two iterations using an interactive Justinmind prototyping tool. Respective to the development iterations, cognitive walk-through and heuristic principles were used to evaluate the usability of the initial prototype. The final prototype was then evaluated using the system usability scale (SUS) survey quantitative tool, which determines the effectiveness and perceived usability of the application. The application scored an average SUS score of 77, which is significantly above the average acceptable SUS score of 68. The standard SUS measurement deems 80 to be an excellent score. Yet a score below 68 is considered below average. The evaluation was conducted by the potential user group which was involved in the initial design process. The ability of the interactive prototyping tool (Justinmind) to mimic the actual final product offered end users a feel of the actual product thus giving the outcome of the evaluation a strong basis to develop the actual product.

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LIST OF ABBREVIATIONS

CT	Computed Tomography
DoH	Department of Health
ECG	Electrocardiograph
eHR	Electronic Health Record
FDA	Food and Drug Administration
GMSA	Global System for Mobile Communications Association
HIV	Human Immunodeficiency Virus
HPCSA	Health Professions Council of South Africa
ISO	International Organization for Standardization
IT	Information Technology
LIS	Laboratory Information System
MDR	Multi-Drug-Resistant
MRI	Magnetic Resonance Imaging
MTB	Multidrug Tuberculosis
NHLS	National Health Laboratory Service
NPP	National Priority Programmes
OTP	One-Time Pin
RIF	Rifampicin-Resistant
SME	Subject Matter Experts
SMS	Short Message Service
SUS	System Usability Scale
TB	Tuberculosis
UCD	User-Centred Design
UI	User Interface
WHO	World Health Organisation

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CHAPTER 1: Introduction

The National Health Laboratory Service (NHLS) established in 2001 by an Act of Parliament provides diagnostic pathology laboratory services to mainly national and provincial health departments and to a lesser extent private sector across South Africa [1]. NHLS is the largest public diagnostic pathology laboratory service entity in South Africa serving approximately 80% of the country's population [2]. Thus to a greater extent, the NHLS offers its services to the public sector medical health facilities and its activities comprise diagnostic laboratory services, research, teaching and training, and production of sera for anti-snake venom, reagents and media for laboratory diagnostics [2]. The NHLS has a network of pathology laboratories across South Africa, structured to use a common laboratory information management system as well as a transport network to support the transportation of samples and delivery of results.

The NHLS delivers laboratory results to the Department of Health (DoH) facilities in three distinct ways. The main mode of delivery is a hard copy paper report which prints at the respective laboratory from the laboratory information system (LIS). Upon printing, the reports are delivered to the respective facilities (hospital wards or surrounding clinics) for filing in respective patients' file. Paper reports generally take much longer to reach the clinicians or may never get to their hands due to inadequate filing processes in the health care facilities in which case the clinician will have to call the laboratory to obtain the result telephonically. It is necessary to bear in mind the impact of receiving patients results over the phone, the biggest risk is possibility of hearing the wrong result leading to making treatment decisions based on incorrect results.

Another mode of delivery utilises short message service (SMS) technology where SMS printers are placed in facilities to print selected priority tests with test results limited to 160 characters. Examples of such tests are Human Immunodeficiency Virus (HIV) and Tuberculosis (TB) test results. The main challenge of SMS results is that the results are limited to 160 characters which is the maximum size of one standard SMS thus there is a limitation to the type of test results which can be sent out using this mode. Any result with characters

greater than 160 are discounted, hence no comments or reference ranges can accompany final results thus limiting the detail that can be passed on to the doctors.

The third method of delivery utilises web technology through an online web application. This application was introduced following the recent implementation of a centralised LIS, TrakCare makes provision for delivery of electronic results via a web application, 'TrakCarewebview'. This is a recent development and is gradually being implemented in health care facilities for use by public sector clinicians. However, this method of result delivery is hampered by poor infrastructure. There is inadequate Information Technology (IT) infrastructure in the DoH facilities which pose a major challenge to the healthcare facilities. [3] Very few health care facilities have good working computers and network connectivity. The situation worsens as you move into the more remote rural areas. Furthermore, the web application is designed primarily for desktop computers and laptops and not for mobile devices. The application is not responsive to different screen sizes especially smaller screens such as tablets and smart phones; thus reducing its usability on tablets and smart phones. This negatively affects the adoption for effective and efficient use of the technology on the mobile platform.

On the current web application, clinicians go through nine steps to obtain a single laboratory result. This further reduces the interest among clinicians to adopt the technology. Public sector clinicians already work under great pressure to attend to as many patients as possible, as such they require a flawless, simple and efficient system to view patients results. Therefore, the shorter the steps it takes a clinician to view a patient's result on an application the more efficient it is.

This study aims to develop a usable mobile application prototype that can be further developed into a product that can be used by clinicians to electronically receive and retrieve patient laboratory results. The design of the prototype will be driven by user centred design (UCD) principles in order to develop a product that is end user focused and meeting their requirements. This inevitably

reduces the gap between the laboratory result and the clinician. Focus is on public sector health clinicians in the South African context.

The approach used to design prototype was user centric to ensure maximum uptake by clinicians. The prototype would have to be a fit for purpose and usable application applicable to hard to reach rural settings.

The expected impact of a usable application would be to reduce laboratory result delivery turnaround times, possible transcription errors through telephone result communication and prevent loss of results. This will in turn reduce the time required by administration staff to file the printed results in patient files thus reducing the cost of human resources in hours. In addition, there will be significant reduction in cost due to reduction in printing of results.

1.1 Problem Statement

To analyse and evaluate the effectiveness of a mobile application prototype designed to deliver patient laboratory test results to public sector medical health clinicians.

1.2 Aim and Objectives

The aim of this project is to design a usable mobile user interface (UI) that has a higher uptake by clinicians and can be used by public sector clinicians to immediately access laboratory results as soon as they are available on the LIS. The mobile application prototype design will follow UCD principles and evaluated using cognitive walk-through, heuristic principles and System Usability Scale (SUS) methods.

The key objective is to design and develop a usable prototype mobile application UI for accessing laboratory results through UCD principles.

1.3 Research question

How can we develop an effective, usable design for a mobile application for rapid retrieval of clinical results by clinicians?

CHAPTER 2: Background

The dawn of mobile technology has stimulated substantial interest among service providers and end users in various sectors. This did not spare the medical sector as seen by the significant mobile technology advances in devices, applications and networking infrastructure. In this chapter, the South Africa mHealth status will be described showing the importance of mobile-access-to-clinical-data by clinicians and patients. A few successful projects in the eHealth space will be described which include patient monitoring, applications for medical providers, electronic health records (her) and telemedicine. The review will present facts that confirm the relevance and usefulness of mobile applications in the health sector. The case studies will to some extent illustrate the usefulness and necessity of the design aspect as a fundamental first step in getting a good final product that meet the requirements of end-users.

The mobile electronic health space covers a broad spectrum of solutions in the medical industry. Examples include home care, emergency rescue services and patient monitoring. A greater number of mobile tools and services are in continuous development in an attempt to improve patient care. This study will contribute towards enhanced delivery of electronic laboratory results via a mobile application. The ultimate goal of the study is to demonstrate the possibility of designing an effective fit-for-purpose and fit-for-use laboratory mobile application prototype interface that is considered usable by potential end users.

2.1 mHealth in South Africa

The WHO defines mHealth as the medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants and other wireless devices [4]. The increase in the availability and affordability of mobile phones even in rural remote areas has seen this as the technology of choice for improving health outcomes in developing countries. Studies have reported that mHealth offers opportunities in the areas of strengthening health systems, and causing an

improvement in health outcomes and health care service delivery in general [5]. mHealth application areas include client education, communicating behavioural change, enhancing decision support, enabling communication between care providers, tracking vital events, collecting and reporting health related data, and the management of human resources. Other areas of mHealth applications are electronic health records, supply chain management, point-of-care testing for patients, education for care providers, work planning, and financial management.

The mHealth application landscape in South Africa shows remarkable expansion as reported by the Global System for Mobile Communications Association (GSMA). The GSMA, a body that represents the interests of mobile operators worldwide, indicates that there are 83 existing mHealth services in South Africa, with the majority focusing on HIV/AIDS and women and children [6]. Also, the GSMA mHealth tracker, a web page that curates mHealth products and services all over the world, shows that there are 98 mHealth initiatives in South Africa, making it the highest in Africa [6]. This is further validated by findings which says about 47% of mHealth applications in Africa are implemented in Southern Africa [5].

2.2 Patient monitoring

The use of mobile devices to remotely monitor the health or location of patients with chronic diseases or conditions has already become a viable option in the medical sector [7]. Significant progress has been witnessed in the medical arena with a few examples as elaborated in the coming text. Mobile device applications can provide public health surveillance, aid in community data collection, or assist disabled persons with independent living [8]. In one study, a single-lead electrocardiograph (ECG) was connected to a smartphone to diagnose and follow treatment of patients with sleep apnoea, providing a possible alternative to costly and labour-intensive polysomnography [9]. Sensors attached to garments that send signals to mobile devices have also been used to monitor and collect medical data regarding chronically ill elderly patients remotely [10]. A clinical monitoring system was developed to monitor

an entire unit, or one bed, in intensive care via a smartphone; it displays an alarm, colour-coded according to severity, based on patient vital signs [7]. The application was developed iteratively using agile development and user-centred design principles.

The mobile application iWander for Android was developed to monitor and track patients with early Alzheimer's disease who are prone to wandering, by using the mobile device GPS [10]. Smartphone applications have also been used to monitor patients during rehabilitation [10]. For instance, a smartphone connected via Bluetooth to a single-lead ECG device enabled the monitoring of patients in their own neighbourhoods when they were unable to reach traditional hospital-based rehabilitation [10].

Regardless of the fact that potentially useful, patient monitoring applications can be limited by factors such as internet connectivity and GPS reliability, as well as the patient's ability to use the device [10]; mobile applications that supplement medical devices are being developed [11]. One example is iStethoscope, which uses the microphone function of the iPhone to auscultate and record [11]. While this application is not officially intended for use as a medical device, it is significant in that its existence suggests that mobile devices can eventually replace medical devices [11]. Mobile devices have also been used to accurately track heart rate and heart rate variability [10]. In January 2011, MobiSante became the first company to receive Food and Drug Administration (FDA) approval for a smartphone-based medical diagnostic tool that uses an ultrasound probe for echocardiography [10]. Work has also already been initiated to develop ECG recording devices that work with smartphones [10].

Worthy of mention are mHealth applications in South Africa that have received international acclamations due to their potentials to improve health outcomes. These applications include Cell-Life MAMA SMS, a text messaging solution targeting women who are pregnant and those with babies aged up to 3 months [5]. Project Masiluleke is a specialized text messaging system aimed at combating HIV/AIDS, while SIMPill is a medication adherence solution, and MomConnect is a mobile phone application that makes it possible for pregnant

women to receive messages based on the stage of their pregnancy to help them improve their health and that of their babies [5].

2.3 Applications for medical providers

The majority of mobile applications are developed for specific target healthcare personnel: nurses, doctors, physicians and assistants. The most common categories of mobile applications development include drug-referencing tools, clinical decision support tools, communication.

The National Priority Programmes (NPP) of the NHLS, South Africa, manages the largest GeneXpert multidrug tuberculosis (MTB) /Rifampicin-resistant (RIF) programme in the world, with over 9.5 million GeneXpert tests performed since March 2011[2]. The GeneXpert instruments are located across 211 laboratory sites in South Africa, which support over 4000 public health facilities. It is NHLS's mandate, as a laboratory service provider, to ensure that both TB-positive and RIF-R results are conveyed timeously to the relevant health care worker within the public health sector [2]. This therefore requires improved patient linkage-to-care, which is a major challenge. This is especially relevant to newly diagnosed multi-drug-resistant (MDR) TB patients, who when remaining unlinked to care continue to present a public health risk. The Treat-TB mHealth solution was developed to address this challenge and was implemented into four MDR-TB treatment initiation sites in the Ekurhuleni district of Gauteng, South Africa, commencing 2 June 2015 [12]. The Treat TB mobile application serves to notify DoH facilities, health care workers, TB coordinators, treatment initiating facilities, tracing/injection teams, district and provincial coordinators of all respective TB-positive and RIF-R patients [12]. The mobile application is integrated with the NHLS results database which feeds the TB data. The TB results are then pushed to the relevant health coordinator who will then track and trace the patient and link them to care. This application was piloted in the Ekurhuleni district in Gauteng on a proof-of-concept basis [12]. The feedback stated that usability was not satisfactory and that many more enhancements were required before roll-out to other provinces in South Africa.

2.4 Electronic health records

Mobile applications may also provide access to eHR and patient information. OpenMRS is a highly configurable, scalable and extensible open source electronic medical record (EMR) application currently applied mainly to HIV/AIDS and TB patients and treatment information management in developing countries [13]. The production implementations of OpenMRS for HIV and TB patient management took place in 2006 in Kenya, followed later by implementations in Rwanda and South Africa [13]. Since then, OpenMRS has been implemented in many other countries, notably in Malawi, Mozambique, Lesotho, Tanzania, Uganda and Haiti [13]. The Millennium Villages Project has expanded the scope of OpenMRS via the Millennium Global Village-Network to include primary health care and plans to implement OpenMRS in eleven African countries [13]. The extension of OpenMRS to mobile phones gave rise to the OpenROSA consortium and the JavaROSA mobile application development projects which are derivatives of the OpenMRS [13].

2.5 Telemedicine and telehealthcare

The implementation of telemedicine and telehealthcare through the application of mobile devices is clearly a practical and potentially low cost choice in the delivery of healthcare. When time is of the essence, applications can increase speed and accessibility to critical specialist care in real time, for example, in stroke or acute trauma [14]. Acute stroke care is made portable and accessible to non-urban centres via real-time video on smartphones [15]. The i-Stroke system was developed to transfer clinical data, computed tomography (CT), magnetic resonance imaging (MRI), angiographic and intraoperative images, as well as expert opinion, all in real time [16].

Acute trauma patients also benefit from timely and efficient management. An iPhone-based teleradiology program was used for the diagnosis of acute cervical trauma, examining CT scans to evaluate for the presence of fractures or displacements [17].

Resource limited settings and remote locations like distant rural areas and desert settlements may benefit from access to specialist care and teleconsultations through mobile technology, particularly in disciplines with no locally residing specialists, such as ophthalmology or dermatology. In one study, the iPhone was used to send fundoscopic images to board certified ophthalmologists for review to detect diabetic retinopathy [18]. Mobile phone multimedia messaging allowed general practitioners to send teledermatology referrals in the form of photos and relevant clinical information to specialist dermatologists for consultation [19].

In some instances, mobile applications may allow telemedicine to replace time-consuming office visits altogether. This modality may benefit specialties who require frequent follow-up care or monitoring, such as rehabilitation or post-operative care of patients. A physical therapy application provided virtual-reality-based balance exercises through a mobile device [20]. Remote physiotherapists with access to the results could adjust the level of exercises accordingly [20]. Surgeons utilised remote real-time monitoring of free flaps via smartphone photography to replace in-person examination [21].

The limited health care professional involvement in the design of most of application has been seen to undermine the users' ability to be informed regarding application content quality [22]. Where medical professionals are involved in the design process, the usability and uptake of the application is remarkably high. Application designers and content developers have been seen to give little attention to the cognitive aspects of user interfaces [22]. It is important there to include all types of users in the design process in order to accommodate all end users.

CHAPTER 3: Approach and methods

In order to conduct this kind of research which involves human subjects as sources of data, ethics clearance has to be obtained prior to conducting the research. The ethics approval emphasises that ethical principles should be upheld throughout all stages of the research, responding appropriately to unanticipated issues. The relevant research ethics committee must be contacted for advice on any ethical issues that may arise. In addition, it is a requirement to remove the option for participants to provide their identity. Instead a number to each participant should be assigned, in order to ensure their anonymity since the identity of the participants is not a key element for the research.

The design of the mobile application prototype is completed using extensive user-centred methods to fully address usefulness and usability aspects. UCD design may be defined in a number of ways depending on the usage purpose and application area of the designed product. The overarching element is the participation of users in the design process of a product from the very start to the end. The International Organization for Standardization (ISO) 13407 is a standard that describes how a UCD process is conducted [23]. ISO 13407 uses the definition of usability from ISO 9241-11 as a reference, defining it as; the extent to which a product can be used by specified users to achieve specified *goals* with *effectiveness*, *efficiency* and *satisfaction* in a specified *context of use*' [23] The UCD method follows four basic steps as illustrated in figure 1 below.

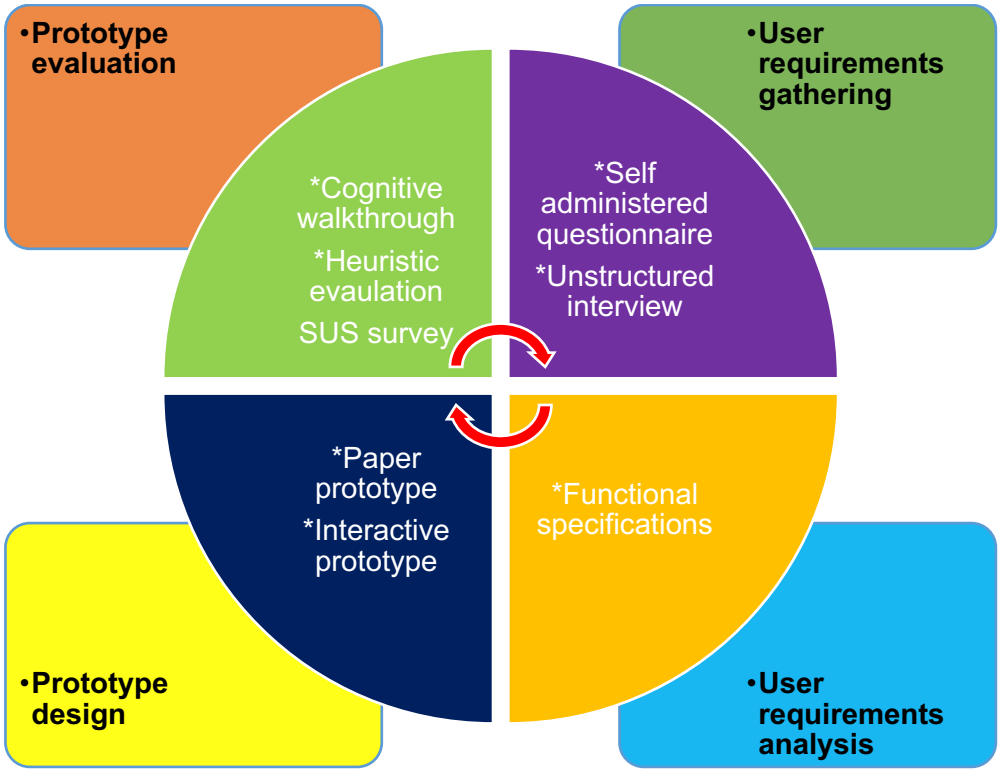


Figure 1: User-centred design iterative process

The methodology involves gathering user requirements followed by a series of prototype design improvement iterations. At each iteration the prototype is evaluated with a specific technique. The evaluation techniques used are cognitive walk-through, heuristic evaluation and the System Usability Scale (SUS) survey which evaluated the design for usability and effectiveness. The goal is to design a UI for a mobile laboratory results application prototype that is usable. A UI that users would utilise frequently when developed into a fully-fledged mobile application. The application should score a minimum acceptable average SUS score of at least 68 on the SUS survey after a design improvement iterative process.

3.1 User requirements gathering

During this stage of UCD, basic system user requirements of the design to determine the scope of work is determined. The evaluation scenarios that will guide the evaluation process are also determined at this stage. The system requirements specifications describe the requirements that the system aims to satisfy. The requirements gathering process is the first step of the UCD

process which is substantiated by the existing challenges faced by the users. As part of requirements gathering, it is also imperative to determine the targeted users' perception regarding the importance of this exercise prior to designing a system to establish the efficacy of the study. A user survey to obtain information is conducted to justify the investment in the development of the innovation. The requirements gathering phase employs a two-step process. The first step is to establish the clinicians' perceptions regarding the use of mobile applications to access laboratory results using a self-administered questionnaire survey. The outcome of the first step serves as basis to justifies the progression to step two. This process involves a quantitative statistical approach to collection and analysis of data obtained from the relevant population group. The second step of this phase is to discover the specific requirements of the intended users of the mobile application. For this study a focus group interview method is used to gather the basic user requirements. This is done through the contextual inquiry method where an unstructured interview process is followed. A contextual inquiry is described a set of concepts that guide the design of information-gathering sessions and is grounded in its use of context [24]. During this first phase of the UCD, the evaluation scenarios are drafted. The evaluation scenarios are presented in the appendix section.

3.1.1 Self-administered questionnaire

A questionnaire is developed as part of the requirement gathering process to establish the perception of sector clinicians in as far as using mobile applications to access laboratory results is concerned. Self-administered questionnaires require the respondents to fill in the questionnaires themselves in whatever format provided, physical template or via an electronic link. The list of questions is carefully designed and administered on the target population in order to get an unbiased outcome from which informed decisions can be made. Self-administered questionnaires are useful in determining user perception of a population group regarding a particular subject matter [25]. At this stage questionnaire is developed, the sampling approach and the data analysis are determined.

3.1.1.1 Questionnaire development

Careful consideration must be employed in designing the questionnaire to eliminate any ambiguity. When developing the questionnaire, specific aspects must be carefully thought through. Variables to be collected should be within the scope of the study, keeping the length of time for completion of the questionnaire within reasonable limits [25]. There are basically eight steps followed in developing a questionnaire [25]. The initial step is to list all the variables to be measured, followed by formulating the question and answer options. The questions should be very specific, simple and non-ambiguous. The third step is to decide on the organisation and structure of each question. During this step, the design and recording procedure with the respondents is determined. The sequence of the questions to ensure logical flow is determined in the fourth step. In step five, the layout and design of the questionnaire is established with clarity, to minimise errors [25].

Step six considers the scale of measurement of the variable as an upfront preparation for the data-analysis stage. At step seven, coding to define specific variables of the questionnaires conducted. The eighth and final step is to consider the means of data analysis. This is critical before the survey is conducted in order to ensure that all the information required at analysis stage is catered for, in order to draw meaningful conclusions [25].

Develop a set of five closed questions, which allows the respondents to select a response from a set of presented possibilities following the eight basic steps used in the development of effective questionnaires. The questions should provide unambiguous results, which are used to provide numerical results. Kaasinen confirms that closed questions encourage quicker, more standardised data collection [26]. The draft questionnaire should be reviewed and tested for relevance by independent subject matter experts to ensure applicability prior to administering.

Survey Monkey, an online web-based questionnaire is used as a platform to design and publish the questionnaire to the target population. An online platform makes it possible to reach out to a large number of people quickly and easily in an effective way across the target population. The raw data collected

is processed, analysed and presented graphically conclusions. Appendix 1 shows the set of questions and possible choice responses on the questionnaire.

3.1.1.2 User group sampling

It is important to clearly define the target group from which one intends to gather the information. In research terms, the target group is known as the study population. After identifying the study population, the next step is to determine the sampling approach. It will not be possible to investigate each and every subject in the population. Therefore, careful consideration of the sampling methods becomes critical in order to draw a representative sample. Sampling approaches can be broadly divided into two categories, random sampling, and non-random sampling. Random sampling is a selection-by-chance technique which can ensure that the sample is representative of the population [25]. Dumas and Redish argue that when conducting a research study to prove or disprove a certain phenomenon, users should be selected with a degree of randomness to support the statistical calculation, which relies on random sampling [27]. This study follows a random sampling technique from a target population of public sector medical clinicians across the country who were registered on the 'TrakCarewebview' application in 2015.

An email with the link to the survey is sent to the target population giving all subjects an equal opportunity to participate randomly. The respondents are given a period of one month to respond with a reminder sent after two weeks from the initial request.

For a population size of 1126, a confidence level of 95% and a margin error of 10% is required the minimum number of responses to be at least 89 in order to get a statistically sound analysis.

3.1.1.3 Data analysis

The data is collected and organised for statistical analysis on Microsoft Excel application. The data is then explored through graphic display, also referred to

as exploratory data analysis [25]. This allows for visual presentation of the data sets where comparative analysis is conducted.

3.1.2 Unstructured interview

The inquiry focuses on getting the users to explain their work experience and their daily tasks. The core part of the process is the inquiry into users' actions. Interviews are conducted in the users' typical work environment. Notes regarding what the users say are taken, and recorded for interpretation. Since the goal of the usability study is to develop a usable product with very minimum errors, the participants for this study are the actual intended users of the final product. The users are therefore sourced through convenience sampling to establish a focus group of five subject matter experts (SME) identified. The group of medical professionals is from Edenvale hospital in Johannesburg, which is very convenient for this study. The medical professionals are from different wards: casualty, paediatric, surgical, maternity and the intensive care unit (ICU). This offers a good representation of the targeted user group of the application. Focus group method is characterised by an intense unstructured but facilitated interview process. The same focus group of five clinicians should be trained and equipped to become expert users to be engaged throughout the design and evaluation iteration phases.

The interview focuses primarily on the setting and structure of public health facilities followed by the process work flow in these institutions. This framework gives the basis of the functional requirements which then informs the initial design of the prototype application interface.

3.2 User requirements analysis

The collected data is then analysed, organised and classified according to significance and appropriateness. The meaningful information is used as the functional requirements and guidelines establishing base information to determine the prototype application design. The evaluation scenarios (Appendix 2) are finalised at this stage.

3.3 Prototype design and evaluation

The next two phases in the UCD process are to design the prototype followed by a subsequent evaluation exercise. The design-evaluation process is highly iterative to produce the desired prototypes. Prototyping involves the initial use of low fidelity techniques like use-cases, storyboarding and paper prototyping. They serve in designing the product at a low level; they describe certain use situations and users' actions at a general level, and provide the requirements for functionality that the system should enable the user. Paper prototypes are developed to clarify the users' requirements and to evaluate their effectiveness. The prototypes are then scaled up in fidelity beginning with a low fidelity paper prototyping approach and ending with the high fidelity functional interactive product. Paper prototypes are chosen because they allow the researcher to express the design and demonstrate functionality whilst allowing the user to feel the design early which can be readily changed. The designed product is subjected to an evaluation to provide input for the next iteration. During evaluation, users are given an opportunity to interact with the prototype and provide feedback guided by an evaluation method.

The first iteration is characterised by a paper prototype design which is evaluated by a cognitive walkthrough process. The second iteration produces an interactive prototype which is subjected to heuristic evaluation. The third iteration produces the final interactive prototype which is be tested for usability using the SUS survey. Figure 2 below illustrates the design-evaluation process.

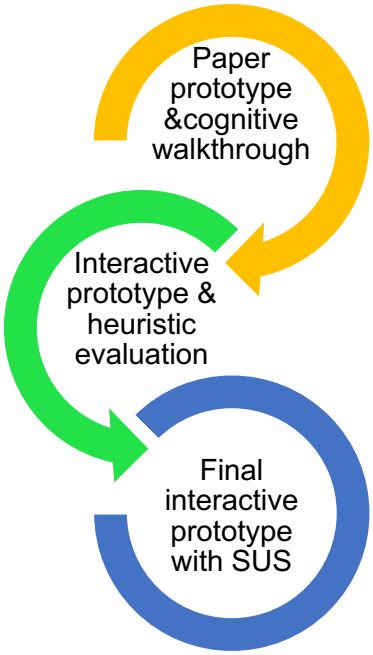


Figure 2: Design iterations

3.3.1 Paper prototype and cognitive walkthrough evaluation

The first iteration design is informed by the outcome of the unstructured interview process which involves brainstorming and paper prototyping. The paper prototype is developed from smart phone (iPhone 6) paper sketches, which allows for rapid ideation with the focus group. Paper prototyping is ideal and used because of its flexible nature. One can easily discard a paper and quickly create another prototype without any hustles. This process is used to design the initial low-fidelity paper prototype on a smart phone frame. Due to its flexibility, paper prototyping allows for alternative designs to be created for users to comment on and give their input. The flexibility also allows for quick changing to the functional aspects and task flow of the design. Fit and finish issues like font size and colour are not addressed at this stage.

The cognitive walk-through method is used to evaluate the paper prototypes. The facilitator describes and explains the prototypes to the expert users in terms of tasks and features. This is then followed by a verbal review and comparison of the prototypes [28]. This session is conducted in a controlled environment with SME from the focus group guided by the evaluation scenarios. The focus group responds to the suggested designs with comments

and suggestions. The proceedings are recorded and highlighted and drawn onto the prototypes. The chosen paper prototype is then refined based on the comments and suggestions and is used as the basis for developing an interactive prototype in the next iteration.

3.3.2 Interactive prototype and heuristic evaluation

Justinmind prototyping software is used during the second iteration to design and develop an interactive mobile application prototype. During this phase of the study, a high-fidelity prototype is designed and developed using the Justinmind tool. This interactive software is necessary at this stage to convey the workings of the interface illustrating the work flow.

The second interactive prototype is a product of the enhanced paper prototype from user feedback from cognitive walkthrough evaluation coupled with the guide of heuristic principles (Appendix 3). This is followed by heuristic evaluation process to determine the enhancements of the prototype. A structured interview process based on the ten usability heuristic principles guided by the evaluation scenarios is conducted with the same focus group of the five expert users. This style of interview provides a set of answers which is compared across several subjects to derive some generalisations of users' opinions of the system.

Nielsen discusses the subject of the number of evaluators needed for heuristic evaluation in the following manner: A single evaluator achieves poor results as he/she typically would only find about 35 percent of usability problems, whereas five evaluators discover around 75 percent of usability problems [29]. This raises the suggestion of applying as many evaluators as possible to the problem. However, Nielsen argues that more evaluators will not find proportionally more problems, as illustrated in figure 3 below. In addition, as employing evaluators comes at a cost, the cost-benefit ratio decreases rapidly after five evaluators as illustrated in figure 3 below [23].

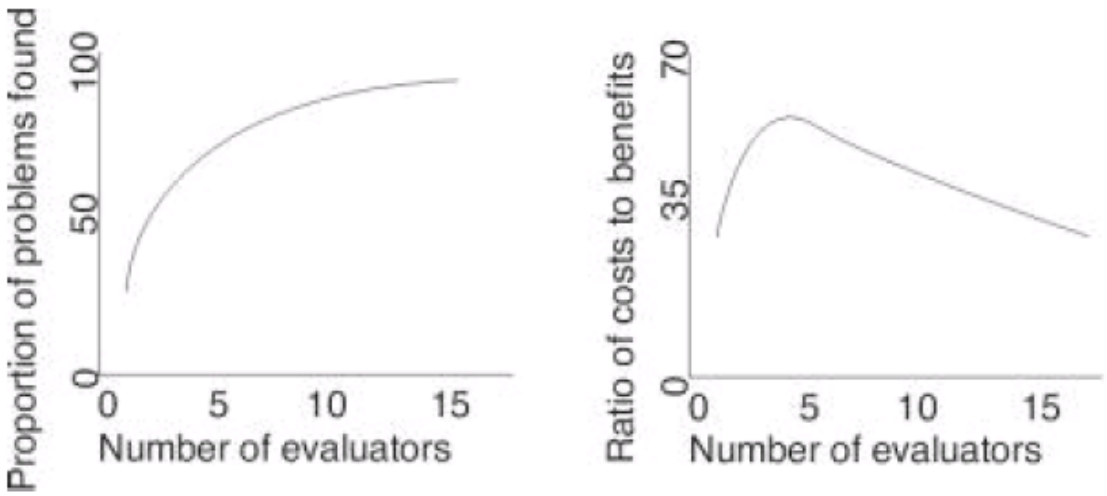


Figure 3: Recommended number of evaluators

The expert users evaluate the prototype by completing the evaluation sheet (Appendix 4), giving comments and suggestions for improvement. The evaluation itself involves working through a scenario of use (an example task that users might perform with the system). In order to identify problems thoroughly, the evaluators work through the scenario twice – once to get an overview of the system, and the second time to assess the usability in depth. Every scenario is subjected to the ten heuristic principles by each evaluator. After evaluators have completed the evaluation, the lists of problems found are compiled into a coherent set. Using multiple evaluators results in more chance of identifying a comprehensible set of problems as each evaluator may perceive problems slightly differently. The problems in the collated set are then rated according to a severity scale of 0-4 [30].

• 0 – do not agree that it is a usability problem

• 1 - it is a cosmetic problem

• 2 – it is a minor usability problem

• 3 – it is a major usability problem - important to fix

• 4 – it is a usability catastrophe - imperative to fix

The results are aggregated to obtain an average score – that of either three or four reflects a usability problem which requires a fix would be addressed in the third prototype, according to the recommendations from the feedback.

3.3.3 Final interactive prototype with SUS evaluation

The third and final iteration of the prototype is designed using the same interactive Justinmind software used during the second iteration. The user feedback from the second iteration evaluation is used to enhance the design the prototype for the third iteration evaluation. This prototype is evaluated by means of the SUS survey method using the same focus group involved in the preceding iterations. SUS survey consists of notable ten system usability questions in which participants respond to the questions on a scale of one to five where a score of five means they agree completely while one means they disagree vehemently [31]. SUS is a free, quantitative tool, used in the majority of usability studies, and considered highly reliable [31].

To calculate the SUS score, first add the score contributions from each item [31]. Each item's score contribution will range from one to five. For items one, three, five, seven and nine, the score contribution is the scale position minus one. For items two, four, six, eight and ten, the contribution is five minus the scale position [31]. Multiply the sum of the scores by 2.5 to obtain the overall value of SU [31]. An average score of above 68 indicates that the application is considered usable [31]. The SUS survey is known to be a robust and reliable measure of the usability of a system [32].

The SUS tool yields a single number representing a composite measure of the overall usability of the system being studied [33]. A Microsoft Excel template embedded with the formula is developed to calculate the measure of usability. The SUS survey exercise is the final evaluation of the prototype design.

CHAPTER 4: Results and discussion

In this chapter the research findings from the investigation will be presented and discussed. This will demonstrate whether the objectives of the study highlighted in chapter one have been fully or partially met, indicating the strengths and limitations of the study. This chapter follows the UCD workflow as illustrated in the approach and methods chapter. This fully demonstrates the outcome of the incremental developments until the final product. As indicated above, the methodology involved user requirements gathering and analysis followed by a series of prototype design improvement iterations. At each iteration the prototype was evaluated with a specific technique. The evaluation techniques used were cognitive walk-through, heuristic evaluation and the SUS survey, respectively. The user requirements gathering phase initiated the process to fully establish users' perception of the idea and their expected outcome.

4.1 User requirements gathering

The user requirements gathering phase was characterised by an interview process in the form of a self-administered questionnaire and an unstructured interview session which gave the basis and direction for the study. The exercise involved the participation of the target medical professionals since they are the potential users of the application. The surveys sought to establish the perception and functional requirement of the design to establish an informed position on specific aspects that related to the study.

4.1.1 Self-administered questionnaire

The questionnaire was administered to a randomly selected population (n) of 1126 medical professionals registered on TrakCarewebview web application. A total 90 medical professionals responded to the survey representing an acceptable representative sample size at 95% level of confidence. The data obtained indicates that 81% of the respondents were doctors, of which 9% were doctors in training. The balance of 10%, were nurses who should also have access to laboratory results since they offer primary health care to

patients. The data obtained from this survey is useful and reliable at 95% confidence level. The data can then be extrapolated to represent all medical health care professional in the public sector in South Africa. A 99% confidence level would have been ideal to give a more accurate position. Since the link was sent via email there is a possibility that some target participants we reluctant to participate or they missed the email. The other reason for a lower response could have been that the survey response window was too short.

The health care professionals use a range of devices from and ordinary phone with telephone and SMS capability to latest smart devices that have various applications and can connect to the internet. The data shows that 98% of the health care professionals primarily use smart devices for their daily endeavours. Only 2% of the clinicians use 'regular' phones, which only offer text and call functionality. Smart phones with Android operating systems were the most commonly used showing 41% of the participants, followed by iPhone with iOS at 35%. The remaining 24% used either Windows or Blackberry operating systems. According to the findings all (100%) doctors carry a mobile telephony device, regardless of type. The outcome proves that medical professionals are abreast with the world trends of technology advancements. It can also be deduced that doctors and nurses in the public sector have the aptitude and capability of using smart devices. The data also shows that 90% of medical professionals carry phones on them while only 10% carry tablets around. Preference of phones over tablets can be explained by the convenience of a phone in terms of size and weight. They are lighter and can easily be carried in a pocket or hand bag. This information provided guidance in the selection of the size of the device used for this study in the design process.

It was of paramount importance to establish the relationship between the willingness of medical professional to use a mobile application to access patient laboratory results and view that this can contribute to patient care. This part had to be done during the requirements gathering phase to ascertain the efficacy of the study. Figure 4 below shows that an overwhelming 94% (strongly agree and agree) of medical professionals are willing to use a mobile

application to access patient results which directly corresponds with 89% (strongly agree and agree) that subscribes to the view that; using a mobile application to access lab results can contribute to improving patient care.

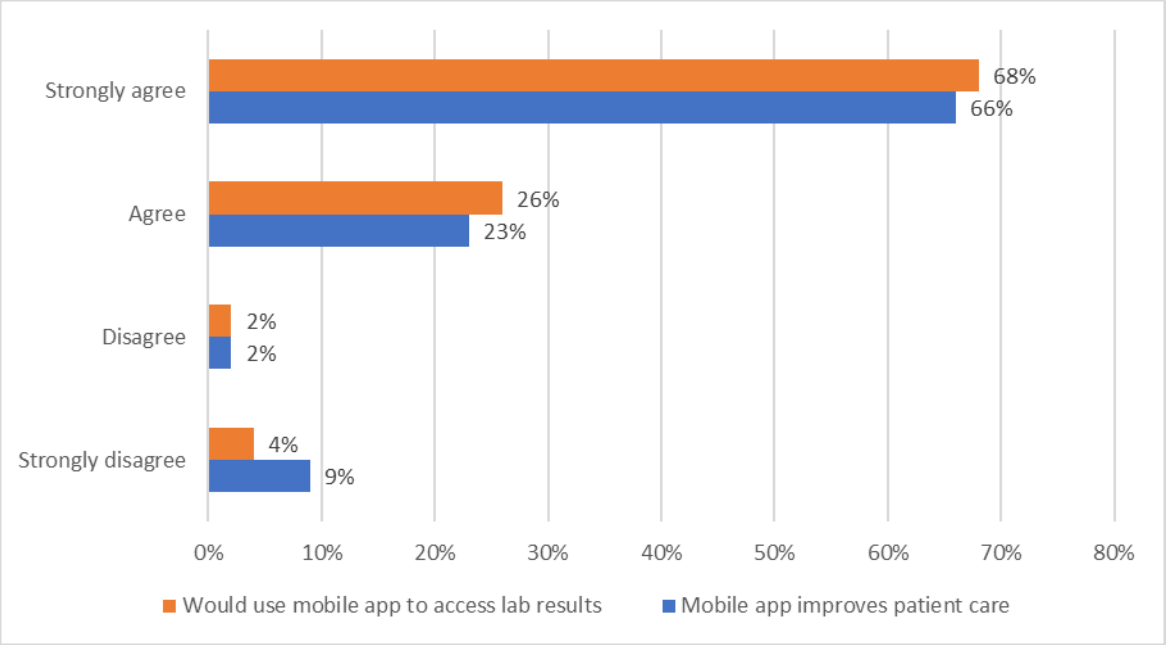


Figure 4: Mobile app use and patient care improvement

The data shows that respondents appear to think there is a correspondence between mobile application use for laboratory results and improved patient care. This can be attributed to the fact that there is a significant reduction in laboratory results turnaround time for a medical professional to act on the results. The result will be delivered directly to the medical professional's device as soon as it is available at the laboratory. Notably 6% of medical professionals are not interested in using mobile applications to access laboratory results with a corresponding 11% not subscribing to the view that mobile application technology has a contribution to patient care improvement. Their reasons could be that not all medical professionals have access to smart devices or they only believe in traditional methods of providing health care.

On the other hand, figure 5 below shows different options available regarding device ownership and data cost preferences, presented to the respondents. The data shows that 69% of respondents prefer using their personal devices at subsidised data costs to access laboratory results. Fifteen percent of the clinicians prefer using their own devices and carrying the data costs.

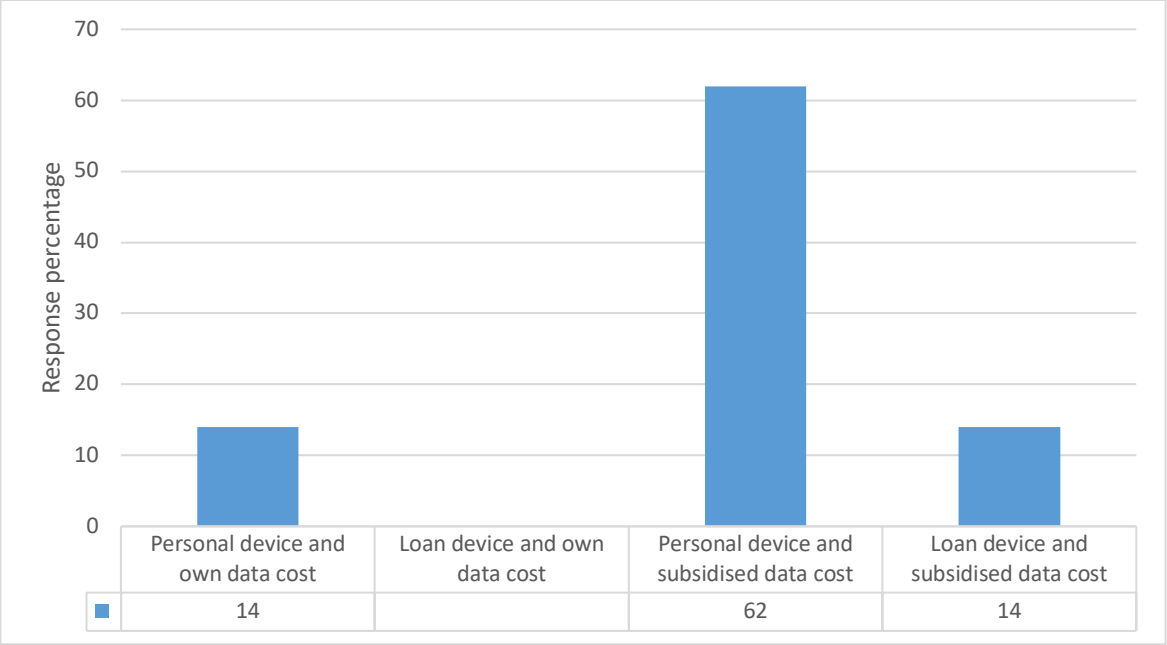


Figure 5: Device and data option preferences

Another 15% would use loan devices with subsidised data costs. None of the interviewed medical professionals desire a loan device with them when carrying the data costs. The majority of medical professionals prefer using their own devices instead of getting a work or loan device. The reason may be convenience of carrying one device as opposed to carrying two devices and also avoid the responsibility of the loan device. In the same vein respondents were much more interested in having subsidised data costs packages with own device. The importance and criticality of providing mobile application data to enable medical professionals to access laboratory results should be noted. Installing free Wi-Fi available to medical professionals will go a long way in increasing the usage of the application thus contributing to improved patient care. An arrangement with mobile data service providers can be made to zero rate or reverse bill data charges when one is accessing laboratory results via the mobile application.

4.1.2 Unstructured interview

The expert users clarified the work flow of a typical public health care facility in the context of a medical professional executing their duties in a facility and defined their expected functional requirements of the proposed design. It was established that medical professionals operate on a shift system. This is to

cater for the 24-hour hospital service delivery model. Medical professionals fit into this service model by rotating the morning, afternoon or evening shifts or on-call services. It was also noted that doctors are not fixed to one facility, they may be called upon to transfer to any of the public facilities as and when the need arise. This means that medical professionals will need full access to all patient results on the entire database. As the doctors perform patient consultations during a round visit, they check patient laboratory results in the patients' folder kept on the bedside. The challenge arises when a copy of the physical results in not filed in the patients' folder which is the usual case.

A typical doctor performs ward rounds, where the doctor on duty performs consultations for patients in the respective wards. When a doctor arrives at a patient he reaches out to the patients file. The patient maybe consulting for the first time, meaning that the doctor will perform the first diagnosis and orders the necessary blood tests by completing the laboratory request form. The blood test results are very useful for the diagnosis of the ailment and will determine the medication prescribed by the doctor. If the patient has been diagnosed previously and blood tests ordered, the doctor will be expecting the results filed in the patient file in order to make an informed diagnosis. If the physical paper result is not in the patient file, the doctor will have to call the respective laboratory to obtain a telephonic result. Alternatively, the doctor can search for the result from TrakCarewebview is the hospital ward if there is a working computer connected to the internet. Due to high work demands, the doctor may not get the chance to call the laboratory or look for a computer to search for the patient's results. This may prompt the doctor to re-order the same tests which comes with costs. When the doctor decides to call the laboratory he/she stands a risk of not getting the correct result of the intended patient due to human error. The laboratory personnel are not always available to provide telephonic results. When the doctor decides to get results from TrakCarewebview, he/she has to go through nine steps to obtain the result. The time taken to retrieve the intended result is dependent on the strength of the internet network connection. This presents a gap in patient care since the laboratory results are not always available for the doctor to confirm diagnosis.

A streamlined application interface with fewer steps to get results was advocated at a high level. On boarding of users should not be cumbersome and user authentication credentials should be the same as that of the existing results web application (TrakCarewebview). The landing page after signing into the application should present search fields at the top followed by a list of unread laboratory result records ordered by the signed in medical professional. The workflow and use-cases outlined in this interview informed the first iteration of the design phase and will be presented in the following section. At this stage a low fidelity paper prototype was developed and evaluated.

4.2 Prototype design and evaluation

The information from the requirements gathering phase informed the design stage where the prototype products were improved iteratively following the UCD principles. Three design iterations were conducted augmented by an evaluation exercise at every iteration to establish usability and recommend areas of improvement. The first iteration involved the use of low fidelity paper prototyping, followed by the use of an interactive prototyping tool for the two proceeding iterations. Cognitive walk-through, Heuristic principle evaluation and System Usability Scale survey evaluation methods were used respectively. The whole exercise was done with the same focus group of five expert users who are potential users of the application. The results and discussion of the iterative design outcomes will be presented in this section.

4.2.1 Paper prototype and cognitive walk-through evaluation

The first iteration was characterised by a paper prototype output, which was design based on the initial interview process with the expert users. The prototype consisted of a smart phone frame illustrating the design of interface pages. The design provided an overview of the four main application pages – ‘sign-in’, ‘search/landing’, ’patient record’ and ‘result’ page.

The design depicts four major screens that a user would follow in order to obtain the desired outcome. The sign-in page, which is essentially the first page on which the user interacts with the application, was designed to handle

the user authentication elements. Image one of figure 6 below illustrates the log-in page where the user enters the username and password to gain access to the application. For security purposes, mobile application users will follow the process of getting access to the TrakCarewebview application from which the mobile application user will be authenticated. The username being the practice number of a medical professional as issued by the Health Professions Council of South Africa (HPCSA) and registered on the existing web results application, TrakCarewebview. This easies the on boarding process for the end users since they will not be expected to go through another registration process. On the other hand, this on boarding process can be a deterrent for new users who wish to only access laboratory results via the mobile application as they will have go through the web application registration process before they can have access to the mobile application. A 'forgot your password' link is available, which allows the user to contact a help desk by calling directly from the application. This will enable the users to be able get help from a help desk. This is a manual process which does not fully empower the user to be self-sufficient. A self-service process using one-time pin (OTP) can be considered in future.

Also illustrated by the figure below on image two is the landing page upon successful authentication. This landing page provides for patient record searches based on the six identifiers that exist on the patient manual requisition form. Search fields were suggested during the user requirements gathering phase by the expert users. The identifiers were suggested as the top six commonly used search fields on TrakCarewebview. This gave a more objective position based on actual experience. The only limitation was that the information was obtained through an oral discussion as opposed to getting the information TrakCarewebview.

Also illustrated by this image is the nature in which approved and unread laboratory results for tests requested by the logged-in clinician present by default on the landing page. In the case of a nurse who does not order laboratory tests, it is the latest unread facility results that appear by default on the landing page. This enables the users to obtain the latest records before

they even attempt to search. This reduces the steps the clinician has to take to obtain the results thus making them more efficient.

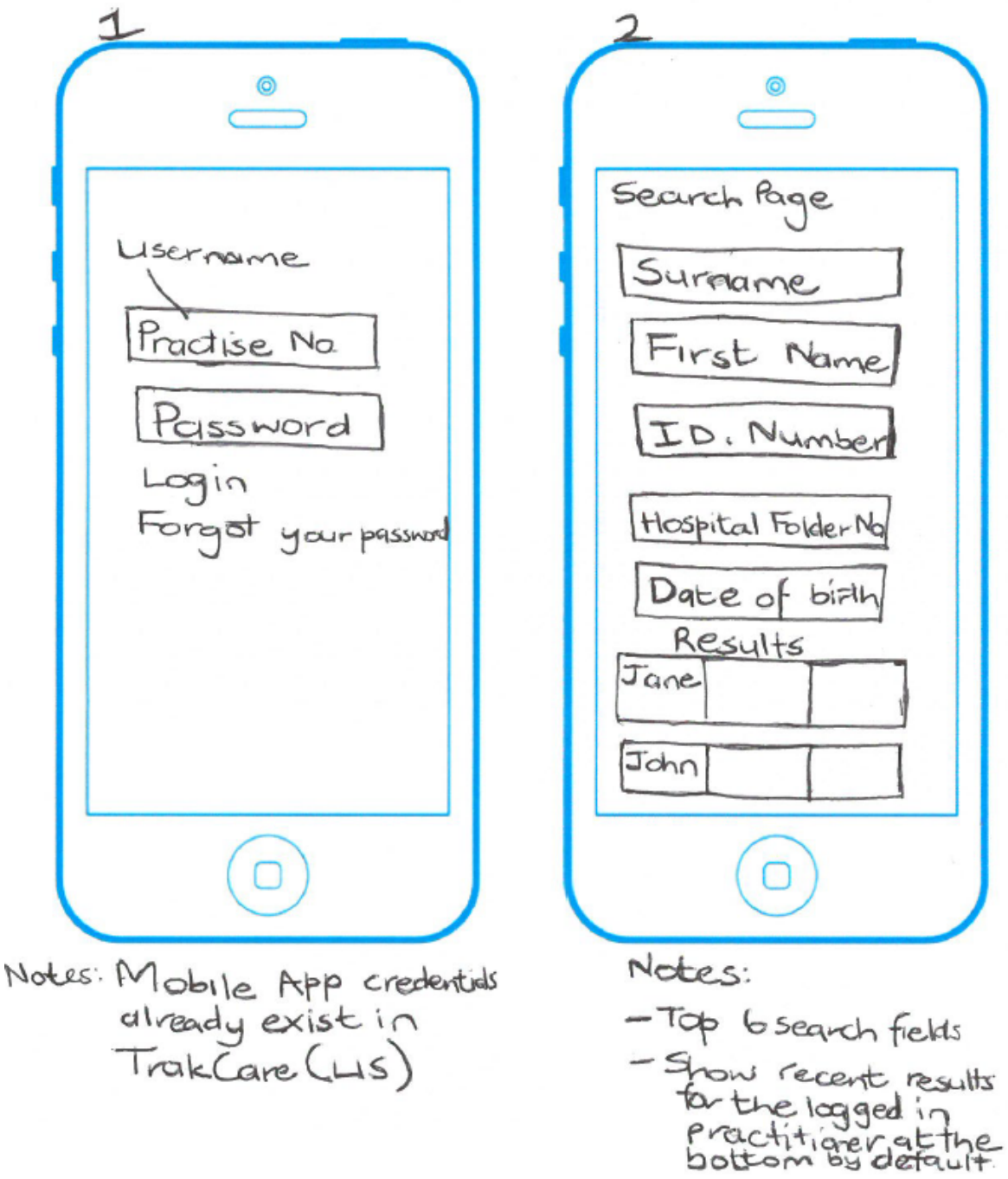


Figure 6: First iteration design overview (Log-in and landing page)

Figure 7 below illustrates the results pages one and two which presents search outcome. Patient records are presented in blocks outlining attributes pertaining to the patient, and sample information as deemed necessary and important by the expert users. Patient information covers demographic data (name, gender and date of birth). Patient identification numbers, hospital folder number and episode numbers are also presented together with sample information such as collection date and test performed. The information presented by image three allows to user to identify the desired record immediately. This allow the user to select the desired record. When the desired record is selected, all test results for the selected record can be viewed from this page. It was also recommended that previous results of the same test for the same patient be presented on this page as well. With these design recommendations, a streamlined process of getting to laboratory result in the shortest possible way was achieved. This low fidelity product was then taken through the first usability evaluation.

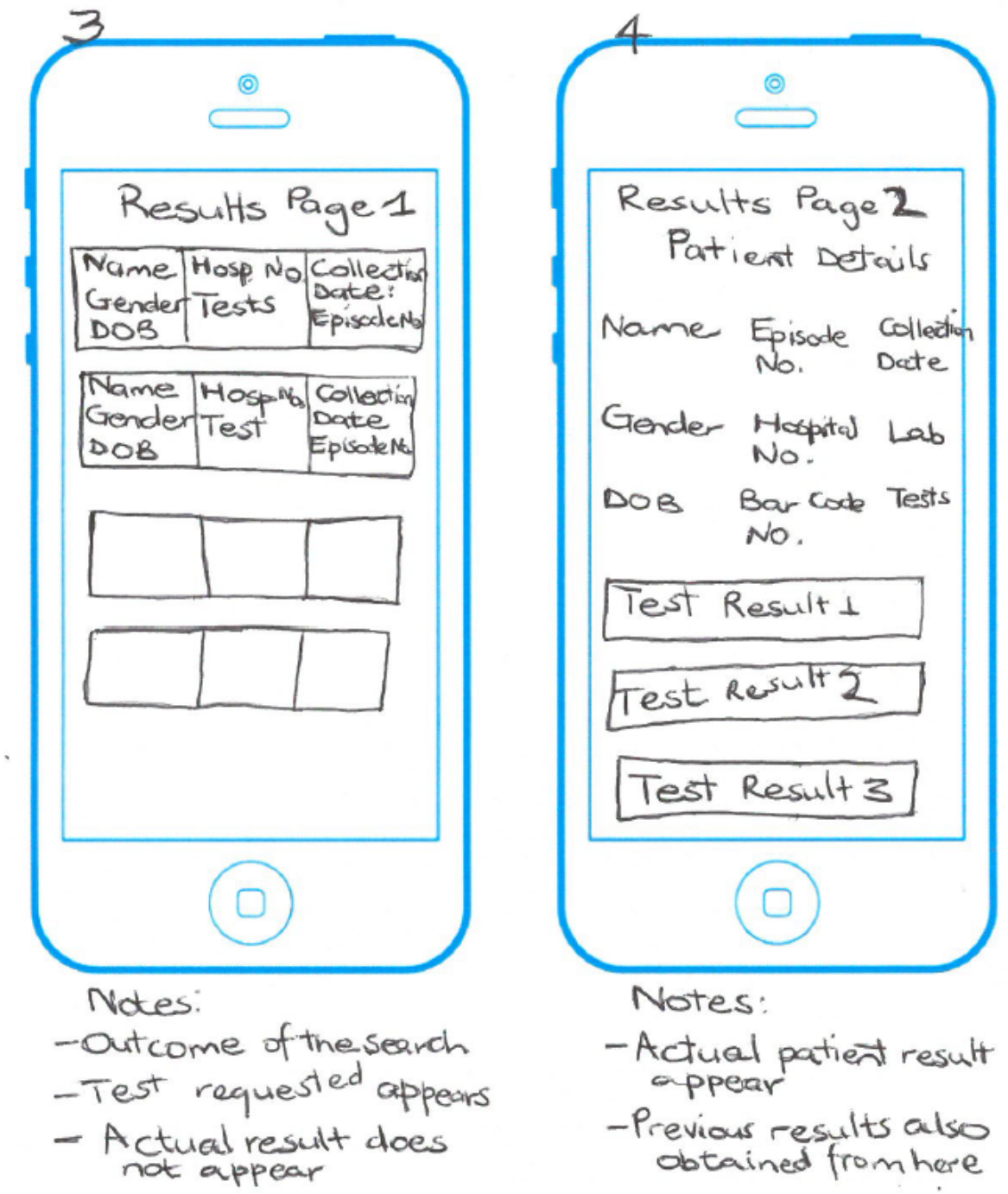


Figure 7: First iteration design overview (Patient result search outcome and results pages)

The first iteration was evaluated through a cognitive walk-through process. The table below shows the feedback comments and suggestions that were submitted by the evaluation focus group. The evaluation was done on the specified four interface pages of the paper prototype described above. The suggestions articulated below where discussed and adopted by consensus.

Table 1: Cognitive walk-through outcome

Page	**Suggestion/comment**
Log-in page	>Change 'log in' to 'sign in' >Add 'terms and conditions' acceptance button on this page
Search page	>Add "submit" button to invoke the search >Rearrange the search fields to the following order of priority: ➢ Form bar code no. ➢ Hospital folder no. ➢ National ID/ passport no. ➢ Surname ➢ First name ➢ Date of birth >Add latest results record to show below the 'submit' button >The record to be designed to accommodate the following: ➢ Full name ➢ Gender ➢ Date of birth ➢ Episode no. ➢ Hospital no. ➢ Test requested ➢ Collection time ➢ Form bar code no. ➢ Laboratory name ➢ PDF format result
Patient record search	>This patient record search page to be designed in the same way as the results record in the 'search' page
Result page	>Results page to be designed to include the entire patient record including the test result
General	>Add 'sign out' button on every page

The changes were adopted and built into the design during the second iteration. Cognitive walk-through method is ideal for low fidelity prototype evaluation since the design is at its infancy and presentation of the design is in its simplest form. This evaluation method however lacks thorough scrutiny to extract significant flaws that may be present in the design.

4.2.2 Interactive prototype and heuristic evaluation

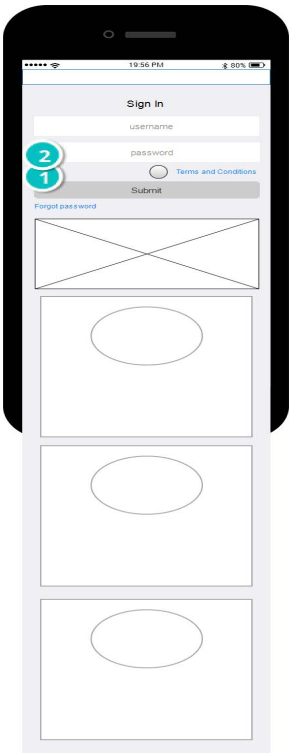
The second design was a build of the first iteration coupled with enhancements recommended by the users following the cognitive walk through evaluation. The design was also guided by the heuristic design principles to create an interactive prototype. At this stage a high fidelity interactive prototyping tool was used. The prototype mimicked the functional steps a user would follow to obtain a laboratory result.

The Justinmind prototype tool was used to design the interface construction on the paper prototype design. The four main pages showing the outcome will be illustrated below.

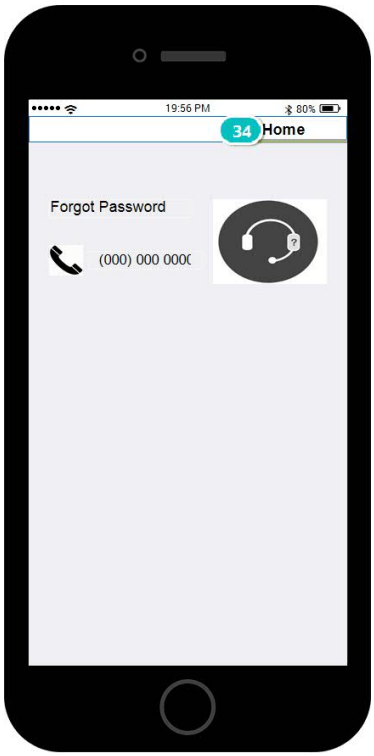
The home page is where signing-in takes place as illustrated on image A in figure 8 below. The user enters the username as registered on the TrakCarewebview database and authenticates with the password to access the application. A radio button has been added for users to accept the terms and conditions prior to signing in. The ‘submit’ button remains grey until the ‘terms and conditions’ button is selected. The application will not allow you to proceed until you accept the terms and conditions.

The ‘forgot password’ option was incorporated, which allows the user to call help desk directly from this page. The link is integrated with the phone-calling mechanism. The space below the ‘forgot password’ link was reserved for app documentation and organisational promotional information.

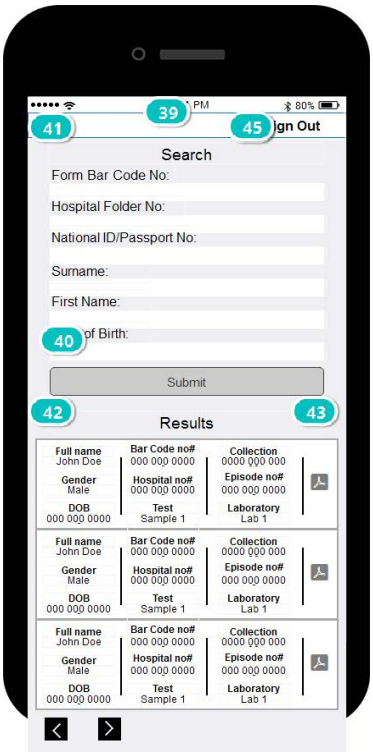
A. *sign in page*



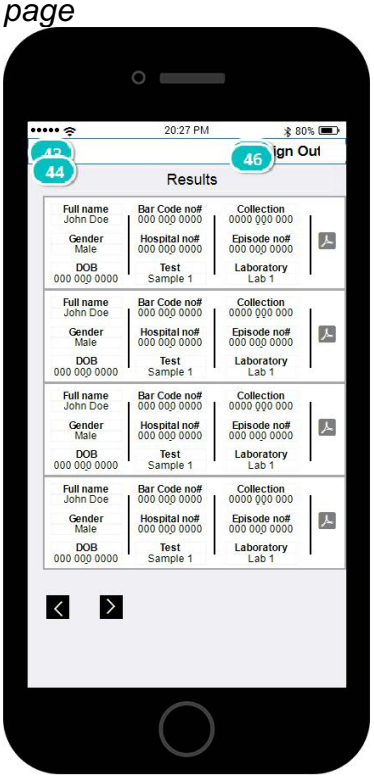
B. *forgot password page*



C. *landing/search page*



D. *search outcome page*



E. *results page*

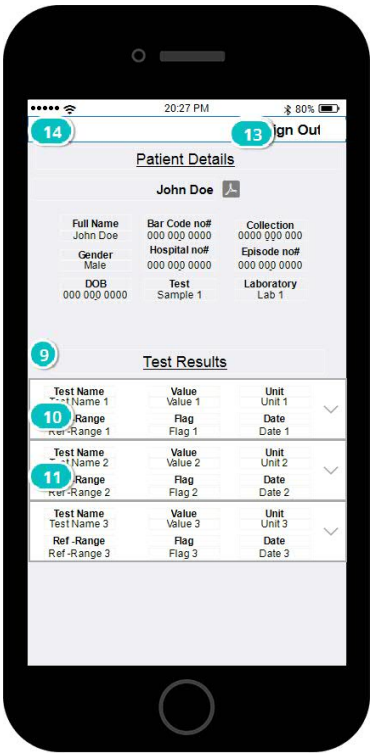


Figure 8: Second iteration design overview

The search fields were rearranged in the desired order of priority as illustrated by image C of figure 8 above. The ‘sign out’ button was added to this page to allow the user to sign out of the application at any time. The latest available results are designed to show on this page to enable the requesting doctor to immediately select the patient result required. A pdf format result option was added in the form of a standard icon to allow for viewing of the full patient report. ‘Next’ and ‘previous page’ icons were added to the design of this page.

The patient result search page (image C) was designed in the same way as the section below the ‘submit’ tab on the search outcome page (image D) above. The user selects the desired patient record to view the results.

The results page depicted by image E on figure 8 was designed to include all the patient demographics as requested in the first iteration. A pdf format is also available on this page, depicted by the standard pdf icon. Multiple test results including units, reference ranges, flags and result dates are shown. The “down” arrow depicts the availability of previous results of the same test. The ‘sign out’ option is also available on this page as requested. At this stage the product design is at an advanced stage with more features and functionality as requested by the end users. The prototype design built on the backbone of heuristic principles was then subjected to a thorough heuristic based evaluation process.

The second iteration prototype was evaluated using heuristic principles. The expert users were exposed to the interactive prototype to get a feel for the application. The users interacted with the prototype based on the scenario supplied (Appendix 2), providing a score for all ten heuristic principles. The heuristic principles are listed and defined in Appendix 3. An average was calculated for every principle. Average scores of three and four presented major usability problems which needed attention. Usability improvement suggestions were provided for the areas that scored three and four. Table 2 below shows the average scores and usability improvement feedback suggestions.

Based on the evaluation conducted, areas of improvements were identified on principles two, four, six and seven. On principles two, three, five, eight, nine

and ten the expert users unanimously agreed that the prototype meets the demand of the principle.

On the first principle which emphasizes on system feedback when an action is taken, the evaluation team identified design aspects that needed to be incorporated. The recommendation was that a status should be added which shows that the application doing a search. This is to keep the user informed about what is going on.

On principle four, a standard ‘menu’ icon was recommended for incorporation in the next iteration. The use of standards makes the application universal in line with international expectations thus empowering users eliminating guessing.

A recommendation was made under principle six to rearrange the results search outcome page to group numbers (Bar Code no#, Hospital no# and Episode no#) in one block and group ‘test’ name with ‘lab’ name and sample ‘collection date’. This design was understood to minimise the user's memory load by grouping similar variables together.

On principle seven a design enhancement to show the current test results and two sets of previous results of the same test after pressing the drop down arrow on the result page was recommended. This was seen as a way of making the system flexible and efficient to use even by a novice user.

This evaluation was more intense and structured and it managed to pick use significant usability short comings that were put forward for consideration in the next iteration. The evaluation was however not straight forward, it required facilitator to train the evaluation team and constantly explaining the required outcomes of each principle in order to get more objective feedback. This is because the expert users are not design experts but rather subject matter experts and potential users. The fact that they were the potential users of the application made them to be the most applicable team to conduct the evaluation. The evaluation could have been much simpler if there was more time to adequately equip the team beforehand. It was a challenge to have all the five medical professionals in one room to participate in this exercise given

their job demands. The five evaluation members gave objectivity to the exercise since an average score could be obtained from their scores to determine the necessity of making design adjustments. This data is therefore deemed reliable and can be extrapolated to public health care professionals in general.

Table 2: Heuristic evaluation results

Heuristic Evaluation Results				
No.	**Heuristic Principle**	**Average Score**	**Interpretation**	**Suggestion for Enhancement**
1	Visibility of system status	3	3. Major usability problem- important to fix	Show status when search is invoked
2	Match between system and the real world	1	1. It is a cosmetic problem	
3	User control and freedom	0	0. Do not agree that it is a usability problem	
4	Consistency and standards	3	3. Major usability problem- important to fix	Add menu page with standard icon
5	Error prevention	0	0. Do not agree that it is a usability problem	

6	Recognition rather than recall	0	0. Do not agree that it is a usability problem	Rearrange the results search page to group numbers together and group test with lab name and collection date
7	Flexibility and efficiency of use	3	3. Major usability problem- important to fix	Show the current test results and two additional sets of previous results of the same test if available
8	Aesthetic and minimalist design	1	1. It is a cosmetic problem	
9	Help users recognise, diagnose, and recover from errors	1	1. It is a cosmetic problem	
10	Help and documentation	1	1. It is a cosmetic problem	

4.2.3 Final interactive prototype with SUS evaluation

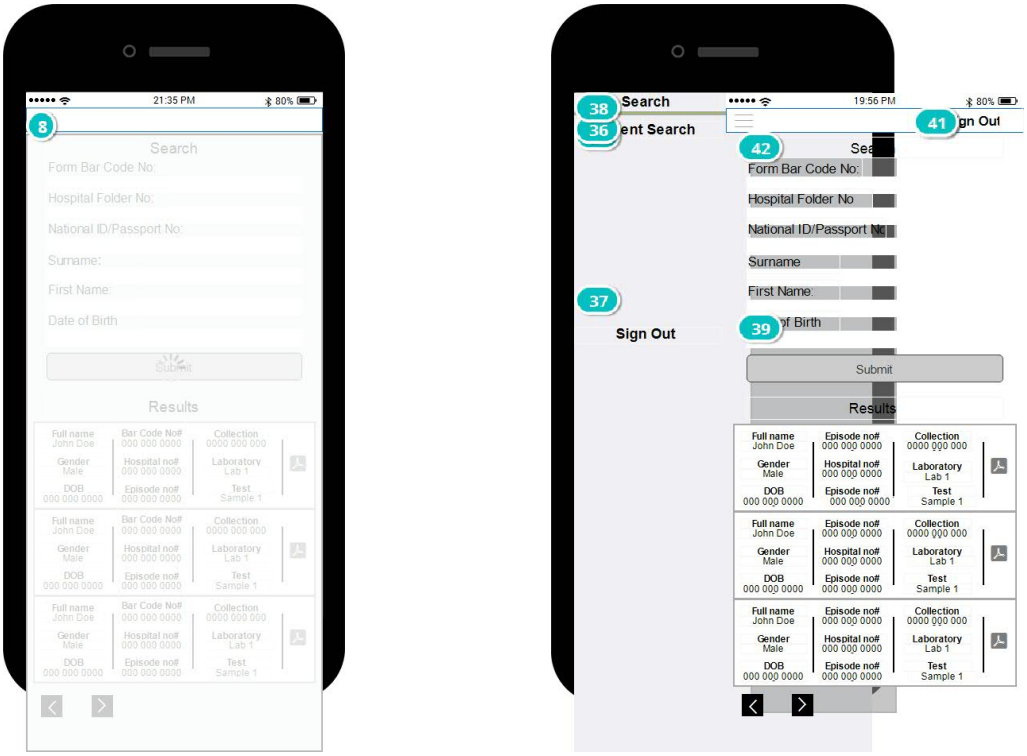
The third and last iterative process improved the design of the prototype using the same interactive prototyping tool, Justinmind. The improvements were based on the feedback obtained from the heuristic evaluation results discussed above.

In addition to the rearrangements on the current graphic user interfaces, additional features and pages were designed to give a more desired outcome. Only the modified pages and additional designs will be presented in this section in line with the evaluation outcome of the second iteration.

This search invoked page illustrated below in figure 9 (image A) was designed to keep the user informed of what is occurring when they invoke a search. The screen fades, presenting a “system busy” conventional icon as feedback to the user. A menu page (image B) was added to the design to allow users to navigate freely through the application giving them the ability to easily leave an unwanted state without going through an extended dialogue. The menu is depicted by a conventional icon for consistency with standards.

A. *search invoked page*

B. *menu page*



C. *search outcome page*

D. *results preview page*

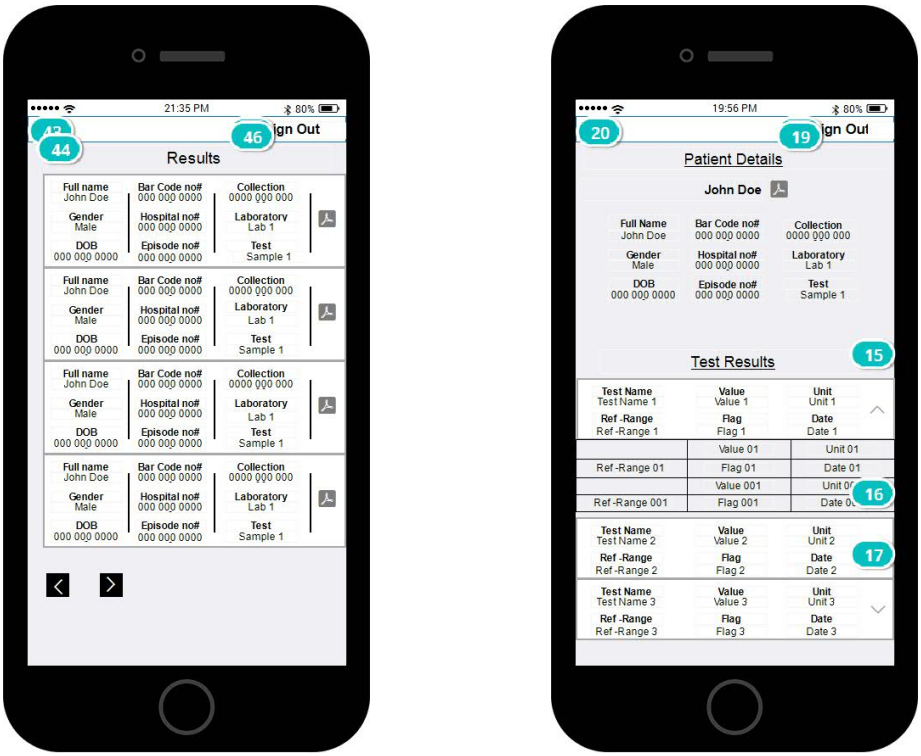


Figure 9: Third iteration design overview

The design of the patient result record format was rearranged to logically present the headings as shown in figure 9 above (image C). The patient attributes are in one section and so are all the patient identifiers. The test attributes are also grouped in a separate section in a logical manner. This makes it easy for the users to utilise the application.

An additional “results preview” page (image D) was designed to illustrate the presentation of the previous results of the same test requested. This allows the user to view at least two previous results for the same patient and test on the same page. A “down” arrow opens the previous results while the “up” arrow closes the previous results. This adds flexibility to the application, making it more usable.

After addressing all the concerns raised, the users were exposed to the improved application following the same scenarios (Appendix 2) used during the second iteration. The same expert users were then asked to take the SUS survey (Appendix 5) to evaluate the prototype. This is a quantitative tool that gives an average score that determines the usability of the application.

The table below shows the SUS survey result scores including the average score for all the five participating expert users. An average score of 77 was obtained on the SUS, proving the usability of the prototype.

Table 3: System usability survey results

System Usability Scale (SUS) Survey Result											
Participant	**I think that I would like to use this system frequently**	**I found the system unnecessarily complex**	**I thought the system was easy to use**	**I think that I would need the support of a technical person to be able to use this system**	**I found the various functions in this system were well integrated**	**I thought there was too much inconsistency in this system**	**I would imagine that most people would learn to use this system very quickly**	**I found the system very cumbersome to use**	**I felt very confident using the system**	**I needed to learn a lot of things before I could get going with this system**	**SU Score**
User 1	4	2	2	1	4	2	4	1	4	1	77,5
User 2	3	1	4	1	3	1	3	1	4	1	80
User 3	4	2	3	1	4	2	3	2	3	2	70
User 4	3	2	4	2	3	2	4	2	4	2	70
User 5	4	1	4	1	4	1	4	1	4	1	87,5
									Average Score		**77**

The figure below demonstrates that the average SUS score of 77 is way above system usability threshold of 68, which means that the laboratory mobile application prototype design is deemed usable.

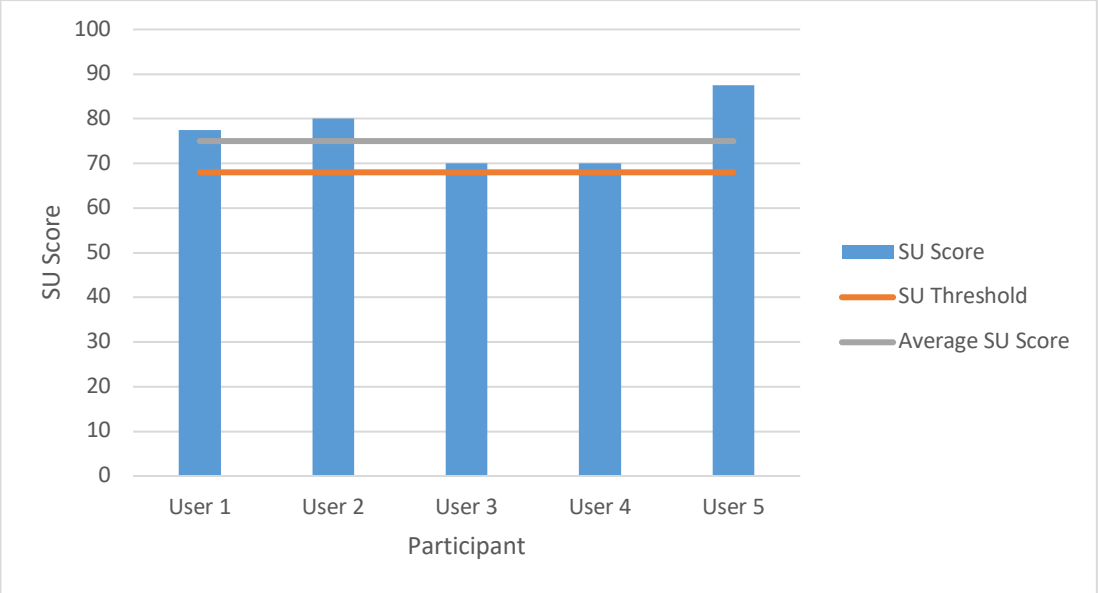


Figure 10: System Usability Scale survey result analysis

The final feedback from the evaluation team was largely positive. The users found the prototype to be well laid out and they felt that there was consistency with general modern designs.

4.3 Discussion

UCD principles that were applied in the design of a mobile application interface prototype for laboratory results produced a design that is usable and effective. The self-administered questionnaire used for the initial survey during the user requirements gathering phase established a sound basis for the progression of the study to the next phase. The five questions managed to point out the users' perception regarding the use of mobile applications for patient care. However, the questionnaire left out some relevant questions relating to the use of the web-based application to access laboratory results. The survey did not attempt to uncover the short comings of the existing TrakCarewebview system. Therefore, the inquiry into the effectiveness and efficiency of the TrakCarewebview was not thoroughly ascertained from the users through this questionnaire. A more thorough validation of the questionnaire was required to further strengthen the investigation.

The design and evaluation phases followed an iterative prototyping approach through cycles which involved the constant engagement of users throughout the process. Findings from the study indicate that SME' insight is highly valued when designing specific domain applications.

A significant discovery from the prototypes is that at every iteration, users used a different evaluation technique to bring variety to the process and eliminating monotony. This also made it possible for the prototype to be critically examined and improved. This success was achieved through continuous engagement with the potential users of the application. The final prototype's design was deemed usable due to the application of UCD principles which augments user requirements based design and user evaluation. In addition, the success of this study was also made possible by the honest evaluation of the incremental prototypes by the users until a final prototype was produced. The key aspects of this method was the involvement of users during the iterations for both design and evaluation stages.

It is important to note that the UCD approach anchors solely on user involvement hence the need for SME who are the intended users of the application. The SME are the only users who fully understand the workflow and were able to address all the vague aspects and major domain glitches in each design. Iterative phases were essential to certify the advancement of the usability of the final product. Each evaluation method produced input for enhancements in the proceeding iteration through honest feedback thus making each evaluation objective and meaningful.

Heuristic evaluation is popular with researchers as well as usability practitioners [34]. Some of the major strengths of heuristic evaluation include the speed at which it can be performed. The heuristic evaluation technique is also a well-documented method that has been used extensively making it easy for non-practitioners [34]. Nielsen found that aggregating the results of heuristic evaluations independently, performed by five evaluators, identified approximately two-thirds of usability problems in a UI [30]. He recommended that evaluators should inspect UI's independently to prevent them from influencing and biasing each other's findings. Nielsen further established that aggregating the results of independent evaluations results in uncovering a

greater variety of errors in comparison to those found by a group of evaluators working together [30]. Another study shows that heuristic evaluation found more problems than empirical usability testing, cognitive walkthroughs and guidelines evaluation [35]. Heuristic evaluation is reported to find the largest number of problems including the most serious ones at the lowest cost compared to any other evaluation technique. Usability testing was found to reveal more severe usability problems, but at a substantially higher cost. A separate study found that heuristic evaluation revealed more usability problems than cognitive walkthroughs, but only when expert evaluators performed the evaluations [35].

In as much as heuristic evaluation is powerful in identifying usability problems, it may not be fully applicable in modern days hence it needs to be complemented by other evaluation methods. Heuristic evaluation poses some limitations in its applicability. One of the major limitations of heuristic evaluation is the fact the quality of the results based on an evaluation largely depend on the expertise of the evaluators. To guarantee that all of the major usability problems are identified in a heuristic evaluation, a set of subject matter experts in a particular field is required. Practitioners performing heuristic evaluations need to be experienced with this technique to provide high quality results. Research indicates that usability specialists are more efficient than non-experts at finding usability problems by performing heuristic evaluations [36]. It was also found that evaluators with less knowledge of the heuristic evaluation process performs poorly [37]. This means that multiple evaluators with knowledge and experience of using the technique are required. Another study found that heuristic evaluation uncovered many specific, one-time and low priority problems suggesting the complementary use of usability testing methods which are believed to uncover severe, recurring and global problems [35]. Nielsen however came to a different conclusion and found that major usability problems have a higher probability of being found by heuristic evaluation than minor problems [36].

Heuristic evaluators are required to have full understanding on how users will interact with the system being evaluated. User education, context of use, frequency and common usage scenarios have to be well documented and understood by evaluators in order for heuristic evaluation to yield relevant

results. In order to make the heuristic evaluation a pluralistic affair, it's prudent to also use human computer interaction (HCI) experts.

The SUS survey evaluation played very fundamental role in the determination of whether the final product was acceptable or not. It defined the success criteria because it provided an objective assessment backed by an effective human behaviour algorithm to come up with a quantitative score. The sample size (five expert users) for the SUS evaluation was adequate for evaluating the final prototype given that all the design end users were involved. The limitation with this approach is that it may cause bias among the evaluators evaluating their design throughout the process. A different set of users would have been ideal to conduct the evaluation to eliminate possible bias of the evaluation process. Furthermore, a larger sample size would have provided more objectivity in the final score by giving more user representation. This means additional resources would have been required to orient the new set of evaluators in order provide meaningful responses. For the actual functional product, it is recommended that a larger sample size be considered for the SUS evaluation in order to fully represent all the end users to provide the best objective score.

The new design presents a lot more offerings when compared with the existing paper-based and web-based (TrakCarewebview) methods of delivering laboratory results. The new design similar to the TrakCarewebview delivers electronic results to the medical professionals as soon as the result is available unlike the paper-based option which is dependent on a courier system to physically deliver the paper result. Both the web-based and the new design provides an additional option of a pdf result format which is identical to the physical printed laboratory report. The new design however stands out due to its ability to offer a mobile friendly platform which will enable the doctor to obtain the patients' results electronically in the ward by the bed side. More importantly, with the new design, the doctor goes through four steps to obtain the patients' result while on the existing web-based application it takes the doctor nine steps to achieve the same. Furthermore, the new design presents the current test results and two sets of the previous results of the same test for the same patient on a single view allowing the doctor to immediately see the

history of the patient. On the other hand, TrakCarewebview only shows the current result in the single view.

CHAPTER 5: Conclusions

The results indicate that public sector clinicians are ready to adopt mHealth technology. Almost all clinicians carry a mobile device for their day-to-day use. A significant part of the population believes that the use of mobile devices to access patient laboratory results will go a long way in contributing to improve patient care. Delivering patient results to a clinician's mobile device in his/her hand is seen to be a key ingredient in improving result turnaround times. Improvement in this turnaround time in turn empowers the clinician to make informed clinical decisions promptly, thereby improving patient care.

It is also encouraging to note that clinicians are willing to use their personal devices for this worthy cause, though a majority would appreciate subsidised data costs. Two ways of addressing this request could be the following: firstly, the DoH could invest in installation of Wi-Fi access points in health facilities to enable clinicians to connect using their own devices to access laboratory results via the mobile application. Secondly, the DoH could make arrangements with mobile data service providers to zero rate or reverse bill the mobile application so that the data costs associated with interacting with the mobile application are redirected to DoH. This would mean the clinicians would not be charged for using the mobile application.

The general objective of the mobile application interface was to reduce cognitive load with a streamlined usable fit-for-purpose interface, which gives patient results after a few touches. This was achieved through an iterative UCD approach involving the full participation of expert users making the process to be very effective for designing a new interface for the accessing of laboratory results. Separating the interface design from the actual software development process allowed for a vigorous focus on user requirement. The adherence to the accepted usability heuristic principles further strengthened the design process. The iterative approach was critical in the design process to further refine and clarify usability requirements and clear any misunderstandings.

It is important to note that this approach experiences limitations especially with regards to the availability of suitable domain experts through the process. It is not easy to have fully committed team of subject matter expert for the duration of the design process. For future endeavours, it is recommended that the

private sector clinician be included in order to increase the pool diversity of views.

Paper prototyping proved to be a bit challenging, as it is limited in terms of illustrating more complex interactions. However, paper sketches gave a good starting point and allowed for more engagement with the end-users. This presented an opportunity to modify the prototype immediately as the users interacted giving feedback. The flexibility of paper prototyping allowed for co-designed sketches to be drawn during the sessions. The higher fidelity, interactive prototyping software (Justinmind) was very effective as it mimicked real-life situations giving user a real life experience with the intended application. Thus, the interactive prototyping tool proved to be a significant ingredient to the successful examination usability and effectiveness in that it provided an ideal platform for the design and evaluation processes.

It was interesting to note that the employing of the three different evaluation methods at each iteration allowed for a process of progressive, consultative refinement, which resulted in a more usable interface. The usability score of 77 (meaning good) was there shy of the minimum required score of 80 to reach excellent, in retrospect it has been reviewed and additional features such as biometric login would make the user journey much easier and possibly increase usability to the excellent region.

The SUS survey added significant value to the process in providing a measureable quantitative score of the usability of the final prototype. In terms of the number of users that participated in the SUS survey, five appeared not to be ideal as the survey was based on user perception questions. Increasing the number of users to participate in the SUS survey is a recommendation seen as imperative in order to bring more objectivity to the evaluation process.

An immediate recommendation for future work would be to develop the actual mobile application based on this design. The mobile application will be reading directly from the TrakCare LIS to ensure real time availability of laboratory results. It is recommended that the user authentication to the mobile application be handled by the TrakCare user management policy to ensure that intended users get the correct level of access without compromising patient confidentiality. This means that users will be setup primarily on the LIS

following the set access management policies which will then be provisioned for mobile access through system integration.

The costs incurred in this project were very minimal considering the benefits experienced in the final product. It is therefore anticipated that future medical software designs and developments will incorporate the UCD approach in order to produce more usable products.

This work will revolutionise the way the public sector works by introducing mobile technology that will have a direct impact on laboratory test turnaround times, thus improving patient care. The gap between the laboratory test results and the clinician will be reduced and a strong laboratory-clinic interface will be established.

As part of future studies and developments, it would be worthwhile to further strengthen the clinic laboratory interface by designing an order entry interface for logging electronic laboratory requisitions from the clinic/ hospital end. This would mean that an electronic record with patient demographic information and sample information is send to the laboratory information system. Linked to this would be a design for tracking samples from the clinic to the laboratory in order to ascertain the full chain of custody of the samples. This will complete the full value chain of the laboratory services making the whole cycle electronic and paperless. This will inevitably reduce turnaround times for laboratory results delivery and make monitoring and evaluation of cycle much simpler by making use of dashboards to monitor performance.

Some limitations were encountered during the study which include the lack of suitable participants, as only SME and intended users were sought. The study could also have been limited by the bias towards the designer (facilitator) in the user's feedback, however this was mitigated by having the users' take the SUS survey independently without the pressure of the facilitator. This gave a more independent objective result score. Furthermore, the feasibility of this design on the actual product could be another limitation. This can be mitigated by having a subsequent design and evaluation iteration post development of the actual mobile application to affirm the usability of interface design.

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Appendix 1: Survey questionnaire

Survey questions on clinician readiness to use mobile applications to access laboratory results

Designation

Job function in the health facility

1. What is your designation?

- Medical Practitioner
- Medical Intern
- Nurse

Other (please specify)

Mobile device in use

Personal mobile device for communication

2. What type of mobile device do you PRIMARILY use?

- Regular cell/mobile phone (not a smartphone)
- Android Phone
- Android Tablet
- iPhone
- iPad
- Blackberry/RIM
- Windows Phone
- Windows Tablet
- I don't have a mobile phone/ Tablet

Improvement of Patient Care

Contribution of mobile application to patient care

3. Can the use of a mobile application to ACCESS LAB RESULTS contribute to IMPROVING PATIENT CARE?

- Strongly disagree
- Disagree
- Agree
- Strongly Agree

Personal choice

Would you personally embrace and use a mobile application to access lab results

4. Would YOU use a mobile application to access lab results?

- Strongly Disagree
- Disagree
- Agree
- Strongly Agree

Preferences

Device and data preferences

5. What is your preference?

- Personal device and own data cost
- Loan device and own data cost
- Personal device and subsidised data cost
- Loan device and subsidised data cost

Appendix 2: Evaluation scenarios

Task #	Task	Scenario
1	Sign in	Sign in to the application and sign out from any of the application pages
2	Failed sign in	Attempt to request for password reset
3	Patient record search	Navigate to search for a patient's record using the existing search fields
4	Viewing of patient results	Navigate to view patients' current and previous results
5	View pdf result	Navigate to view patients' results in pdf format and close

Appendix 3: Ten heuristic principles

The ten refined heuristic principles that will form the basis for the user-based evaluation are explained below [8].

I. Visibility of system status

The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.

II. Match between system and the real world

The system should speak the users' language, with words, phrases and concepts familiar to the user. Follow real-world conventions, making information appear in a natural and logical order.

III. User control and freedom

Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.

IV. Consistency and standards

Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.

V. Error prevention

Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.

VI. Recognition rather than recall

Minimise the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another.

VII. Flexibility and efficiency of use

Accelerators -- unseen by the novice user -- may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.

VIII. Aesthetic and minimalist design

Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.

IX. Help users recognise, diagnose, and recover from errors

Error messages should be expressed in plain language (no codes), precisely indicating the problem, and constructively suggest a solution.

X. Help and documentation

Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

Appendix 4: Evaluation response template

1. Visibility of system status

Does the system always keep you informed about what is going on, through appropriate feedback within reasonable time?		Tick most appropriate rating for the scenario
0	Do not agree that it is a usability problem	
1	It is a cosmetic problem	
2	Minor usability problem	
3	Major usability problem- important to fix	
4	Usability catastrophe- imperative to fix	
Open Question	Do you have any suggestions for enhancement on this aspect?	

2. Match between system and the real world

Does the system speak your language, with words, phrases and concepts familiar to you? Follow real-world conventions, making information appear in a natural and logical order.		Tick most appropriate rating for the scenario
0	Do not agree that it is a usability problem	
1	It is a cosmetic problem	
2	Minor usability problem	
3	Major usability problem- important to fix	
4	Usability catastrophe- imperative to fix	

Open Question	Do you have any suggestions for enhancement on this aspect?	

3. User control and freedom

Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Does the system support undo and redo?		Tick most appropriate rating for the scenario
0	Do not agree that it is a usability problem	
1	It is a cosmetic problem	
2	Minor usability problem	
3	Major usability problem- important to fix	
4	Usability catastrophe- imperative to fix	
Open Question	Do you have any suggestions for enhancement on this aspect?	

4. Consistency and standards

Users should not have to wonder whether different words, situations, or actions mean the same thing. Does the system follow platform conventions?		Tick most appropriate rating for the scenario
0	Do not agree that it is a usability problem	
1	It is a cosmetic problem	
2	Minor usability problem	
3	Major usability problem- important to fix	
4	Usability catastrophe- imperative to fix	

Open Question	Do you have any suggestions for enhancement on this aspect?	

5. Error prevention

Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Does the system eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action?		Tick most appropriate rating for the scenario
0	Do not agree that it is a usability problem	
1	It is a cosmetic problem	
2	Minor usability problem	
3	Major usability problem- important to fix	
4	Usability catastrophe- imperative to fix	
Open Question	Do you have any suggestions for enhancement on this aspect?	

6. Recognition rather than recall

Minimise the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Does the system have this ability?		Tick most appropriate rating for the scenario
0	Do not agree that it is a usability problem	
1	It is a cosmetic problem	
2	Minor usability problem	

3	Major usability problem- important to fix	
4	Usability catastrophe- imperative to fix	
Open Question	Do you have any suggestions for enhancement on this aspect?	

7. Flexibility and efficient of use

Accelerators -- unseen by the novice user -- may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions. Does the system have this ability?		Tick most appropriate rating for the scenario
0	Do not agree that it is a usability problem	
1	It is a cosmetic problem	
2	Minor usability problem	
3	Major usability problem- important to fix	
4	Usability catastrophe- imperative to fix	
Open Question	Do you have any suggestions for enhancement on this aspect?	

8. Aesthetic and minimalist design

Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility. Does the system have this ability?		Tick most appropriate rating for the scenario
0	Do not agree that it is a usability problem	
1	It is a cosmetic problem	

2	Minor usability problem	
3	Major usability problem- important to fix	
4	Usability catastrophe- imperative to fix	
Open Question	Do you have any suggestions for enhancement on this aspect?	

9. Help users recognise, diagnose, and recover from errors

Error messages should be expressed in plain language (no codes), precisely indicating the problem, and constructively suggest a solution. Does the system have this ability?		Tick most appropriate rating for the scenario
0	Do not agree that it is a usability problem	
1	It is a cosmetic problem	
2	Minor usability problem	
3	Major usability problem- important to fix	
4	Usability catastrophe- imperative to fix	
Open Question	Do you have any suggestions for enhancement on this aspect?	

10. Help and documentation

Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large. Does the system have this ability?		Tick most appropriate rating for the scenario
0	Do not agree that it is a usability problem	

1	It is a cosmetic problem	
2	Minor usability problem	
3	Major usability problem- important to fix	
4	Usability catastrophe- imperative to fix	
Open Question	Do you have any suggestions for enhancement on this aspect?	

Appendix 5: System usability scale template