User-interface design and evaluation in a mobile application for detecting latent tuberculosis

Prepared by:

Jaydon Ethan Farao

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Supervisor: Professor Tania S. Douglas

Co-supervisors: Dr Bessie Malila & Dr Tinashe Mutsvangwa

DECLARATION OF AUTHORSHIP

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ABSTRACT

Treatment and monitoring of tuberculosis have been met with various interventions to reduce its prevalence. One such intervention, to detect and prevent latent tuberculosis infection (LTBI), is the tuberculin skin test (TST), for which an induration response on a patient's arm is an indication of LTBI. The test requires the patient to return to a clinic 48 to 72 hours after TST administration for assessment of the response. This is a challenge because of financial and accessibility obstacles, especially in under-resourced regions. A mobile health (mHealth) application (app) has been developed for remote assessment of the response to the TST. The previous version of the LTBI screening app, however, had usability limitations. The app is intended for use by patients and healthcare workers; thus, ease of use is important. There is a lack of literature on the usability of mHealth apps, especially in under-resourced settings.

In this project, the user interface of the app was redesigned and tested. The Information Systems Research (ISR) framework was integrated with design thinking for this purpose. The project included creating mock-ups of the interface which were iteratively prototyped with ten student participants, adjusted, and assessed according to the user feedback. Thereafter, the Android Studio software was used to adjust the user interface based on the insights gained through the progression of prototypes. The usability of the updated app was tested and assessed with ten healthcare workers at a community health clinic in Khayelitsha in Cape Town, South Africa. Data collection and analysis comprised both qualitative and quantitative methods. Observations, the "think aloud" approach, and the post-study system usability questionnaire were used for data collection.

Student participants highlighted various usability limitations of the app during each iteration. The major usability limitations included: the complex image capture protocol, misunderstanding of instructions, and time taken to capture images. Engagement with students allowed for improvement of the app interface and enabled adequate preparation for testing in the field with end-users. Furthermore, improving the app interface before engaging with healthcare workers, enabled context-specific limitations that would affect the usability of the app, to be explored during the field testing. These included safety concerns when using the app and the privacy of health information. Future work should explore how these concerns, as well as other social factors, affect usability. Furthermore, improving the image capture protocol is required for improving the usability of the app.

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ABBREVIATIONS

CHW	**C**ommunity **H**ealth **W**orker
HMWQ	**H**ow **M**ight **W**e **Q**uestion
ISR	**I**nformation **S**ystems **R**esearch
LTBI	**L**atent **T**uberculosis **I**nfection
POV	**P**oint **o**f **V**iew
PSSUQ	**P**ost-**S**tudy **S**ystem **U**sability **Q**uestionnaire
TB	**T**uberculosis
TST	**T**uberculin **S**kin **T**est

1 INTRODUCTION

Mobile applications (apps) have become popular globally with the increasing adoption of mobile phones. This has resulted in the appropriation of this technology in various sectors including health (Clifford & Clifton, 2012). Mobile health (mHealth) apps have become an active area of research and development, as they are expected to play a key role in enabling governments to meet the United Nations Sustainable Development Goal on ensuring good health and well-being by 2030 (Global System for Mobile Communications, 2018). One such opportunity lies in creating ways to better manage and treat tuberculosis (TB), a disease that primarily affects the lungs, and is the leading natural cause of death in South Africa (Statistics South Africa, 2018). Latent tuberculosis infection (LTBI) is a condition where a patient is infected with the Mycobacterium tuberculosis (M. tuberculosis) bacterium which causes TB but shows no symptoms of active disease.

The standard method of detection and early prevention of LTBI is the Mantoux tuberculin skin test (TST) (Nayak & Acharjya, 2012). The TST involves injecting tuberculin into the patient's arm. An immune reaction to tuberculin is expected, after 48 to 72 hours, in the form of an induration (a hardened mass usually circular in shape). The TST consequently requires the patient to visit a clinic within 48 to 72 hours of administration of the tuberculin, in order that the patient's response to the TST may be assessed. The diameter of the induration is used to determine whether a patient has been exposed to TB infection. Traditional TST diagnosis involves marking the edges of the induration with a ballpoint pen and measuring the resultant diameter with a ruler. This technique introduces potential errors in the measurement (Pouchot et al., 1997). The challenge that arises for patients at this stage of the procedure is that time, financial and accessibility constraints often determine whether they are able to revisit a healthcare facility, especially in a developing country such as South Africa (Oliveira et al., 2011). Returning to a clinic or healthcare facility is vital, because there is a high risk of subsequent active TB in a patient with a positive TST outcome (Rangaka et al., 2012). Thus, addressing the challenges faced by patients in returning to a clinic for assessment of the test results, would improve the TST as a method for LTBI screening.

An mHealth app designed to aid health professionals in the diagnosis of LTBI is currently in development at the University of Cape Town (Naraghi et al., 2018). The app aims to diminish the constraints mentioned above. The app aims at remote assessment of the results of the TST by using an Android-based mobile phone to obtain two-dimensional (2D) images of an induration and proceeds to reconstruct the images into a three-dimensional (3D) model for measurement of the diameter of the induration. Image capture with the mobile phone can be done by a patient or a healthcare worker.

The development of the app anticipates two use cases. The first is the use of the app by patients being screened for LTBI. This would involve a healthcare worker assisting the patient with app installation on an initial visit and demonstrating what is required of patients for successful use of the app. A limitation to this use case is that patients would need to complete the image capture by themselves, which is difficult without assistance. Additionally, the privacy of their data needs to be ensured on their mobile phone. On the other hand, in this use case, healthcare workers would save effort and time during LTBI screening. However, if healthcare workers are primary users of the app, they can be trained to operate the app for routine image capture, either at the clinic or in the field. While use of the app at the clinic would not address the factors that impede a second clinic visit by patients for assessment of the TST response, it has potential in low-risk countries (Dendere et al., 2017), where healthcare personnel may have limited experience in reading the TST.

1.1 PREVIOUS MOBILE APPLICATION

The previous version of the app had the basic functionality required for assessing the TST response; however, as reported by Naraghi et al. (2018), the interface is complex and difficult to follow. The image capture of the LTBI screening mHealth app involves capturing seven images of the induration induced by the TST. The image capture begins with the placement of a scaling sticker, designed by Naraghi (2018), around the induration, shown in Figure 1. The scaling sticker assists in the 3D reconstruction and evaluation of the images. After placing the sticker, images are taken at different orientations with respect to the induration to enable 3D reconstruction and determination of the size of the induration, as an indication of LTBI. For users to capture the images at the desired positions and orientations, assistance tools are incorporated into the app for image capture. These are:

1) An orientation panel, with a text box and image capture signals, that informs the user to tilt the mobile phone to take the desired image. It also only allows the image to be captured at the correct orientation (roll and pitch);
2) A marker guide box used for scaling the image;
3) An axis, indicated on the mobile device display, representing the orientation along the length of the arm of the user;
4) An induration guide box to ensure that the induration is at the correct location in the image.

The different orientations of the seven images (three images from the left, three from the right and one top view image) are shown in Figure 1.

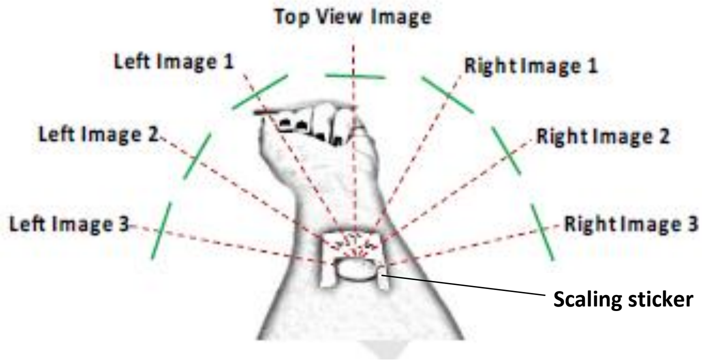

Figure 1: Orientations for image capture procedure (Naraghi, 2018).

The captured images are linked to patient-specific information, so that the results for that patient can be recorded. The success of the mobile app-based LTBI screening procedure depends on the captured images satisfying requirements for 3D reconstruction and processing. This result is influenced by the usability of the mobile app. Some screenshots of the current version of the app's user-interface are shown in Figure 2. According to the results obtained by Naraghi (2018), the users had difficulty following and remembering the instructions for the image capturing protocol; the users attributed this to the lengthy text, which included an in-depth description of image capture and how to interact with the app. Naraghi also identified complexities within the interface that affect low-proficiency English readers as well as low literacy users. This influenced the quality of captured images and could possibly affect the uptake of the app by the targeted end users.

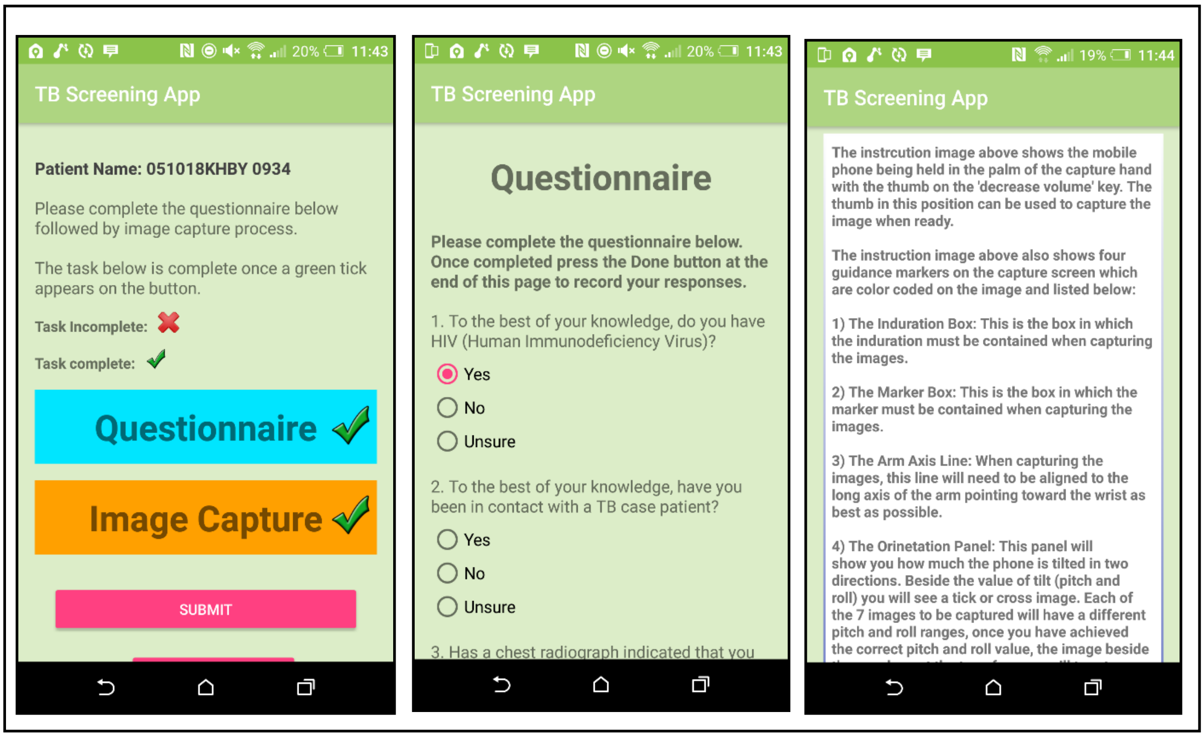

Figure 2: Screenshots of LTBI screening app developed by Naraghi (2018).

The data related to the usability of the app were collected through a questionnaire completed by participants who were fluent in English and familiar with technical terms (Naraghi, 2018). These participants did, however, raise concerns about the tedious instruction pages and the image acquisition process. If an app is difficult to use, and has an unengaging interface, it is most likely to frustrate the user, which could lead to inaccurate or incomplete results, as well as low uptake.

The success of mHealth apps largely depends on their functionality *and* their usability (Linares-Vásquez et al., 2013). Prioritising both is essential in creating a durable, robust, and effective app. Some of the problems that arise when designing mobile apps include designing for the widespread population with various education levels; designing for multi-tasking functions; and designing for limited input/output facilities on the mobile devices (Dunlop & Brewster, 2002; Kumar, Krishna & Manjula, 2016).

This project seeks to address the limitations of the current version of the user-interface of the app, by assessing and improving its usability. The project employs a user-centred approach for the design of the app interface, using design thinking techniques. Not many usability design frameworks are available for mHealth apps. There are, however, usability frameworks for generalised mobile apps, but the metrics used for these apps may not be appropriate for the functions of an mHealth app, such as the one in this project. Available design frameworks have been adapted for the TST application.

1.2 Aims and Objectives

The aim of this project was to improve the design of, and evaluate, a user-interface for a mobile phone-based LTBI screening app. The aim was achieved through the following objectives:

1) Redesign and improve the user-interface of the UCT LTBI screening mHealth app.
2) Assess the usability of the redesigned mHealth app in a clinical environment.

While the app can potentially be used by healthcare workers to assess the TST response at patients' homes or at the clinic, or by patients themselves, this project focuses on the use of the app by healthcare workers.

1.3 Overview

Chapter 2 presents a literature review detailing the existing knowledge concerning the usability and design of mobile health applications. Chapter 3 introduces and motivates the design approach for this study. Chapter 4 presents the findings related to the user-interface design and testing of the LTBI screening app. Finally, Chapter 5 discusses the results and concludes this report.

2 LITERATURE REVIEW

This chapter serves to explore existing literature on usability and design of mobile applications. The two main areas covered are the usability and design of mobile applications, presenting available theoretical and practical guidelines for the realisation and evaluation of mHealth apps. The chapter also provides an overview of the current developments on mHealth apps and user interaction and introduces design thinking as an approach to innovation for designing mHealth systems.

2.1 USABILITY

Designers of interactive devices, such as appliances, computers, and cellular phones, are usually concerned with how easy they are to use. Mobile devices present operational difficulties as a result of their small form factor. Small screens, limited input/output facilities, and increasing complexity in cellular software impact their ease of use (Gafni, 2009). These complexities, along with "usability" concerns, have naturally evolved with increased adoption of mobile applications.

Different standards define usability in various ways. The Institute of Electrical and Electronics Engineers (IEEE) defines usability as, "the ease with which a user can learn to operate, prepare inputs for, and interpret outputs of a system or component" (IEEE, 1990:80). According to the International Organisation of Standardisation (ISO), usability is 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" (ISO, 1998:2). Both definitions hold core ideas on what usability is, but the ISO definition adds three important components of usability that guide the understanding of the term in the context of mobile apps, specifically mHealth apps.

1) Effectiveness: "the accuracy and completeness with which specified users can achieve specified goals in particular environments";
2) Efficiency: "the resources expended in relation to the accuracy and completeness of the goals achieved";
3) Satisfaction: "the comfort and acceptability of the work system to its users and other people affected by its use."

The three components combined with "context of use" create valuable insights into what it means for a product to be usable. "Context of use" is defined in terms of the users' perspective and opinions, which in turn serves as a guide to evaluate usability (Moumane, Idri & Abran, 2016). When evaluating mHealth apps, user comfort and operationality should be a priority since this allows users to carry out required tasks more efficiently (Gafni, 2009). To achieve a satisfactory usability, one needs to define characteristics and metrics that may be used to measure how “usable” a product, device, or even an application is.

Usability characteristics and metrics have been defined differently by multiple organisations, including the ISO and the International Electrotechnical Commission (IEC). They define a standard for software engineering, ISO/IEC 9126, that translates “quality” into many characteristics as it relates to usability (ISO/IEC, 2001). The standard is aimed at providing metrics that allow measurement *during* the use of a system, which is termed “quality in use”. These metrics include functionality, reliability, usability, efficiency, maintainability, and portability. The standard also aims to determine whether users are able to complete tasks with “effectiveness, productivity, safety, and satisfaction”, in the context of use (ISO/IEC, 2004). The standard also includes usability as a component of quality, which is further broken down into understandability, learnability, operability, attractiveness, and usability compliance.

The aforementioned measurement metrics of usability inform the quality of the system software. A combination of these metrics when the product is in use, determines the “quality in use”. Once again, the non-specific nature of this standard allows it to be used to assess mobile app systems, including mHealth apps. The usability component of the standard provides guidelines and a foundation on which to build a more specific usability framework. However, the usability of products and how to improve them still needs to be investigated in a practical environment. The following section reviews literature related to methods and frameworks for assessment and evaluation of usability.

2.2 ASSESSMENT OF USABILITY

According to Preece, Rogers, and Sharp (2002:345-346), there are four methods usually used to assess and evaluate usability. These are:

1) Heuristic evaluation or expert-based evaluation, where one or more human experts define potential problems that inexperienced users could face during the use of an interactive system;
2) Observation, which involves collecting data of users interacting with an interface through the use of video recording, the “thinking aloud” protocol or direct observation;
3) Obtaining users’ or experts’ opinions and feedback through questionnaires and interviews;
4) Using experimental evaluations to obtain expert and/or user reports on usability issues through questionnaires, interviews, and software logging.

These methods are used in either a laboratory or field environment, the former providing a less realistic output while the latter is difficult to carry out (Kaikkonen et al., 2005). The different methods also provide both subjective and objective data depending on what medium is used to obtain the information. Since there are multiple ways in which usability can be assessed and evaluated for generalised systems, researchers have made efforts to investigate the most appropriate methods for specific contexts. This is also the case with mobile applications.

Schnall et al. (2016) use the "Post-Study System Usability Questionnaire" (PSSUQ) to assess the usability of an mHealth app as it relates to user satisfaction. This assessment tool, developed by the International Business Machines Corporation (IBM), consists of 19 questions which require responses ranging from 1 (strongly agree) to 7 (strongly disagree) (Lewis, 1992). The questions relate to ease of use, efficiency, and likability of the user-interface (Schnall et al., 2016). Additionally, the questions in the PSSUQ are arranged to assess the following three factors; system usefulness (questions 1 to 8), information quality (questions 9 to 15), and interface quality (questions 16 to 18). The final question relates to the user's overall satisfaction with the system. Fruhling and Lee (2005) define system usefulness as the ease of use and learning, the speed at which users become productive, and the effective completion of tasks. Information quality is defined as the various feedback the system provides related to error messages and fixing problems. It also refers to how well the information is organised, whether it is easy to understand, and whether it helps the user complete tasks. Interface quality is defined as the affability of the system for the user, as well as the likeability of the system. Schnall et al. (2016:247) cite Lewis (1995) who reports the PSSUQ to have a "strong reliability, and content and construct validity".

Hussain and Kutar (2009) present a systematic review of existing and previously utilised usability evaluation criteria and select various guidelines for the usability of mobile applications. The review uses the ISO 9241-11 standard as the reference point to delineate usability. They discovered that most of the studies investigated use "effectiveness, efficiency, and satisfaction" as quality characteristics, and they used these three as the drivers for the fundamental guidelines in their study (Hussain & Kutar, 2009:3). Using the Goal Question Metric (GQM) as designed by Basili, Caldiera, and Rombach (1994), they attempted to develop a usability metric. The "goals" were represented by the guidelines for usability, obtained during the systematic review, and the questions were determined so that the responses work towards the goals. Table 1 illustrates the usability guidelines, showing the links between quality characteristics, goals, and the associated metrics used to measure usability.

Table 1: Usability guidelines adapted from Hussain and Kutar (2009:3-4).

Quality Characteristic	Goal	Guidelines
Effectiveness	Simplicity	-Ease with which to: • input the data • use the output • install • learn
	Accuracy	-Accurate -Should be no error -Successful
Efficiency	Time taken	-To response -To complete a task
	Features	-Support/help -Touch screen facilities -Voice guidance -System resources information -Automatic update
Satisfaction	Safety	-While using the application -While driving
	Attractiveness	-User-interface

Using the GQM approach, Hussain and Kutar discovered that certain questions could not be answered objectively and needed to be accounted for when user satisfaction was interpreted. Fruhling and Lee (2006) add trust as another usability characteristic to consider with mobile applications, especially its relationship with the user-interface, usability, and electronic health interventions. Idri, Moumane, and Abran (2013) further investigate the issues pertaining to usability and its evaluation, and provide an alternative perspective by using multiple standards of evaluation.

Idri, Moumane, and Abran (2013) identified limitations in mobile devices that could affect the quality of apps and have a negative effect on usability. These limitations included smaller screen size, low display resolution, and the context in which the device is used. The authors developed a usability evaluation framework based on the software quality standard ISO 9126 in mobile environments. Their findings led to the conclusion that the evaluation of usability of apps should begin before the launch of the app.

Moumane, Idri, and Abran (2016) expanded on their research by evaluating their developed framework. Their study focused primarily on the usability component of their framework because it is a “key characteristic for an application to be learned, attractive and easy to use by final users” (Moumane, Idri & Abran, 2016:2). Their results show that usability is influenced primarily by a user-interface with limitations. This means that there are multiple restrictions pertaining to the physicality of mobile phones that affect usability. For example, a restricted display screen size limits the features that can be added on the user-interface. Considering these limitations, the designer of mobile apps has to "adapt the human machine interface of apps to this constraint" (Moumane, Idri & Abran, 2016:5).

Both objective and subjective measures were used to explore the limitations present when using mobile apps. The objective measures used included time to install, time to learn and use, and data entry time. The subjective measures used were overall reaction, the screen evaluation, and the technical online help. Additional factors affecting mobile limitations included the clarity of the user guide and instructions, and online help. These become additional considerations for the design of mobile apps and would be relevant when designing mHealth apps, because if mHealth apps do not accommodate the needs of end-users, they will fail to operate as intended (Maguire, 2001).

2.3 DESIGNING MOBILE APPS

The increasing use of mHealth apps by both ordinary citizens and healthcare professionals, has created the need to develop better user-interfaces (Schnall et al., 2016). Schnall et al. recognise the lack of standardised frameworks for designing mobile apps, especially mHealth apps. Their study proposes the use of a particular design process called the Information Systems Research (ISR) framework (Hevner, 2007), shown in Figure 3. The framework consists of an iterative, user-centred design approach, which Schnall et al. use to influence the design of an mHealth app for HIV prevention. The design process involves consulting both end-users and experts in an iterative fashion, thus providing a way to validate the app design before implementation.

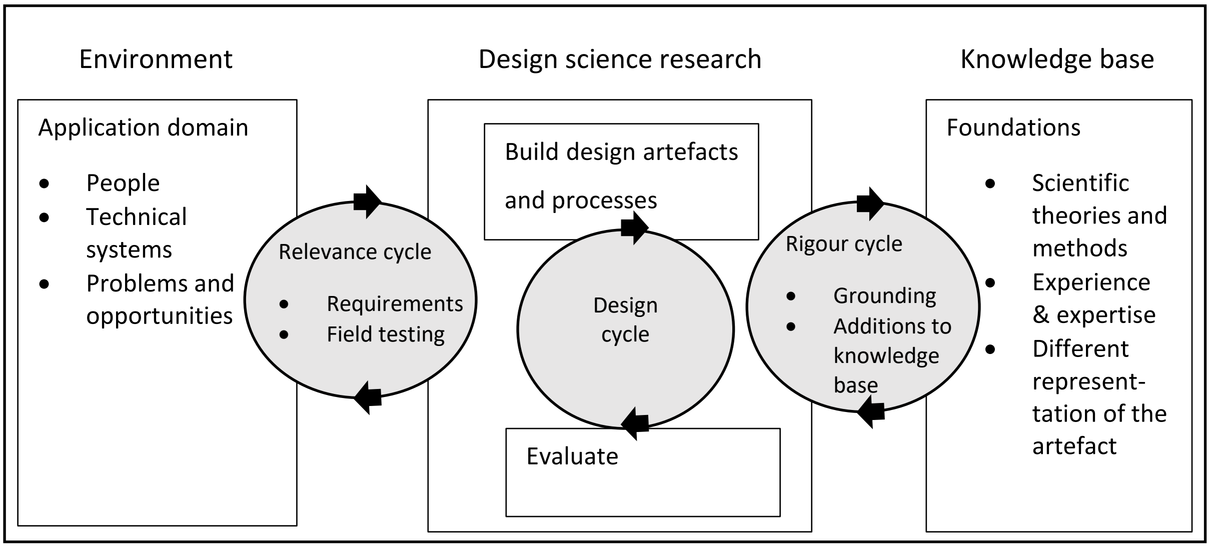

Figure 3: Information Systems Research Framework cycles (Hevner, 2007).

This framework has three cycles 1) the relevance cycle, where the environment of the end-user is understood; 2) the design cycle, where objects relating to the problem are created and assessed; and

3) the rigour cycle, where findings from the evaluation form part of the existing knowledge base within the problem space (Hevner, 2007). The cycles link three domains. The first being the environment domain, which contains the context in which the design of the interface will take place. This includes the study population, technologies used, and the opportunities and problems that arise during the design of the user-interface. The second link is to the design science research domain, which includes the design methods used to develop the innovation. Any changes made to the design occur within this domain. The domain is linked to the environment and knowledge base domains through the relevance cycle and the rigour cycle, respectively. As a result, the design domain processes always need to consider the data represented within the adjacent domains. The knowledge base domain includes any information gathered during the prototyping and iteration of an innovation, as well as evidence from literature and research that is appropriate for the context of the innovation. It forms the foundation for further changes made to the innovation and informs the various artefacts created during the design cycle (Schnall et al., 2016). The design cycle of the ISR framework does not define a specific design approach, therefore it allows designers to innovate the way in which they approach a particular problem, in a particular context.

The limitations of the approach, highlighted by Schnall et al. (2016), include the manner in which participants are chosen, especially those who have experience with mobile technologies; as well as the risk that the sample selected for user evaluations is non-generalisable. This framework allows for the appropriation and/or adaptation for other mHealth apps.

Lopes et al. (2018) present a different approach to user-centred design for mobile applications, which involves the use of "personas" for assessing user experience. This is described by Lopes et al. (2018:3)., citing Cooper (1999), as "fictitious, specific and concrete representations of target users". Personas were used in conjunction with "scenarios" and together they represented the procedure and interaction between the user and the system. To better understand the needs of the variety of potential users of the app, this user-centred design approach uses "interaction models". This allows the researchers to interpret the behaviour of the system during user interaction. Overall, the study provides an inspection method of mobile app systems, that works towards improving the quality of use of mobile apps. Lopes et al. do, however, highlight how diverse mobile technologies could require different methods of design and inspection, and thus a diversity of methods should be considered depending on the technology.

Herman, Grobbelaar, and Pistorius (2018b) propose the use of an already developed inventory/design framework (Herman, Grobbelaar & Pistorius, 2018a) on *MomConnect,* a healthcare technology developed in South Africa. The technology provides health information to pregnant and postpartum women. The authors analysed the various components of the platform by considering the overall objectives of the *MomConnect* technology. They also applied a user-centred design framework for each stakeholder; namely the platform owner, the developer, and the end-user. The framework, as it pertains to the end-user, focusses on the following concepts; context of use, ensuring quality in use, allowing user feedback, and the attractiveness of the app. The end-users in this case are mothers, caregivers, and healthcare workers. While the study introduces a framework with which to design, develop, and implement healthcare technologies in South Africa, it does not go as far as the implementation of the framework.

Table 2 summarises the aforementioned mobile app design approaches and their appropriateness for the purposes of this study.

Table 2: Mobile app design approaches, their advantages, disadvantages, and appropriateness for the study.

Mobile app design approach	Advantages	Disadvantages	Appropriate characteristics for study
ISR framework (Hevner, 2007)	• Iterative • User-centred • Flexible design approach	• Non-specific selection process for participants • Non-generalisable sample for user evaluations	The iterative and user-centred nature of the framework makes it an opportune approach for designing the user-interface for the LTBI screening mHealth app.
Personas and scenarios (Lopes et al., 2018)	• User-centred • Investigates behaviour of app during usage	• Singular approach that requires additional methods for design.	Creating personas and scenarios has the potential to better understand both users and the mHealth app, leading to better user-centred design.
MomConnect inventory framework (Herman, Grobbelaar & Pistorius, 2018a)	• User-centred • Multi-stakeholder design approach	• Framework has not been implemented	Acknowledging the different roles of stakeholders and how they influence the design is a favourable approach for the mHealth app.

2.4 DESIGN THINKING

Design thinking, originally conceptualised by the design and innovation company IDEO, is a way of solving complex problems and conundrums by being solution-focused instead of problem-focused, while nurturing creativity (Brown, 2008). It relies on creativity, systemic reasoning, and intuition in order to investigate the opportunities for desired outcomes to benefit the primary user (Brown, 2008). Design thinking is an iterative and interactive process where designing begins with a pictorial depiction that evolves into more complex representations as detail is added (Do & Gross, 2001). The iterative process involves modifying the current design, along with the design specifications and requirements, according to new information gathered from users (Braha & Reich, 2003). This allows continuous improvement of ideas, while generating creative concepts which are aligned with the specifications of the user and designer. It also reinforces a key element of the design thinking philosophy, i.e. empathy.

2.4.1 The design thinking process

The design thinking process, as introduced by the d.school at the University of Stanford and the Hasso Plattner Institute at the University of Potsdam, consists of five modes which represent the phases of the process (Doorley et al., 2018). Within these modes exist multiple mindsets which support the creative process and assists designers.

Doorley et al. (2018) define the five modes as follows. The first mode is called *empathise*. This mode is based on a qualitative research approach, which involves observing user behaviour, engaging directly with users, and immersing oneself in the experiences of users. The next mode is *define,* which involves collation and analysis of the information gathered during the *empathise* stage into the needs of the user, while picking out valuable insights and putting the broader design challenge into perspective. The third mode is called *ideate.* This phase focuses on generating as many ideas as possible, through exploring the opportunities in the space, by producing a diverse, as well as a large quantity, of ideas. The fourth mode is *prototype,* which involves translating ideas from thoughts into their physical representations, with the intention of creating quickly and using the resources available to the designers. The final mode is *test,* which involves defining and improving prototypes, while testing how the intervention addresses the design challenge and context.

All the modes are iterative, allowing designers to go back to previous modes if necessary. Any issues discovered during testing can be addressed through one or more iteration loops. For example, if one finds that the prototype is not satisfactory to the user and their environment, and that the problem needs to be understood further through additional user engagement, one can revise the prototype or return to the *empathise* mode to gain more insights and understand the problem space better (Thoring & Muller, 2011).

2.4.2 Design thinking in healthcare

Research in the healthcare sector, where constant innovation is required to meet patient and healthcare workers' needs, has not always taken stakeholder requirements into consideration when exploring new interventions (Searl, Borgi & Chemali, 2010). This has resulted in slow adoption of interventions, an increased gap between development and implementation, as well as products that become futile because the human context was not considered during development (Lyon & Koerner, 2016; Munro & Savel, 2016). Inclusion of end-users during app development would eliminate risks associated with unmet user requirements (Kellermann & Jones, 2013), as well as promote user engagement with the health technology intervention through easy to use and useful design tools (Davis, 1989). Design thinking provides an approach that assists designers and innovators to integrate user needs when developing ideas and products in the healthcare sector, while bridging the gap between development and implementation (Altman, Huang & Breland, 2018).

Eckman, Gorski, and Mehta (2016) propose a design thinking framework as a means of designing for healthcare, specifically for the creation of sustainable mHealth systems. In this framework, a successful mHealth intervention begins with an understanding of the users' or community's needs and goals, and thereafter a product is designed that meets them. Furthermore, they define a sustainable mHealth intervention as one which considers the preferences and propensities of the user during development.

While the prospects of success for design thinking are promising, their application in healthcare can introduce some challenges. One of these challenges is the possible disparity between what users want and what researchers and healthcare workers believe would be advantageous to the user (Witteman et al., 2015). Another challenge is the different approaches of health research methods and design thinking. The former relies heavily on large samples to generalise results, while the latter seeks to understand smaller user samples (Altman, Huang & Breland, 2018). While large samples produce quantitatively significant data, small samples can produce better and valuable insights and themes prevalent in the user sample group. These tensions may hinder interventions innovated using design thinking, especially their implementation, and should be considered when formulating the design methodology.

2.5 Summary

Usability evaluation guidelines are not always translatable across different technologies and platforms. While Hussain and Kutar (2009) generate a guideline for usability evaluation, the guideline has not been applied to mHealth apps. Moumane, Idri, and Abran (2016) highlight objective and subjective considerations during usability evaluation and how such evaluation should dictate the design of mobile apps. Another consideration is the contextualisation of the app during the design, relating to the region or country it is to be used.

Schnall et al. (2016) and Herman, Grobbelaar, and Pistorius (2018b) open up the possibility of investigating design frameworks for mHealth, with Herman et al. doing so in a South African context. Schnall et al. utilise the ISR framework, developed by Hevner (2007), to design an HIV prevention mHealth app. They also highlight the limitations to the framework, revealing opportunities for including a specific design approach within its framework.

Design thinking, a user-centred approach, allows designers to contextualise innovation and implementation of healthcare interventions. One of the benefits of using this approach towards increasing accessibility of healthcare services is its quick prototyping methodology, which allows designers, healthcare providers, and users to interact and develop ideas collectively, in order to increase the success of solutions. Design thinking promotes engagement with users and the centring of users' needs. The ISR framework for the design of mHealth apps, as proposed by Schnall et al. (2016), centres the user and employs an iterative approach; both these features are shared by design thinking. Thus, design thinking is a promising design approach for the ISR framework.

3 RESEARCH METHODOLOGY

This chapter describes and motivates the research approach. It presents the methodology to achieve the aims and objectives of the research project which consists of two parts:

1) Redesign and improve the user-interface of the UCT LTBI screening mHealth app.
2) Assess the usability of the redesigned mHealth app in a clinical environment.

While there are two use cases for the use of the LTBI screening app i.e. use by patients and healthcare workers, this project focuses on the latter.

Data collection and analysis comprised quantitative and qualitative methods. For the purpose of this study, the sample of users of the mobile app was limited to students in the Division of Biomedical Engineering at the University of Cape Town, and healthcare workers at clinics in Khayelitsha in the Western Cape, the latter representing end-users. The Information Systems Research framework combined with design thinking was used to engage with students and design the user-interface iteratively. Thereafter, once the user-interface was improved upon, healthcare workers were engaged with to test the user-interface in a clinical setting.

3.1 ETHICS APPROVAL

Ethics approval to conduct the research was obtained from the Human Research Ethics Council (HREC) of the Faculty of Health Sciences at UCT (HREC REF: 214/2019), the City of Cape Town Department of Health (ID Number: 8003), and the Western Cape Department of Health (REF: WC_201806_006). Ethics approval was also obtained for the involvement of university students through the University of Cape Town's Student Affairs office. Informed consent was obtained from all participants.

3.2 DESIGN APPROACH

The Information Systems Research framework (ISR), as adapted by Schnall et al. (2016) from Hevner (2007), was used as the design approach for this study. Since the framework does not specify a design method to be utilised within its respective cycles, design thinking was used as an approach for user-centred design. Design thinking is compatible with the iterative nature of the ISR framework, and also allows for user engagement throughout the design process. Thus, the ISR framework was modified to incorporate design thinking into its implementation. The modified ISR is shown in Figure 4.

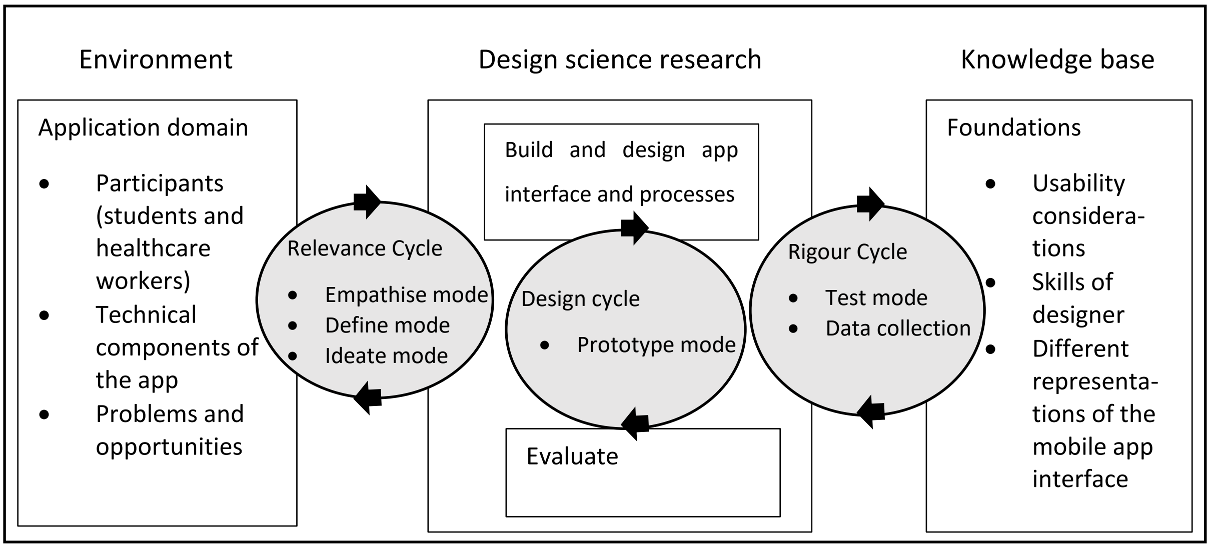

Figure 4: Modified Information Systems Research framework (Hevner, 2007) incorporating modes of design thinking into the relevance, design, and rigour cycles.

The following modifications were made to the framework:

- The *empathise, define,* and *ideate* modes of design thinking were included in the relevance cycle. This was done because the relevance cycle involves understanding the user's environment. The aforementioned modes effect this task through user engagement and formulating ideas to solve the problem, as well as facilitating the progression from the relevance cycle to the design cycle.
- The *prototype* mode was included in the design cycle. The design cycle is concerned with creating and assessing objects, in this case the app user-interface, related to the problem. Iterative prototyping, as employed by design thinking, allows for development of an app interface within this cycle. In this study, prototyping also added to what is known about the current user-interface in terms of usability, referred to as the knowledge base in the ISR framework. This directed the testing an updated version of the interface for evaluation.
- The *test* mode was included in the rigour cycle. This cycle is where data is collected and used to add information to the knowledge base regarding the problem and the user's environment. The *test* mode facilitates this data collection. Additionally, it provides ways in which the interface can be improved and iterated upon. The feedback affected the user requirements as described in the relevance cycle.

The modified ISR framework with design thinking incorporated within its cycles was employed for user-centred design of the user-interface of the LTBI screening app.

3.3 DESIGNING THE USER-INTERFACE

During the design of the user-interface for the LTBI screening app, design thinking methods, especially understanding the user and the diagrammatical representation of prototypes, was combined with the ISR framework within the relevance, design, and rigour cycles, in order to obtain a better, usable app that can be tested and assessed in the field.

3.3.1 The study population

The design and initial prototyping of the user-interface relied on students of the Division of Biomedical Engineering at the University of Cape Town as study participants. A subgroup of three to four students was used for each phase of the design thinking process as described below. In total, ten students were recruited. University students were used in order to quickly iterate the user-interface prototype. While these participants were not representative of the end-user population, they still provided useful insights into improving the existing interface, allowing for an enhanced version to prototype and test in the field.

All recruited students were postgraduate students in the fields of Biomedical Engineering or Health Innovation. As such, all participants had some knowledge concerning the technology involved in the study. The procedures related to the study were carried out in an office within the Division. Since students may be expected to differ from the intended end-user, namely healthcare workers in low-resource areas, with regard to knowledge of smart phone use, the feedback from students was used as preliminary data, while keeping the actual end-user in mind throughout the design process.

A convenience sampling strategy was carried out for recruiting student participants (Marshall, 1996). The most accessible students within the Division of Biomedical Engineering were requested to participate. This saved time, effort, and resources during the initial stages of the design process.

3.3.2 Relevance cycle

The design process often begins with identifying a need or dissatisfaction with the status quo, which motivates work towards solving a problem (Razzouk & Shute, 2012). Many approaches are available to begin the design process in various contexts. In this study, the modified Information Systems Research framework described in Figure 4 formed the foundation of the design methodology. The relevance cycle formed the initiation stage of the interface design; however, as suggested by Schnall et al. (2016), the framework was employed iteratively.

Define mode of design thinking

In order to begin using design thinking techniques, the first task required was to redefine the "design challenge" or problem statement into an "actionable problem statement" to facilitate idea generation (Doorley et al., 2018). This redefinition of the problem statement is known as a Point of View (POV). The primary focus of the POV is the user, the need, and the insight based on the need. Following this step a design thinking technique known as "segmenting by themes" was utilised (Kimbell & Julier, 2012:37). The purpose of this step was to define the requirements of specific target users who will be focused on during the design. These divided groups allowed for an investigation into the needs and resources of each group so that the end-design might match these needs and resources. Segmentation by themes was carried out by collating the information gathered on the contexts of the users. Once the themes were decided upon, "How Might We Questions" (HMWQs) were applied to provide a foundation for idea generation in the next mode. HMWQs allow for ambiguous questions to produce flexibility in the scope of ideas (Doorley et al., 2018). The questions were formulated by the researcher and they were phrased to target specific needs of the user related to the problem. The questions were answered by the researcher through the *ideate* mode, by formulating ideas that address the HMWQs. Once the HMWQs were created, they formed the basis to enter into the *ideate* mode of design thinking.

Ideate mode of design thinking

Using the HMWQs the *ideate* mode was entered with the aid of "Braindumping". This is a brainstorming activity which is used to produce ideas for the design of the app interface. Each HMWQ is used as the inspiration for braindumping. The activity consists of short, dedicated time periods, in the range of five to ten minutes. The time period is allocated for each question in order for the researcher to generate as many ideas as possible which address a particular question. These new ideas, as well as the POV and HMWQs, were all arranged in accordance with design thinking practices, together in one large space, in the form of sticky notes. This allows for a visual and pictorial depiction of design progress which is preferable in design thinking methods to purely written progress. The ISR framework's design cycle (Figure 4) was initiated next, along with the *prototype* mode of design thinking.

3.4 PROTOTYPING THE USER INTERFACE

The user interface was prototyped iteratively using both software and physical resources. The methods and materials used were chosen in order to improve the user interface quickly and allow maximum engagement with users.

3.4.1 Design cycle: Prototype mode of design thinking

This mode involved the creation of a low-fidelity prototype based on the recommendations made by Naraghi (2018). The prototype was divided into three components in order to demonstrate the LTBI screening app extensively. The first component of the prototype consisted of depictions of the mobile app page displays. These depictions were created using the Adobe XD[1] software which allowed for the creation of a digital prototype with which participants could interact by clicking on a mobile phone screen. The second component comprised instruction videos pertaining to the image capture function of the LTBI screening app. This was aimed at decreasing the text within the app, a usability issue that arose in Naraghi's (2018) study. The prototype remained a low-fidelity one since the interface did not have the complete functionality of the LTBI screening app. The final component of the prototype was image acquisition, which was incorporated using the current version of the app. This enabled the researcher to observe and note feedback during one of the main functionalities of the app. The overall structure of the low-fidelity prototype is depicted in Figure 5. The purpose of the prototype was also to create a representation of what a user would experience during the use of the LTBI screening app – an approach known as "storyboarding" (Kimbell & Julier, 2012:27). Storyboarding aims to map out the journey of the user during the app usage pictorially and visually from beginning to end.

[1] Adobe Systems. 2019. Adobe XD. 18.2.12.2 ed.: Adobe Inc. Interface design and user experience prototyping tool for mobile and web applications, ibid.

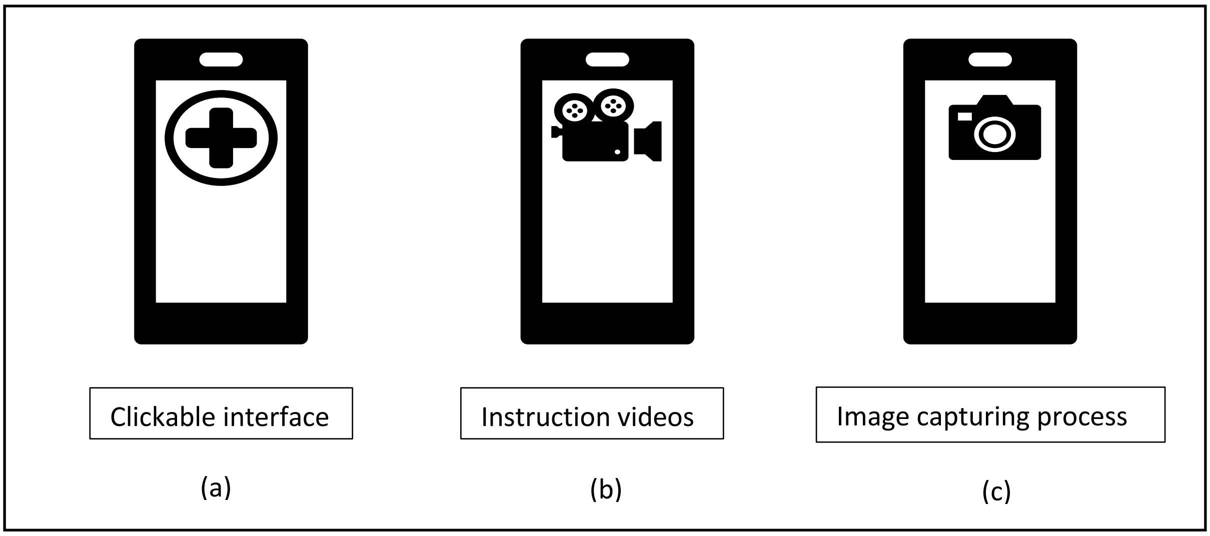

Figure 5: Low-fidelity prototype composition including; a) the clickable interface, b) instruction videos, and c) the image capturing process.

"Plotting an outcomes matrix" was the next step employed. This step uses the segmentations defined previously to direct possible outcomes for particular groups of people (Kimbell & Julier, 2012:41). It aims to explore the impact of the app on the users as it pertains to their needs. The ways in which outcomes are assessed was defined, and this informed primary criteria for the assessment of the app. The steps described above were applied iteratively until minimal difficulties were indicated by the study population regarding the user-interface. Since the prototype is based on recommendations for improvement by Naraghi (2018), the completion of this mode represented an updated version of the previously developed app. Figure 6 presents the iterative design thinking approach that was used for the design of the app interface.

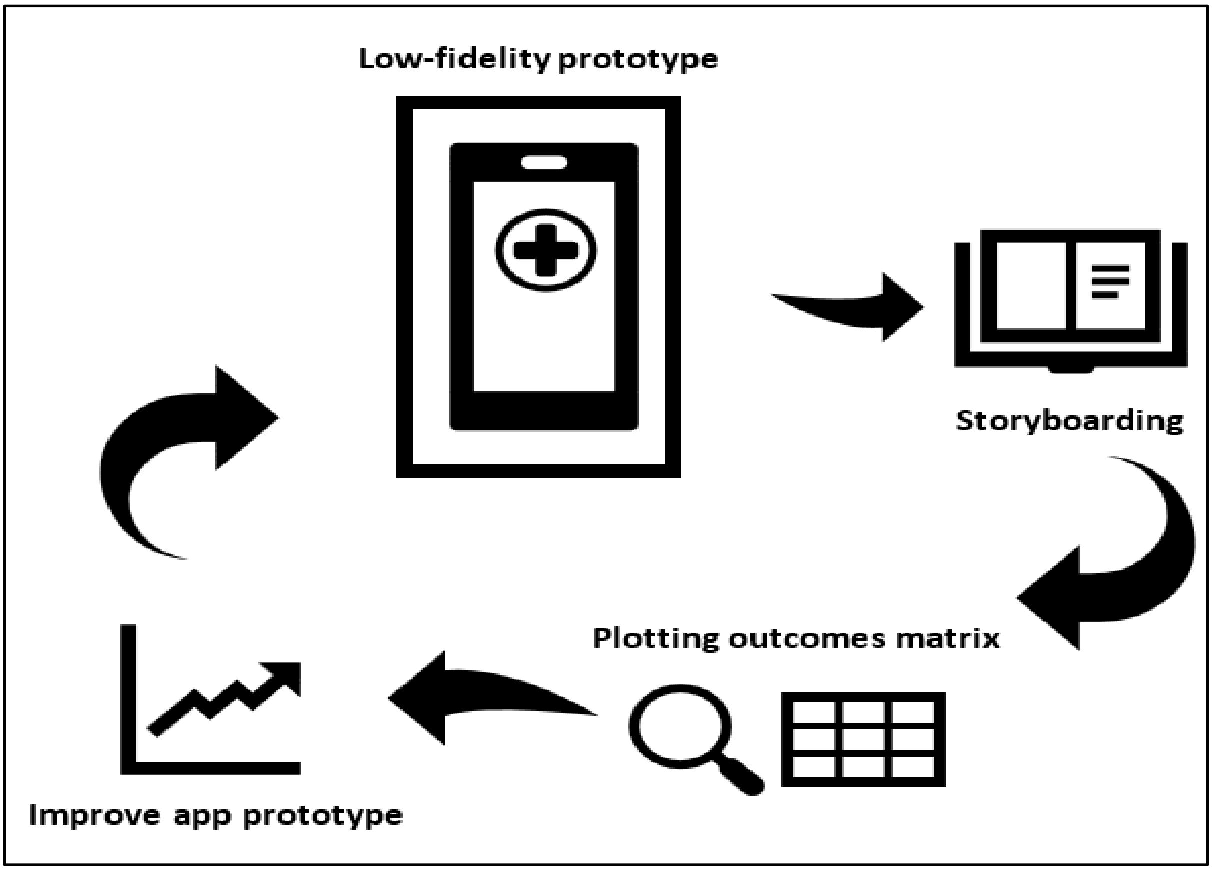

Figure 6: Iterative prototyping.

In some instances, during the prototyping of the interface, the sequence shown in Figure 6 was not followed. Instead, prototyping may have taken a different pathway during the design flow. For example, after storyboarding, the information gathered may have required an adjustment to the prototype before advancing further. This non-linear approach was supported by the ISR framework.

3.4.2 Rigour cycle: Test mode of design thinking and data collection

During the first iteration of the interface, students were recruited, and their feedback was collected until saturation of the feedback was reached. Saturation was reached when, based on the collected and analysed data for that iteration, no new information was discovered, thus data collection could cease. Three data collection tools were used; observation, the "think aloud" tool, and a questionnaire. "Think aloud", as described by Jaspers et al. (2004), was used to acquire information on the cognitive and thought processes of participants. Participants were required to talk aloud as they were completing the tasks related to the app. Their comments and insights were written down and formed part of their feedback. This was supplemented by observations by the researcher, in order to gain a better understanding of participants' experiences when interacting with the prototype. The observations involved taking notes as described by Baker (2006). Both "thinking aloud" and observation are in accordance with usability assessment and evaluation practices defined by Preece, Rogers, and Sharp (2002) (Section 2.2). Lastly, a questionnaire was devised to generate feedback regarding particular components of the interface and the instruction videos provided; it allowed for comments by participants. This questionnaire can be found in Appendix B.

The extreme user case, where user needs are amplified, was implemented. This is a design thinking strategy to better understand the needs of users that fall outside the ideal case (Doorley et al., 2018). The extreme user case involved having participants capture images of simulated indurations on their own arms. This was considered the extreme case because capturing images of one's own arm at various angles is more challenging than capturing images of someone else's arm. Additionally, the extreme case was considered to be an individual without any assistance during use of the app. Designing in this manner acknowledged the extreme considerations for the use of the app, to create an easier to navigate and use interface for any user. Thus, the prototyping procedure involved the participants interacting with the interface, then using a mobile phone to follow the image capture protocol with a simulated induration in the form of a sticker on their left forearm, which is where a real induration would appear. The collected data directed the second iteration of testing the user-interface.

In the second iteration, new students were recruited, along with the first iteration students, to interact with the updated prototype. This served both for evaluation of the improvements to the interface design and for evaluation of the updated interface prototype by first-time users. The same approaches were used to collect data and, once again, the data guided improvement of the interface for the next iteration of testing the interface. For both the first and second iteration, the participants required the assistance of the researcher to navigate between the different components of the prototype e.g. switching from the user-interface mock-ups to the instruction videos on the mobile phone.

In the third, and final, iteration of testing the user-interface prototype, the participants' feedback during the previous engagement was used to code improvements to the original LTBI screening app (Naraghi, 2018). This involved the use of the Android Studio Software[2] to incorporate changes for an updated app. Once the app was coded and installed on the mobile phone[3] used for this study, participants were recruited once more and were divided as follows: five previous users and five new users. Observations and "think aloud" were used once more as qualitative tools. The "The Post-Study System Usability Questionnaire" (PSSUQ) as designed by Lewis (1992), shown in Appendix C, was used

[2] Google & JetBrains. 2019. Android Studio. 3.4.2 ed.: Google. The official integrated development environment (IDE) for Android operating systems.
[3] HTC One (M8), 5.0" screen size (1080x1920 pixels), 4MP main camera, 2GB RAM.

as the quantitative tool for this iteration. The questionnaire contains 19 questions related to three usability factors, namely: system usefulness, information quality, and interface quality. Each question requires participants to score their responses from 1 (strongly agree) to 7 (strongly disagree). The PSSUQ was provided to participants in order to generate feedback with regard to ease of use and concerns when confronted with the interface. The questionnaire was introduced at this iteration because at this stage the mobile app design was in a form that integrated all of the feedback into the interface.

Once the changes to the app were made based on the feedback and data collection tools, the mobile app was almost ready to be tested in the field. One last task remained which was to make the text and language appropriate for the study population of healthcare workers. In addition to the instructions and text within the app, Naraghi (2018) included a screening questionnaire for interpreting the size of the induration when reading the result of the TST. The language used in this questionnaire is technical and contains words that could be inaccessible to non-specialist healthcare workers, especially low-proficiency English readers. This introduced a usability limitation. Since the majority of the study population in the next phase of the study was located in the Khayelitsha area in Cape Town, where the majority of residents speak isiXhosa, the mobile app text was translated before testing with healthcare workers. This was done in order to diminish any barriers to use and to create an app interface that is empathetic to its envisioned primary user.

3.5 ASSESSING USABILITY IN THE FIELD

The transition of the study from students to healthcare workers required an understanding of the new context as well as the characteristics of the study population. The rigour cycle (ISR) and test mode (design thinking) initiated engagement with healthcare worker participants, which involved their interaction with the digital prototype of the app.

3.5.1 Study population and context

This part of the study focussed on participants employed at clinics in Khayelitsha, a township in Cape Town. For assessing the usability of the app, ten participants were recruited from the Khayelitsha Site B Ubuntu Community Health Clinic. The participants were healthcare workers within various roles in the clinic system. This group of participants represented users who would use the app on patients being screened for LTBI. This study population includes professional nurses, assistant nurses, community healthcare workers, and counsellors. A range of such participants was selected in order to assess the usability of the app with a diversity of users.

The levels of health workers who participated and their role in the clinic ecosystem in South Africa are shown in Table 3. These roles mentioned are for healthcare workers directly involved in patient care in communities and clinics, and thus were suitable for inclusion in this study.

Table 3: Roles and description of healthcare workers in Khayelitsha clinics.

Healthcare worker role	Description
Professional nurse	A qualified and competent healthcare worker who can practise comprehensive nursing and midwifery at a professional standard (Nursing Act, No. 33 of 2005, 2006:s30).
Assistant nurse	A healthcare worker who provides quality primary nursing care services under the direction of a professional nurse (Nursing Act, No. 33 of 2005, 2006:s30).
Community health worker	Members of a community that provide community-based care with a specific focus on HIV and TB care (Tsolekile, Schneider & Puoane, 2018).
Counsellors	Health workers that perform HIV and TB counselling, especially adherence and testing assistance (Hu et al., 2018).

Khayelitsha is one of the poorest communities in Cape Town with high levels of unemployment and more than half of the residents living in informal housing (Cremers et al., 2018). This has led to overcrowding due to the large population living in a confined area, a result of Apartheid spatial planning, which is a high-risk factor for the spread of TB (Cox et al., 2010). In fact, Khayelitsha has been described as having one of the highest drug-susceptible TB and drug-resistant TB burdens in the world (Médecins Sans Frontières South Africa, 2011). Residents of Khayelitsha face multiple adversities that contribute to lower health outcomes. These include poverty, hunger, unemployment, disease, and violence (Wexler, DiFluvio & Burke, 2009). Since the risk and prevalence of TB is high in this region, TB (and HIV) care is available at various clinics, including the Khayelitsha Site B Ubuntu Community Health Clinic (Cremers et al., 2018). At this clinic, a room was allocated for the purposes of this study. This allowed for privacy and comfort of participants.

Healthcare workers were recruited through the purposeful sampling technique (Marshall, 1996); the aforementioned healthcare clinic in Khayelitsha was visited and the study was presented to potential participants. Any healthcare worker within the clinic ecosystem would be eligible to participate, regardless of their knowledge of the TST. This sampling strategy was implemented in order to test whether a user in a clinical setting with any level of knowledge of the test would be able to operate the app successfully. A total of ten healthcare workers were recruited.

3.5.2 Rigour cycle: Test mode of design thinking

The usability assessment in the field began in the *test* mode of design thinking, which forms part of the rigour cycle in the modified ISR framework depicted in Figure 4. This mode was entered at this stage of the methodology because once the app interface was improved upon using the preliminary data collected from students, end-user feedback was necessary in order to gauge whether the app was usable by the target population.

Testing the user-interface with participants in the field followed the same approach as used when testing with students, except that, since healthcare workers were the target end-users the test involved the participants completing the protocol with a research assistant as a “patient” with a simulated induration. When healthcare workers reached the image capture stage, they captured images of the simulated induration on the research assistant’s arm, whereas student participants had captured images of simulated indurations on their own arms. While these were not the conditions of patients having the TST administered, it still allowed for valuable insights into the usability of the app and provided access to the intended end-user group.

Participants were first asked whether they preferred to use the app in isiXhosa or English. The language was changed accordingly, and participants were left to work through the app, while using the “think aloud” technique. They were also observed as notes were taken to record behaviours, activities, and events during the interaction. On completion they were given the PSSUQ to assess usability. In cases where participants were not comfortable with reading English, the questionnaire was read out to them in order to help them understand its contents. Ideally, the questionnaire should be provided in a participant’s language of choice to ensure optimal comprehension. Since the questions in the PSSUQ assesses particular usability factors, a translation of the questionnaire and its interpretation would need to be validated. This was outside of the scope of this research.

3.6 SUMMARY

This chapter has described the incorporation of design thinking into the ISR framework and the implementation of the modified ISR framework. Since the ISR framework does not prescribe a specific design methodology to use within its cycles, design thinking is proposed as an effective methodology to design the user-interface of the LTBI screening mHealth app. Its iterative nature aligns with that of the ISR framework. Additionally, the emphasis on the user and their contexts is a component shared by both the ISR framework and design thinking. The chapter thus makes a contribution to the set of tools available for mHealth app design. The following chapter describes the implementation of the methodology and the results it produced.

4 RESULTS

This chapter discusses the results from the design and testing of the mobile app interface. The feedback from observations and questionnaires deployed in both the iterative design process, and the testing of the app in the field, is described. The results are presented as the development of the design unfolded i.e. first with students as participants and subsequently with healthcare workers as participants.

4.1 DESIGNING AND TESTING THE USER-INTERFACE

To initiate the design thinking process an actionable problem statement, or point of view (POV), was phrased based on the objectives of this study, the previous work conducted by Naraghi et al. (2018), and the end-user considerations. The POV usually takes the form:

[User…(describing user)] needs [Need…(describing the need)] because [Insight…(describing the perspective taken towards the problem)]

This format is used to articulate the challenge of the study in a way that both can be understood by an unfamiliar reader and can facilitate the generation of ideas. The POV formulated for this study was therefore:

> People who are being tested for LTBI and healthcare workers who administer these tests (user), need to understand, and feel comfortable while using, the LTBI screening mobile app (need), because their ability to capture images of the induration is a key feature of the LTBI screening app (insight).

The POV already centred users and their needs with respect to the app. In order to further prioritise users' needs, segmentation of themes, based on the users and their contexts, was used to identify the key areas of ideation for the design of the user-interface. The themes identified included poor eyesight, low-literacy, and low-proficiency English readers. For the purposes of this study, low-proficiency English readers include people who: have weaknesses understanding inferences in text, have difficulty linking information beyond two sentences, and struggle to understand difficult vocabulary and phrases (Liao, 2010). These divisions allowed for ideating and prototyping for specific needs, and thereafter investigating how the app could be improved accordingly. Using these themes and the POV, "How Might We Questions" (HMWQs) were formulated. Six questions were phrased as follows:

(1) How might we make users more comfortable with the mobile app interface?
(2) How might we explain the image capturing procedure so that users understand it?
(3) How might we accommodate users with low literacy?
(4) How might we accommodate users with visual/auditory impairments?
(5) How might we indicate to users that their images were captured successfully?

At this stage of the design process, post-it notes were used to depict and visualise the progression of ideas during the design. This conformed to design thinking practices and permitted for an organised depiction of the formulation of ideas. This depiction can be found in Figure 7.

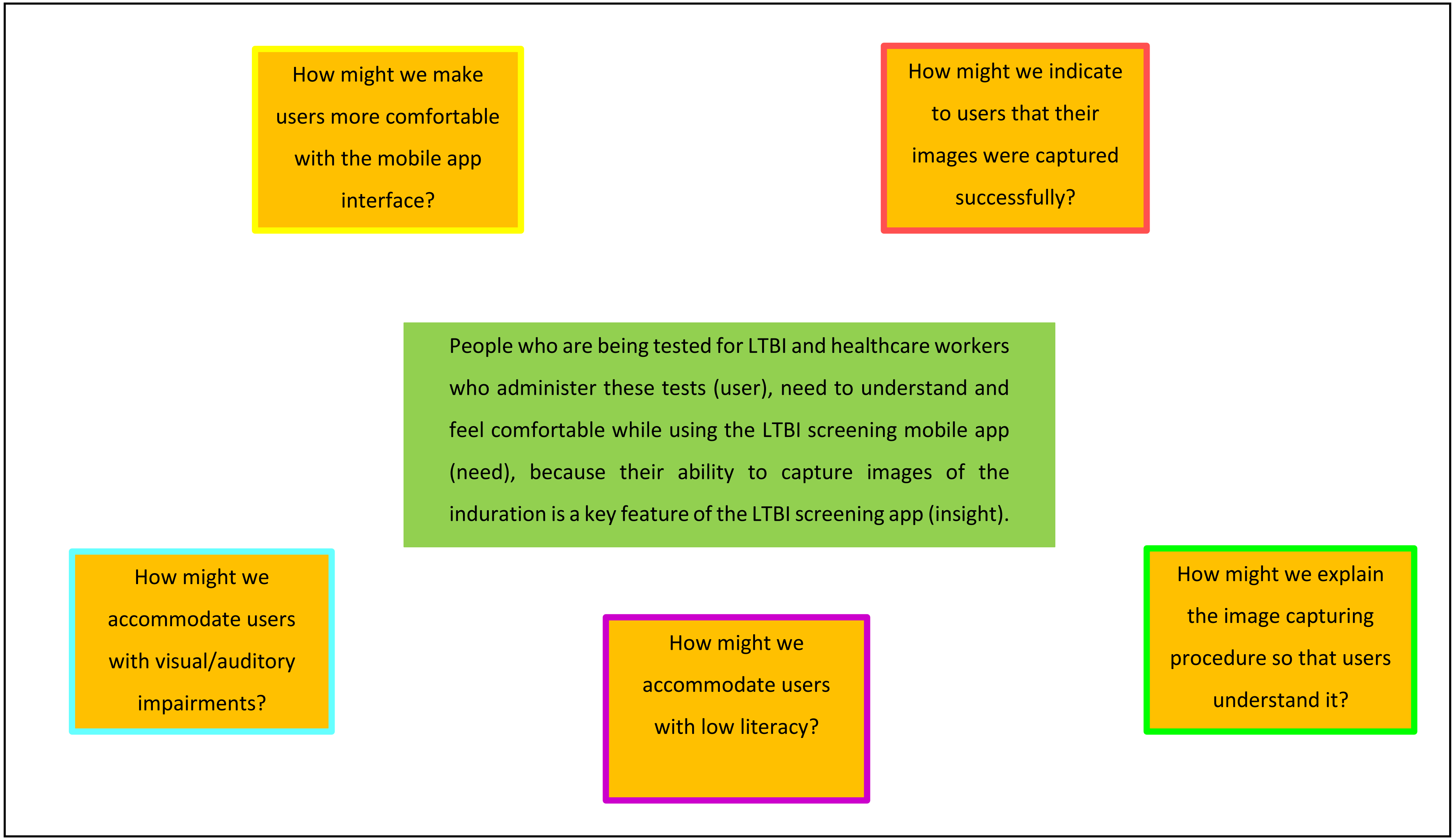

Figure 7: Point of View with How Might We Questions in post-it arrangement.

The HMWQs allowed for the entering of the *ideate* mode of design thinking as each question addressed particular needs of the user and the requirements of the LTBI screening app. Using "braindumping" as an ideation technique the following ideas were generated with their respective HMWQ, shown in Table 4.

Table 4: How Might We Questions and the corresponding ideas.

How Might We Question	Ideas
How might we make users more comfortable with the mobile app interface?	- Distinct flow (linear, guidance, ensure users don't get lost) - Minimal text (use images for instructions) - Use 3 contrasting colour schemes when prototyping (visually appealing) - Use 3 fonts (clear, large, semiformal)
How might we explain the image capturing procedure so that users understand it?	- Use explicit guiding icons in videos or images - Step-by-step instructions - Translated text - Have someone else take the images - Use images for instructions - Use short videos for instructions (maximum 15 seconds long, animation) - Voice guidance for image capture
How might we accommodate users with low literacy?	- Use visual cues (arrows, use videos/images, highlight segments of videos/images) - Minimal text/no text - Have the healthcare worker complete the screening questionnaire (saving the data linked to a patient ID) - Have an audio aid for any text - Only have the image capturing procedure in the app (remove the screening questionnaire)
How might we accommodate users with visual/auditory impairments?	- Vibration/beep when images should be/are taken - Auditory guide through the app ("Tap to move ahead") - Clear, bright colours to distinguish any text or guiding tools - Have someone else take the images - Utilise video, images, and audio for assistance
How might we indicate to users that their images were captured successfully?	- Allow users to see images after capture (check/retake) - Voice messages indicating success or failure - Audio sound in the form of a beep/buzzer for a good/bad image respectively - After each image display the image with a grid showing a green or red filter depending on successful image capture

The themes, HMWQs, and corresponding ideas contributed to the arrangement of post-it notes shown in Appendix D. These ideas influenced the changes made to the user-interface of the app as well as the composition of the prototype. As described in Figure 5, the prototype was composed of 3 sections.

Once the prototype was finalised, an outcomes matrix was plotted based on the template devised by Kimbell and Julier (2012:42). The matrix details a theme selected for the end-user, what matters to the end-user in relation to the functionality of the app, the changes effected by the app for the user, and how the changes are measured through gathered data. The completed matrix is shown in Table 5.

Table 5: Outcomes matrix based on segmented themes.

Segmented theme	What matters to the user?	Outcome	Measure
Poor eyesight	No strain on eyes during the operation of the app.	Correctly capturing images.	• Review the quality of images captured. • Observe where users find difficulty seeing the contents of the app.
Low-literacy	Being comfortable using the app with minimal anxiety about making mistakes.	Correctly capturing images and fully understanding instructions.	• Review the quality of images captured. • Use think-aloud technique to probe users when they feel stuck using the app. Indicating areas of low clarity.
Low-proficiency English readers	Being able to operate the mobile app in their language of choice and be comfortable during usage of the app.	Correctly capturing images and fully understanding instructions.	• Review the quality of images captured. • Compare whether a translated app used by low-proficiency English readers performs similarly to the original app used by proficient English readers.

For all themes, the expected outcome is the overall desired functionality of the LTBI screening app i.e. to ensure correct capture of images of an induration on a patient's arm. The formulation of the POV, HMWQs, resultant ideas, segmented themes, and the outcomes matrix allowed for the prototype to be prepared for testing and iterating with students.

4.2 PROTOTYPING THE USER INTERFACE

Three iterations of the prototype were carried out with students. After each iteration, alterations were implemented on the prototype according to the feedback gathered during student participant interactions. Subsequent to the final iteration, the prototype was altered once more, before assessing its usability in the field.

4.2.1 First iteration

Using the Adobe XD software, a clickable prototype was designed to represent the app interface. To test a variety of fonts, colour schemes, and layout designs, three different interfaces were prototyped on a mobile phone. Indicated in the figures as themes a), b), and c). The colour schemes were chosen using the Adobe Color[4] online resource. This allowed the creation of colour palettes based on colour schemes chosen by the designer.

The ideas implemented in the prototype, and their corresponding themes (Table 5) included:

- increasing the size of the text – poor eyesight;
- changing the colour scheme – poor eyesight;
- including single page instructions – low literacy;
- pictorial instructions – low literacy;
- decreasing the number of screens within the app – low literacy;
- reducing the amount of text – low literacy and low-proficiency English readers;
- removal of jargon and technical terms used in the app – low literacy and low-proficiency English readers;
- adding videos to describe the image capturing process – poor eyesight, low literacy, and low-proficiency English readers.

Screenshots of the updated interface are shown in Figure 8 and Figure 9. These only represent a few of the alterations, all of which can be found in Appendix E.

[4] URL: https://color.adobe.com/create

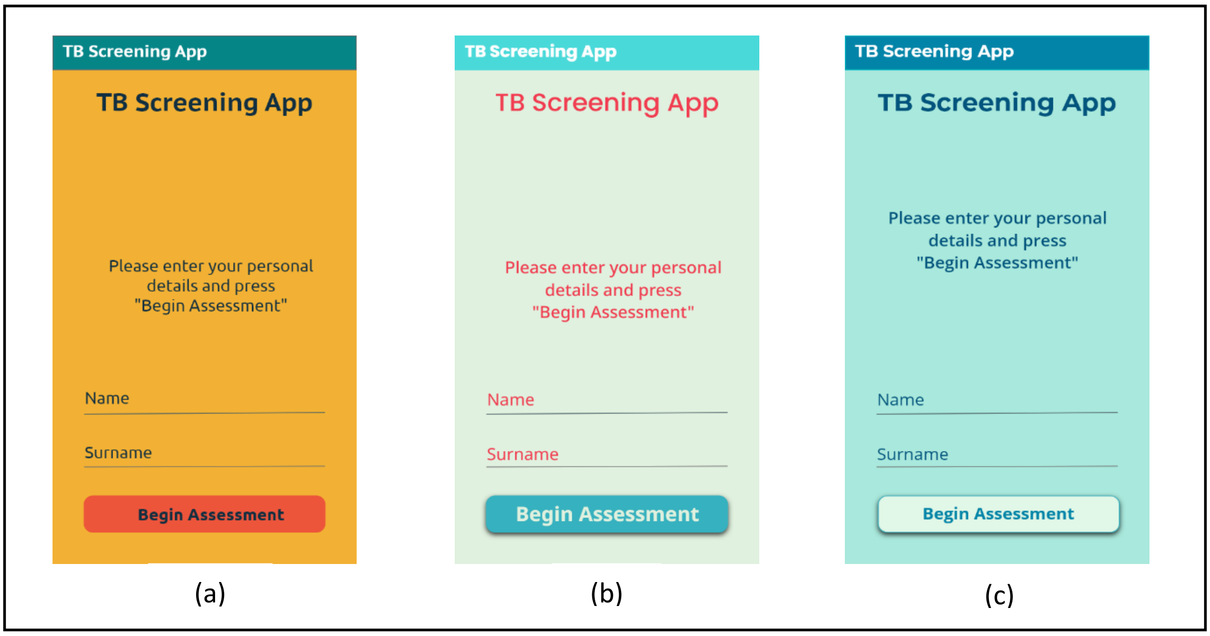

Figure 8: First iteration prototype screenshots – landing page.

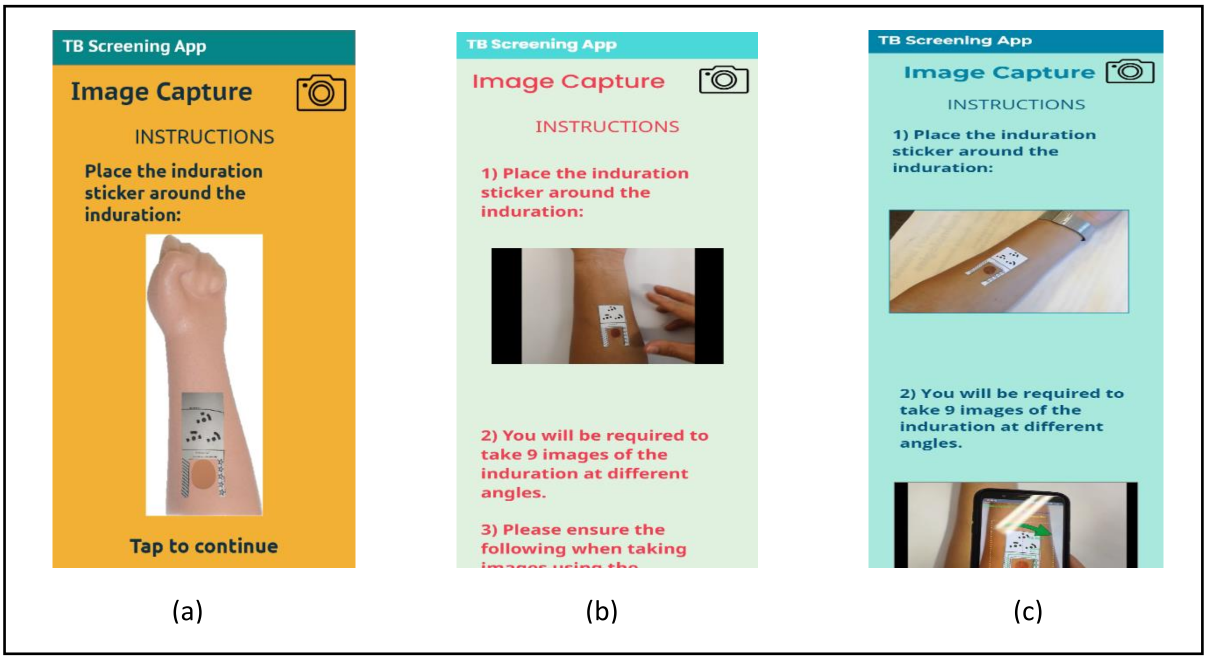

Figure 9: First iteration prototype screenshots – instruction page.

After four participants had been recruited, saturation of the feedback was achieved. Users were required to complete a questionnaire (Appendix B) after interacting with the prototype interfaces. Screenshots of the interfaces were presented to them with the questionnaire, in order for them to appropriately consider their responses to each interface design. Based on the responses, the colour scheme of the third interface was preferred by three of the participants. However, comments from those participants suggested that having a primary-coloured background may make different coloured text difficult to read, and that a white background may work better. Three participants were indifferent to the font selections and stated that all the options were clear and easy to read. All participants found the videos to be clear and understandable for the tasks required, but two participants suggested adding audio assistance for clarity of the instructions. Based on observation, one of the main obstacles encountered by participants was the image capture, particularly when images need to be captured on the left-hand-side of the induration. All participants noted the left side as their non-dominant and weaker side. During interaction with scrollable pages in the app, it was observed that participants were uncertain how to progress to the next page, unaware that they needed to scroll, indicating insufficient guidance within the interface. However, all participants preferred a single scrollable page instead of separate pages for navigation. The comments, observations, and questionnaire responses represented the overall feedback during this iteration.

4.2.2 Second iteration

The collated feedback influenced the next iteration which produced the interface pages shown in Figure 10 and Figure 11. The observations also led to alterations in the presentation of the videos, namely making navigation easier and making the videos more visually appealing. These interface pages are presented in Figure 12.

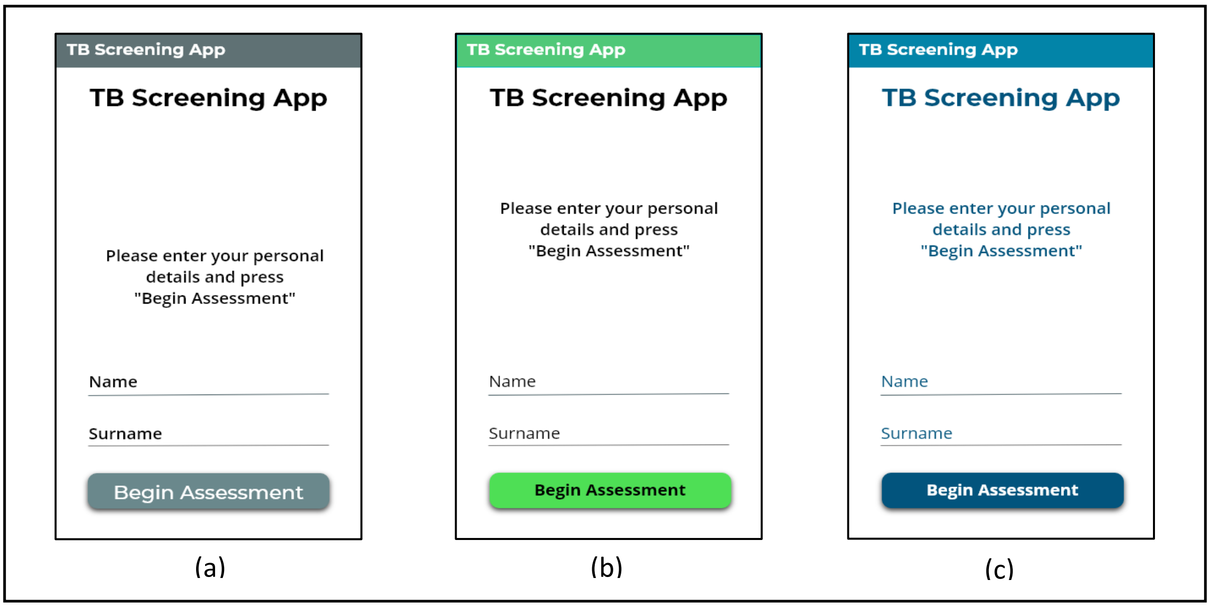

Figure 10: Second iteration prototype screenshots – landing page.

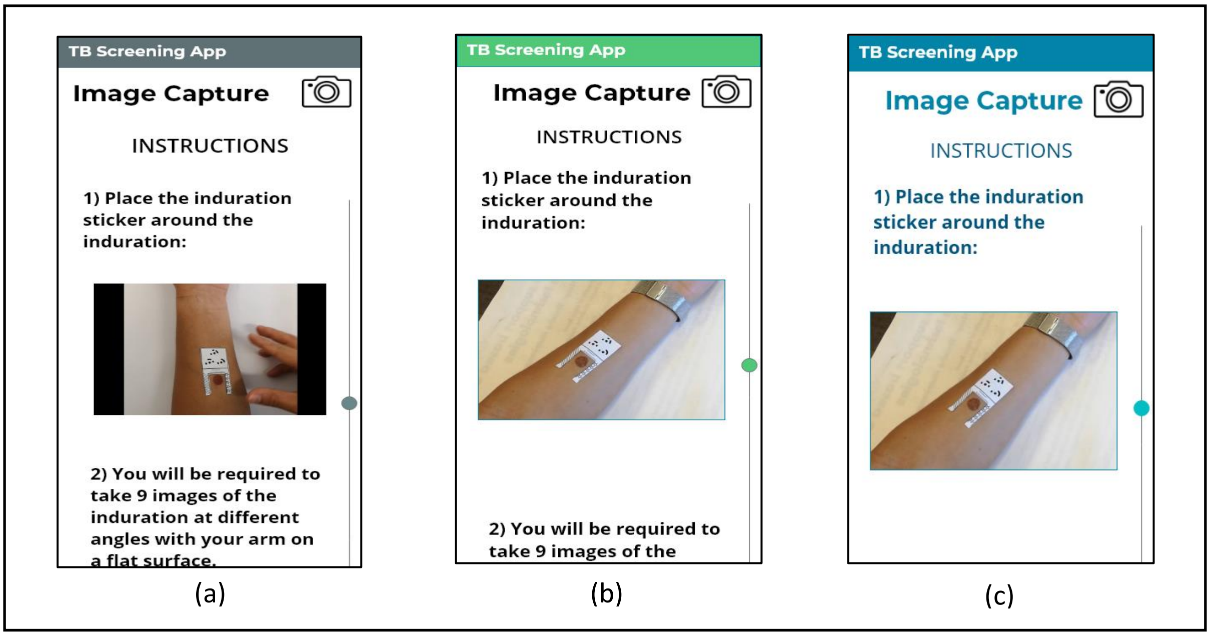

Figure 11: Second iteration of the prototype screenshots – instruction page.

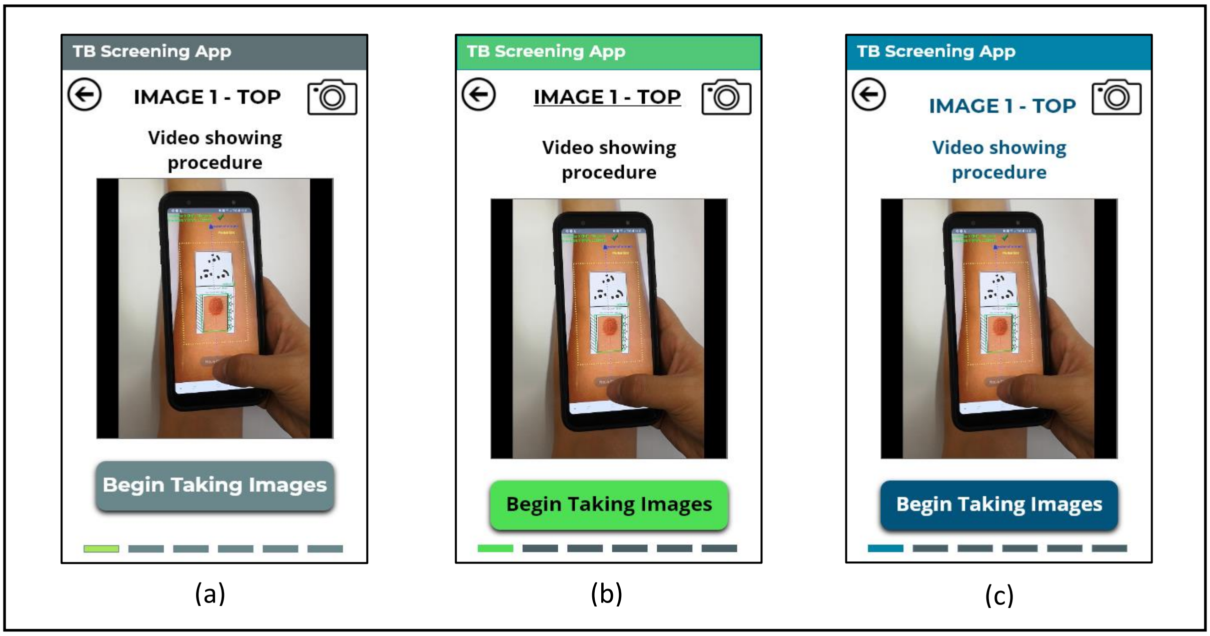

Figure 12: Second iteration prototype screenshots – video tutorial page.

As depicted in the figures above, the following ideas were implemented for the second iteration:

- colour scheme changes;
- single font in all themes;
- adjusting the video tutorial page;
- adding audio to the video instructions;
- scrolling icon to indicate a scrollable page;

- decreasing the text on the instruction page.

During this iteration, seven students were recruited. The description of the participants is shown in Table 6, indicating whether they were: repeat participants, preferred the app in isiXhosa or English, and comfortable with a mobile smartphone. These were regarded as characteristics that could influence usability. The table also includes their sex.

Table 6: Participant characteristics and responses during the second iteration.

Participant description		
Sex	Male: 4	Female: 3
Repeat participants	Yes: 4	No: 3
App language	isiXhosa: 0	English: 7
Comfortable using a smartphone	Yes: 7	No: 0
Total	7	

Repeat participants unanimously noted the improved interface with the updated colour scheme. Four of the participants ranked the third interface [Figure 10(c)] as their preferred option, while the rest ranked it second. Participants found the videos to be helpful, especially with the challenging image capture process. However, they noted that if the voice accompanies each video for every image to be captured, it may become an annoying feature which could affect app usability. Most participants (six out of seven) interacted with the prototype with relative ease. One participant, however, indicated a level of difficulty that resulted in incomplete use of the prototype. All users indicated that the translation of the mobile app into a language suitable for a clinical context would be beneficial to usability. The feedback informed the transition into the third iteration.

4.2.3 Third iteration

During the third, and final, iteration before testing in a clinical setting, the changes based on the first two iterations of testing were applied to the code of the interface using Android Studio software. The updated prototype was installed on the mobile phone. This resulted in the third iteration having the interface, instruction videos, and image capture all linked together within the app prototype, instead of as separate sections as described in Figure 5. The following additional changes were made in the updated prototype:

- Integrating the videos within the app;
- including patient ID instead of “name” and “surname” for login (to ensure privacy of patient information);
- handling all the errors present in the initial app;

- adding extra guidance when capturing images at different angles;
- allowing submission of images with ease through clear presentation buttons and instructions.

Once again, both repeat participants and new participants were recruited to interact with the interface. Saturation of the data was reached after ten participants had interacted with the interface. The characteristics of participants are shown in Table 7. The Post-Study System Usability Questionnaire (Appendix C) was provided at this stage for quantitative assessment of the app usability (Results in Section 4.4). Repeat participants included users who had had challenges capturing the images in previous iterations. The prototype for this iteration is presented in Figure 13.

Table 7: Participant characteristics and responses during the third iteration.

Participant description		
Sex	Male: 5	Female: 5
Repeat participants	Yes: 5	No: 5
Low-proficiency English readers	Yes: 0	No: 10
Comfortable using a smartphone	Yes: 10	No: 0
Total	10	

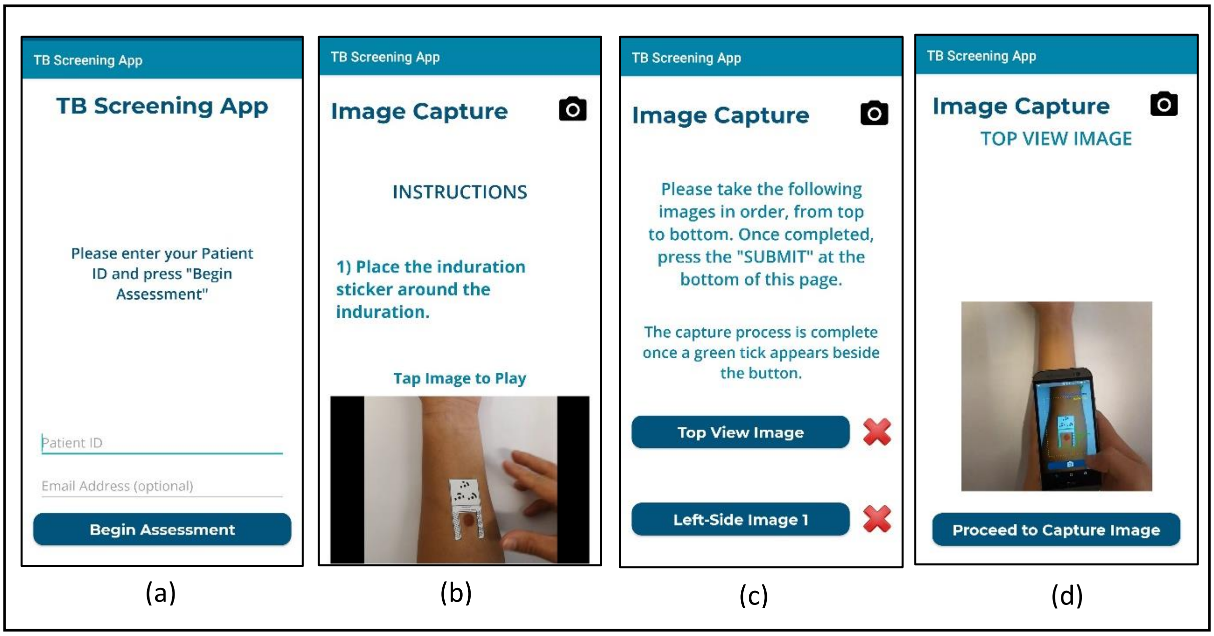

Figure 13: Third iteration prototype screenshots - a) landing page, b) instruction page, c) image capture page, d) image capture instruction video.

Repeat participants performed notably better than in their previous interaction with the app. These participants also indicated that repeat engagement with the interface was easier. Correspondingly, new participants indicated that with time they would be able to learn and improve on their performance when using the app.

The app was translated and thus available in both English and isiXhosa, adjustable according to the user's preference. This updated version of the LTBI screening app was considered appropriate for usability testing and assessment in the field.

4.3 ASSESSING USABILITY IN THE FIELD

For the testing of the user-interface in the field, ten participants were recruited from the Khayelitsha Site B Ubuntu Clinic. These included counsellors, professional nurses, assistant nurses, and community health workers. Their user characteristics are detailed in Table 8. Four of the participants preferred to use the translated version of the app.

Table 8: Participant characteristics and responses during testing in the field.

Participant description		Responses	
Counsellors	Sex	Male: 0	Female: 2
	App language	isiXhosa: 0	English: 2
	Comfortable using a smartphone	Yes: 2	No: 0
Professional Nurses	Sex	Male: 1	Female: 1
	App language	isiXhosa: 0	English: 2
	Comfortable using a smartphone	Yes: 2	No: 0
Assistant Nurses	Sex	Male: 0	Female: 2
	App language	isiXhosa: 0	English: 2
	Comfortable using a smartphone	Yes: 2	No: 0
Community Health Workers	Sex	Male: 0	Female: 4
	App language	isiXhosa: 4	English: 0
	Comfortable using a smartphone	Yes: 4	No: 0
Total		10	

With participation of ten participants, saturation of the feedback was reached. During the interaction with the app, participants were asked to verbally specify any issues or concerns they had related to their experience using the app. All participants indicated increasing frustration as they progressed through image capture, often enquiring how many more images they needed to capture. All six of the participants who preferred the English version asked for clarity regarding some of the instructions. Once it was explained they continued with no further questions. All participants required additional assistance during capture of the first two images (top image and left image 1), especially to ensure the simulated induration was within the bounds indicated on the app. Once they were assisted, the researcher limited interference for subsequent images in order to gauge how well the participants learnt the procedure and its requirements. Despite this, the final images captured by all participants did not meet the requirements specified in the instructions. In other words, the quality of the images was not adequate for successful further analysis. Images of adequate quality, in this case, were:

images where the induration fits within the prescribed bounds, non-blurry images, and the correct positioning, proximity, and orientation of the phone with respect to the induration.

Common problems that arose with health worker participants were the following:

- incorrectly positioning the scaling sticker on the induration;
- upon viewing the instruction videos, assuming the image capture follows automatically, whereas participants were required to navigate further until prompted to capture images;
- not spending time watching the instruction videos;
- incorrect distance of the phone from the induration site;
- rushing through the final images without much regard for quality of the images.

These problems were observed while participants operated the app, and even though participants were assisted and corrected when necessary, some of the problems persisted during subsequent image capture. While these problems occurred during the participants' first and only interaction with the app, they indicated that the image capture protocol would be learnable on consequent interactions with the app. Many participants commented that they "just need time to learn".

The app does not currently have any features that monitor image quality. For example, it does not detect whether the induration is within the image frame and bounds, so it requires the user to know this after viewing the instructions. Thus, even with the correct orientation, an image can be taken without any induration in the frame, or with an induration outside of the bounds, and be perceived as correct if instructions were not fully understood. These errors were increasingly prominent during the capturing of the last few images of the app.

When the LTBI screening app was introduced to community health workers (CHWs) before their engagement, they raised a few questions related to the practicality of the app. One of the concerns that arose was that of safety. CHWs are often located within communities and are mobile as they deliver care to patients. With the introduction of a mobile phone capable of operating the LTBI screening app, CHWs felt that they would be vulnerable to threats to their safety if it became known that they carry a mobile phone on their person. Additional concerns included whether patients would operate the app themselves and where the images would go after image capture.

When healthcare workers participated, they were required to capture images of a simulated induration on a research assistant's arm instead of their own arms as was the case with students, with students representing the extreme user case. The healthcare workers interacted with the app with more ease than students did. For example, most healthcare workers did not have any hesitation moving around the research assistant to capture images of the induration, while students struggled to manoeuvre the mobile phone to capture images of their own arms.

4.4 THE POST-STUDY SYSTEM USABILITY QUESTIONNAIRE (PSSUQ)

Using the questionnaire found in Appendix C, all participants were requested to answer the PSSUQ, which includes 19 questions, rating different aspects of usability on a scale from 1 (strongly agree) to 7 (strongly disagree).

The average scores for the student participants and the health worker participants were calculated for the aspects of usability addressed in the questionnaire. This value represented a "level of agreement" for each usability component. A graphical representation of the "levels of agreement" is shown in Figure 14. Additionally, all the responses to questions can be found in Appendix G (Table 9 & Table 10).

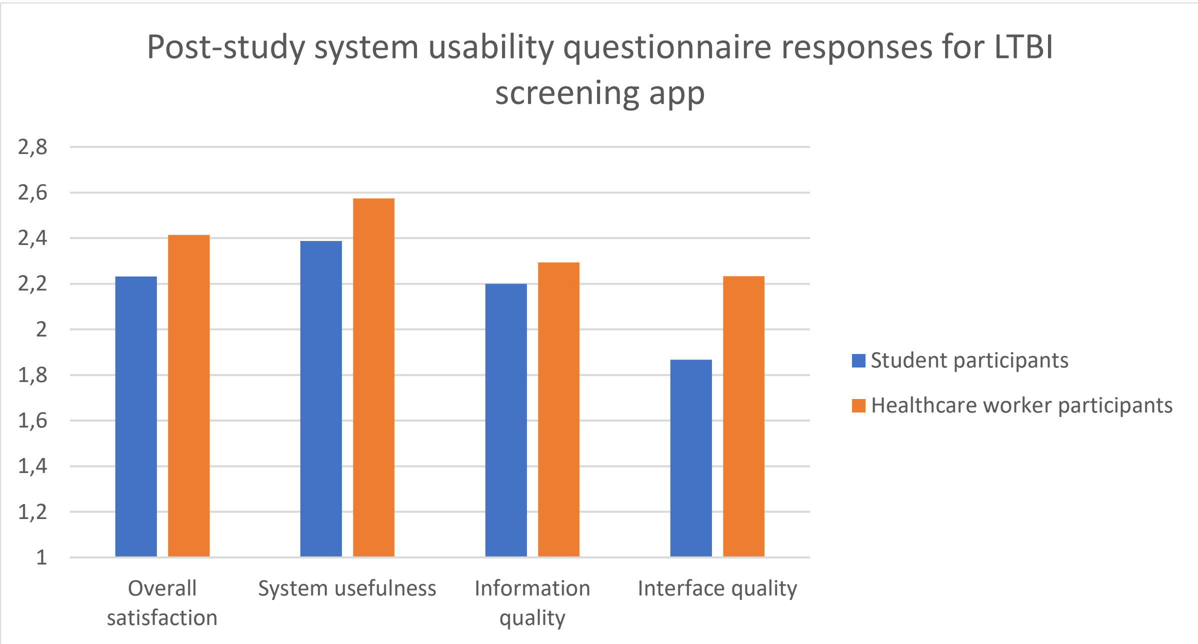

Figure 14: Responses to the PSSUQ by student and healthcare worker participants.

Both groups of participants scored the app similarly. As shown, the average score is below three for all usability aspects, one representing strongly agree and three being neutral. Thus, the satisfaction with the aspects of the app tested in the questionnaire is neutral to strong (Fruhling & Lee, 2005).

Some participants in both sample groups left comments on the questionnaire related to their experience using the app. Many of these comments related to the learnability of the app and how consequent attempts will result in better and quicker completion of the image capture protocol.

Student and health worker participants noted that training would be necessary for accurate and successful progress throughout the app. All participants identified the interface as visually-pleasing, while attributing some of the usability concerns to the long and challenging image capture. The video and audio guidance were recognised as helpful for the protocol, but the number of images required remained a concern.

Upon reviewing the responses to the questionnaire from participants in the field, there was a discrepancy between the quality of the images taken and the ratings provided on the questionnaire. As shown in Figure 14, healthcare worker participants had a high level of agreement overall, as well as the separate usability aspects it assessed. The “system usefulness” was the least agreeable component for healthcare workers, but it still scored an average level of agreement less than three, a score of one representing “strongly agree”, seven representing strongly disagree. With student participants, the PSSUQ responses correlated with the quality of images taken during app usage. High levels of agreement were reflected with high levels of quality of the images. Conversely, healthcare worker participants found difficulty capturing the images as required, but still found the interface usable according to the PSSUQ responses.

4.5 Summary

This chapter has detailed the results gathered during the prototyping and testing of the LTBI screening app. The feedback gathered during each iteration influenced the progression of the app. As an example of what the progression of the app through development looks like, the instruction pages of each prototype are shown in Figure 15. The progression from the previous interface to the updated interface, after three iterations, is shown. Iterating with students before health workers allowed for quick and efficient refinement of the user-interface design, in order to allow for more meaningful interactions when testing in the field. This chapter has also described the progression of the design of the interface and the results of the usability assessments with the two user groups. In the next chapter, these results will be discussed.

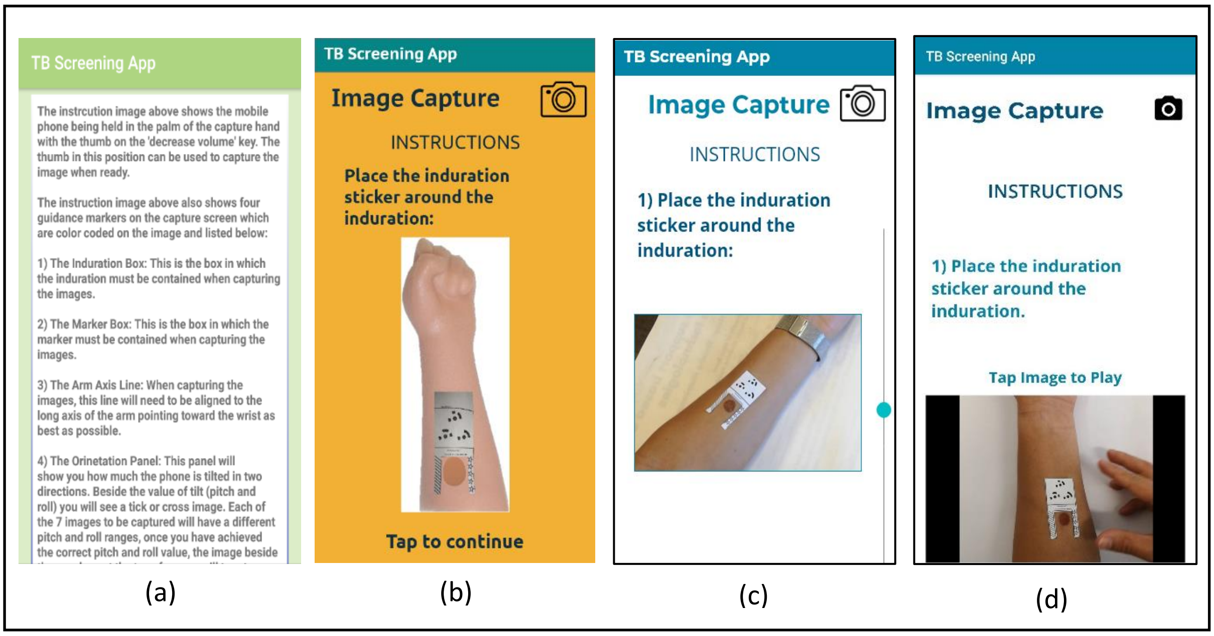

Figure 15: Prototype progression of the instruction pages of the mobile app; (a) is the previous interface, with progression through (b) and (c) leading to (d), the updated interface.

5 Discussion and Conclusion

The purpose of this study was to re-design and assess a user-interface for a mobile phone-based LTBI screening app. To achieve this goal, the Information Systems Research (ISR) framework was combined with design thinking as the design approach. This combination involved the integration of design thinking modes with the cycles of the ISR framework (Figure 4). The design process began in the relevance cycle of the ISR framework and the define mode of design thinking. The user-interface designed by Naraghi (2018), was used as an initial prototype. Through the creation of a Point of View (POV), segmented themes, and How Might We Questions (HMWQs), ideas were generated in order to address the usability concerns related to the LTBI screening app. Some of the key areas of concern regarding usability highlighted through the Naraghi study, were the tedious instruction pages, the image acquisition process, lengthy text, and difficulty remembering instructions. Additionally, the interface also lacked aesthetic appeal. These limitations were addressed through the implementation of the design approach that involved iterative prototyping and interaction with both student participants and healthcare worker participants in a clinical environment.

5.1 Objective 1: Redesign and improve the user interface of the LTBI screening mHealth app

Integrating design thinking into the ISR framework provided a foundation for user-centred design and evaluation of the LTBI screening app. The ISR framework allows for the iterative nature of design thinking. Therefore, when new information about users and their needs regarding the app were gathered, the user interface could be improved upon in order to test with users once again. The iterations with students were particularly important during the design of the interface. Engaging with an accessible user group decreased the time required to test with healthcare worker participants in a busy clinical environment. It allowed for refinement of the app considering its usability constraints. The progression of the user interface of the app, and the design considerations, were facilitated through design thinking.

Design thinking provided a means of generating ideas towards catering for the end-user. The segmenting of the end-user population by themes and the HMWQs served as an approach to idea generation. They ensured the characteristics of the end-user were at the forefront of design decision-making. Through consideration of the end-user and themes associated with the user group, the interface was simplified significantly in order to accommodate the needs of the end-user and the image capture requirements. These considerations conform to the "context of use" characteristic of usability, defined by Moumane, Idri, and Abran (2016) as "the users' perspective and opinions, which in turn serves as a guide to evaluate usability" (Section 2.2).

Considering that the ISR framework does not include a methodology for the generation of ideas, design thinking offered a basis for design changes made to the initial prototype. Visualising the interface of the app through a low-fidelity prototype allowed for student participants to interact with a representation of the interface while decreasing the effort and time taken to develop the interface.

Idri, Moumane, and Abran (2013) suggest the evaluation of apps before launching them. In this study, prototype iterations were also evaluated before testing with users in the field. Usability limitations were identified in each iteration with student participants. Iterative prototyping allowed for the design approach to incorporate frequent feedback from users.

5.1.1 Limitations in the choice of participants

The user-interface was tested on a user group that does not represent the end-users of the app. The environments and identities of users in a tertiary institution such as the University of Cape Town contrast with those of users in a primary healthcare clinic setting. These disparities were balanced with the imperative in design thinking to iterate quickly, in order to obtain a workable prototype to test in the field. Ideally, one would want to iterate quickly with end-users *in* the field; however, carrying out such iterations would inevitably lengthen the design process, as rapid recruitment of users was not feasible. Healthcare workers have to attend to obligations related to their work before they can allow for unrelated activities, especially in an under-resourced health setting such as the one in which the participants are employed (Dixon & Tameris, 2018; Engelbrecht et al., 2018). Engaging with them for the initial prototypes would therefore have been impractical. The iterations leading to the final product reduced the effort required of end-users in improving the app during the initial design stages, creating more opportunities for meaningful interaction with end-users who had limited time to spend on the study.

5.2 Objective 2: Assess the usability of the redesigned mHealth app in a clinical environment

Assessing the usability of the redesigned mHealth app in a clinical environment was necessary because design thinking necessitates engagement with the end-user. Furthermore, there is a lack of evaluation of mHealth apps in a practical setting in South Africa, as highlighted by Herman, Grobbelaar, and

Pistorius (2018b). One of the main barriers to carrying out the evaluation of this app was accommodating the time and pressure constraints of healthcare workers. While this is a limitation, the feedback gathered by participants in the field was invaluable in understanding how the app would affect both patients and healthcare workers. Therefore, it was necessary to engage with end-users in the field during the design of mHealth apps, in order to prioritise the context of use, along with the additional system usability characteristics.

Utilising the rigor cycle of the ISR framework and test mode of design thinking, the user interface was tested with healthcare workers. When healthcare worker participants interacted with the app interface, further usability constraints arose despite the multiple iterations with students. This emphasised the importance of addressing usability limitations extensively, before entering a clinical environment. The environment and knowledge base domains of the ISR framework include the context of the end-user, and the information gathered during research, prototyping, and iterations, respectively. Both domains, prior to assessment in a clinical environment, included mostly information from students and secondary sources, including literature. Hence, in order to conform to user-centred design, end-user information was necessary to add to the domains, acknowledging that the contexts of the participant groups are different.

One of the main differences in prototyping with student and healthcare worker participants was the image capture of the simulated induration. The extreme user case was carried out with students (i.e. self-capture of images), while healthcare workers represented ideal users (capturing images of others). Using the extreme user case for the initial iterations with students aided in better accommodating healthcare workers.

Another consideration that arose when interacting with healthcare workers, specifically community health workers, was their personal safety. The usability of the app is thus affected, since healthcare workers may be deterred from using the app for LTBI screening in the field if they are vulnerable to theft and other threats to safety. Coetzee et al. (2017) report concerns of safety when community health workers in Khayelitsha carry devices with them. Hussain and Kutar (2009) include safety as a component within their usability guidelines for mobile apps (Table 1). Requiring a healthcare worker to visit patients with a smartphone to apply the app, would introduce danger in many of the regions in which healthcare workers are based.

Labrique et al. (2013) emphasise that confidentiality of data is also compromised should a phone with sensitive information be stolen. Data confidentiality should be considered in further design of the app. The relationship between usability and trust is a consideration in mHealth apps, which is affected by data confidentiality. This relationship, while not specified in the usability guidelines adapted by

Hussain and Kutar (2009), is emphasised by Fruhling and Lee (2006). They report that this relationship is vital to consider when attempting to implement an electronic health intervention, such as an mHealth app. Since the LTBI screening app handles sensitive information, there would be an expectancy of reliable and confidential data handling. Should trust in the mHealth app be lacking, the app may become undesirable. Therefore, trust needs to be established with users as it influences the usability.

Efforts were made to counter any researcher-participant tensions and power imbalances, in order to ensure participant comfort and trust, and the validity of responses. This was done because power dynamics and unequal hierarchy between researcher and participant will always exist (Bhopal, 2009). Reflexivity assists researchers to account for differences between themselves and participants, and allows for sensitivity when engaging with participants, especially marginalised individuals (Bhopal, 2010). Some of the measures taken in this project were: having a female research assistant present who also spoke the home language of some participants (isiXhosa), and giving users an opportunity to ask questions and comment on their experiences using the app. This formed part of the "think aloud" technique and aimed to give participants a voice.

5.3 THE POST-STUDY SYSTEM USABILITY QUESTIONNAIRE

After interacting with the app, users were asked to complete an evaluation questionnaire. The questionnaire used during this stage of the design differed from the one introduced by Naraghi (2018), who used the System Usability Scale Questionnaire (Appendix A). The questionnaire in this study was based on the Post-study System Usability Questionnaire (PSSUQ). Phrases were changed to simpler wording in an attempt to limit the use of long words and sentences. This accommodation for low-proficiency English readers is important because a lack of comprehension of the questions compromises the validity of the data and responses (Finstad, 2006). Providing a questionnaire in the primary language of the users may add more valuable feedback, as users would be more comfortable sharing their thoughts and ideas related to the app, especially in the section of the questionnaire that requires suggestions and comments. Since the questionnaire evaluates specific usability characteristics, translating the questionnaire would require its further validation, as direct translation might introduce errors when evaluating the results. Design thinking supports the provision of multi-lingual questionnaires where empathy with the primary user is prioritised, but this was not achievable within the scope of this research project.

Through analysis of the PSSUQ responses and the observations, it was found that participants' comfort during use of the app was not a determining factor for the accuracy with which they completed tasks.

This discrepancy can be attributed to users distinguishing between the user-interface and the lengthy image capture during evaluation, a misunderstanding of what an acceptable image looks like, or a misunderstanding of the PSSUQ. These factors could result in a perception that merely completing the image capture is enough to operate the app successfully, which is undesirable for the functionality of the app.

5.4 IMAGE QUALITY

During the interaction with healthcare workers the quality of images became a concern, especially the quality of images taken towards the end of the image capture. This indicated a level of impatience, frustration, and lack of concentration, which was noted through observation and 'think aloud'. While it does not directly relate to the user-interface, the image capture, and user requirements thereof, are important to understanding usability of the entire system. The instructions provided were meant to achieve a better understanding and use of the app; however, the complexity of image capture resulted in persistent usability limitations, despite engagement with users during the user interface design. Thus, the feedback received from healthcare workers confirmed the challenges to implementation when users are not consulted during the formulation of a product or service (in this case the image analysis protocol and the associated image capture requirements), as reported by Munro and Savel (2016). User consultation during the design of the image analysis protocol may have alerted the designers to the usability limitations of the image capture requirements.

The length of time required to complete image capture, described by participants in the previous study as "awkward", "complex", and "cumbersome" (Naraghi, 2018:97), remains a concern for the usability of the app. All participants in this study indicated their dislike of this part of the app. This dislike was emphasised in the healthcare setting. Thus, future work in the development of this app should prioritise decreasing the time needed for completion of the image capture task. This could involve the use of video capture, as recommended by Naraghi (2018), or significantly reducing the number of images required. Such improvements would conform to usability guideline components adapted by Hussain and Kutar (2009), specifically efficiency and time-taken. Based on observations and user-feedback in this project, improving these aspects will increase usability.

5.5 THE INFORMATION SYSTEMS RESEARCH FRAMEWORK

The Information Systems Research framework was used to design the user-interface of the LTBI screening app, with design thinking for user-centred design. To the knowledge of the researcher, design thinking has not been proposed as a design approach for the ISR before. Evidently, this allowed for some of the limitations of the framework to be alleviated, specifically the choice of participants (Section 2.4). Design thinking prescribes the engagement of the end-user during the design and testing processes, as well as prototyping with a group of participants that can aid quick development. Throughout this study, the engagement with both participant groups resulted in valuable feedback that influenced design alterations. Where the ISR framework and design thinking techniques continue to be limited is the non-generalisable nature of the data collected. The recruitment of ten participants for each of the final two iterations of the app contributes to the non-generalisability. However, as Hwang and Salvendy (2010) report, a sample size of 10±2 is sufficient in discovering 80 per cent of usability issues. Testing in diverse contexts would be required if the mobile app is to be scaled across more diverse healthcare settings and diverse user groups.

5.6 CONCLUSION

Using the Information Systems Research framework with design thinking has enabled the app interface to be improved, through quick iterations, constant feedback, and usability testing in the field. Design thinking, specifically, provided tools with which users and their contexts are considered extensively. It allowed for reflexivity from the researcher, the centring of the user, and design considerations that were appropriate for the context in which the app would be implemented.

The initial development of the app focused on image capture for 3D reconstruction and analysis, rather than on the end user (Naraghi, 2018), with the user experience being assessed at the end of the design stage. This resulted in usability limitations related to the technical aspects of the app, notably image capture, which could not be addressed fully by a more usable interface. This limitation emphasises the need for user-centred design for mHealth apps throughout development, especially being cognisant of user contexts and characteristics. Further research should focus on decreasing the complexity and the duration of image capture, and may require a reformulation of the image analysis protocol.

The ethical considerations of designing and implementing an mHealth app for LTBI screening in under-resourced areas extends beyond the gaining of ethical approval and access to participants. It involves the constant consideration of users' contexts and their identities within those contexts. Usability depends on these considerations and how the intended technology will impact the user. Furthermore, privacy, safety, and trust play an important role in implementing new health technologies. Usability is therefore not limited to the technology itself but is also connected to how the technology affects the well-being of users. These considerations influenced the design approach for this research. Further research should include a focus on the social impacts of integrating the mHealth app within community and health structures.

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APPENDIX A: LTBI SCREENING APP EVALUATION FORM

The evaluation form below was used by Naraghi (2018) to evaluate usability of the mHealth app.

TB Screening App Evaluation Form

Please answer the following questions regarding the usability of the TB Screening App:

		Strongly Disagree				Strongly Agree
1.	I think that I would like to use this mobile app frequently.	☐	☐	☐	☐	☐
2.	I found this mobile app unnecessarily complex.	☐	☐	☐	☐	☐
3.	I thought this mobile app was easy to use.	☐	☐	☐	☐	☐
4.	I think that I would need assistance to be able to use this mobile app.	☐	☐	☐	☐	☐
5.	I found the various functions in this mobile app were well integrated.	☐	☐	☐	☐	☐
6.	I thought there was too much inconsistency in this mobile app.	☐	☐	☐	☐	☐
7.	I would imagine that most people would learn to use this mobile app very quickly.	☐	☐	☐	☐	☐
8.	I found this mobile app very cumbersome/awkward to use.	☐	☐	☐	☐	☐
9.	I felt very confident using this mobile app.	☐	☐	☐	☐	☐
10.	I needed to learn a lot of things before I could get going with this mobile app.	☐	☐	☐	☐	☐

Do you have any suggestions on how the app could be improved? If yes, please share below:

____
____
____
____
____
____

Do you have any other comments regarding the application? If yes, please share below:

____
____
____
____
____

*Questions in this questionnaire were adapted from online questionnaire found at http://satoriinteractive.com/system-usability-scale-a-quick-usability-scoring-solution/

APPENDIX B: PROTOTYPE QUESTIONNAIRE

Thank you for participating in the prototyping stage of this project. Please complete the following questionnaire based on your experience while engaging with the prototype.

Please rank your experience with each interface (version 1, 2, or 3) with regard to:

Colour Scheme

1st ☐

2nd ☐

3rd ☐

Comments:

Please select your preferred version of the questionnaire page:

Questionnaire Page

Tick Boxes: ○

Highlighted Bars: ○

Please rate how helpful the short tutorial videos were in helping you during the image capturing procedure, on a scale of 1 to 5:

1 ○ 2 ○ 3 ○ 4 ○ 5 ○

Comments:

APPENDIX C: POST-STUDY SYSTEM USABILITY QUESTIONNAIRE

The Post-Study System Usability Questionnaire			Strongly Agree						Strongly Disagree		
			1	2	3	4	5	6	7		N/A
1	Overall, I am satisfied with how easy it is to use this system.		○	○	○	○	○	○	○		○
2	It was simple to use this system		○	○	○	○	○	○	○		
3	I could effectively complete the tasks and scenarios using this system.		○	○	○	○	○	○	○		
4	I was able to complete my work quickly using this system.		○	○	○	○	○	○	○		
5	I was able to efficiently complete my work using this system.		○	○	○	○	○	○	○		
6	I felt comfortable using this system.		○	○	○	○	○	○	○		
7	It was easy to learn to use this system.		○	○	○	○	○	○	○		
8	I believe I could become productive quickly using this system.		○	○	○	○	○	○	○		
9	The system gave error messages that clearly told me how to fix problems.		○	○	○	○	○	○	○		
10	Whenever I made a mistake using the system, I could recover easily and quickly.		○	○	○	○	○	○	○		
11	The information (such as online help, on-screen messages and other documentation) provided with system is clear.		○	○	○	○	○	○	○		
12	It was easy for me to find the information I needed.		○	○	○	○	○	○	○		
13	The information provided with the system is easy to understand.		○	○	○	○	○	○	○		
14	The information was effective in helping me complete my work.		○	○	○	○	○	○	○		
15	The organization of information on the system screens was clear.		○	○	○	○	○	○	○		
16	The interface of this system was pleasant.		○	○	○	○	○	○	○		
17	I liked using the interface of this system.		○	○	○	○	○	○	○		
18	This system has all the functions and capabilities I expect it to have.		○	○	○	○	○	○	○		
19	Overall, I am satisfied with this system.		○	○	○	○	○	○	○		

Appendix D

Distinct flow (linear, guidance, ensure users don't get lost)

Use 3 fonts (clear, large, semiformal)

Minimal text (use images for instructions)

How might we make users more comfortable with the mobile app interface?

Use 3 contrasting colour schemes when prototyping (visually appealing)

Allow users to see images after capture (Check/retake)

Voice messages indication success or failure

How might we indicate to users that their images were captured successfully?

Audio sound in the form of a beep/buzzer for a good/bad image respectively

After each image display the image with a grid showing a green or red filter depending on successful image capture

People who are being tested for LTBI and healthcare workers who administer these tests (user), need to understand and feel comfortable while using the LTBI screening mobile app (need), because their ability to capture images of the induration is a key feature of the LTBI screening app (insight).

Have someone else take the images

Utilise video, images, and audio for assistance

Clear, bright colours to distinguish any text or guiding tools

How might we accommodate users with visual/auditory impairments?

Vibration/beep when images should be/are taken

Auditory guide through the app ("Tap to move ahead")

Use visual cues

How might we accommodate users with low literacy?

Only have the image capturing procedure in the app (no questionnaire)

Have an audio aid for any text

Minimal text/no text

Have the healthcare worker complete the screening questionnaire

Step-by-step instructions

How might we explain the image capturing procedure so that users understand it?

Use short videos for instructions (maximum 15 seconds long, animation)

Use images for instructions

Have someone else take the images

Translated text

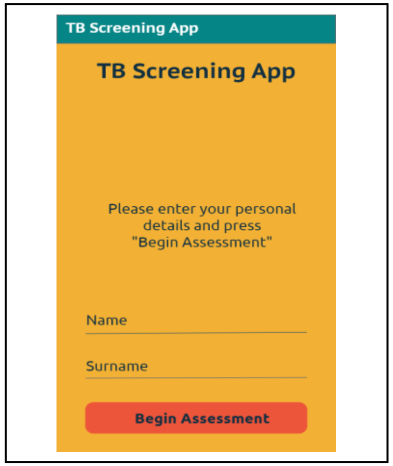
Use explicit guiding icons in videos or images

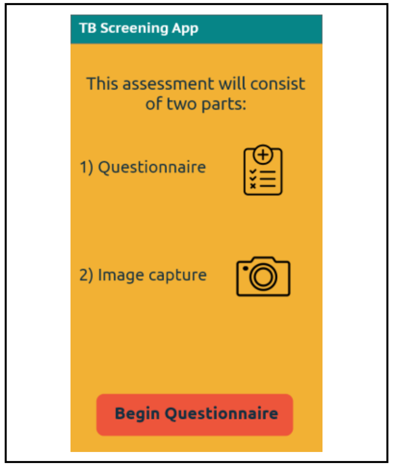
Voice guiding of the image capturing procedure

Figure 16: Point of View, How Might We Questions, and Ideas in a post-it note arrangement

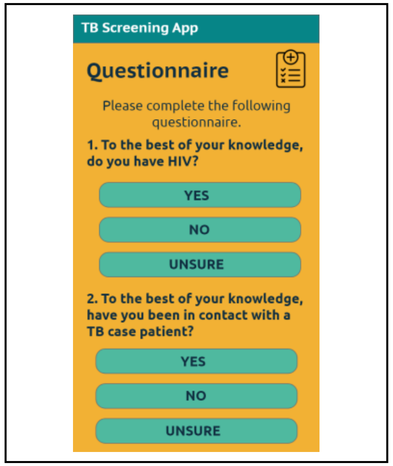
APPENDIX E: FIRST ITERATION PROTOTYPE SCREENSHOTS

Login Page

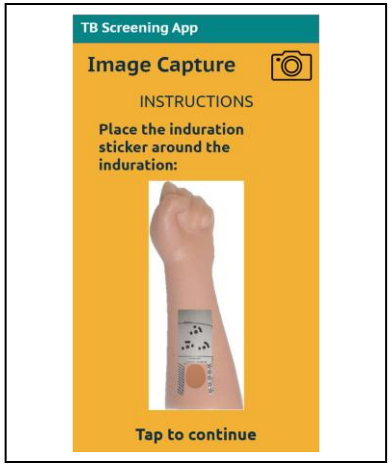


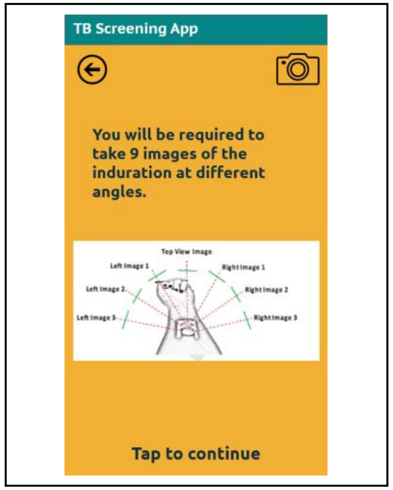


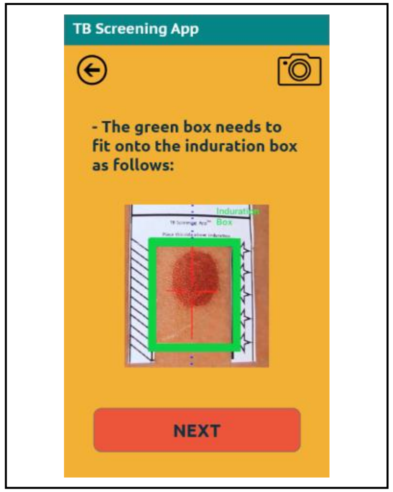
Questionnaire



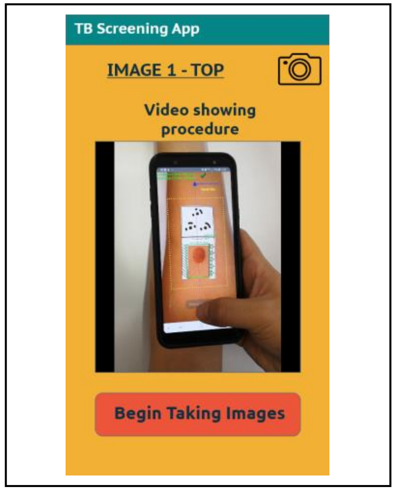
Instructions

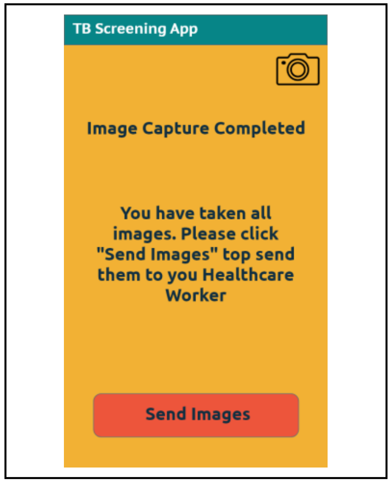






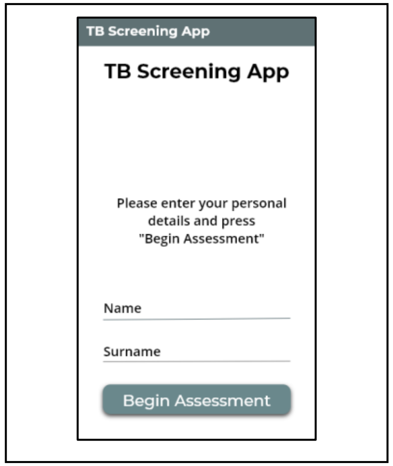
Tutorial

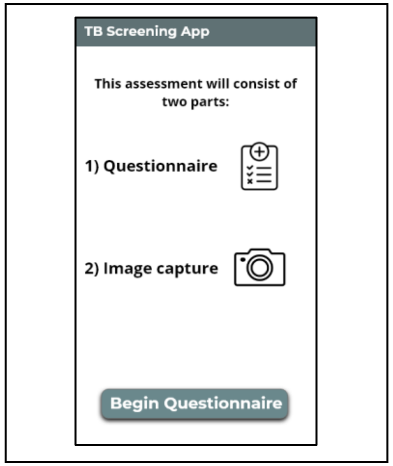




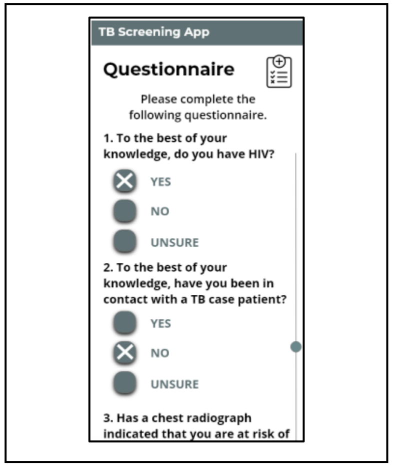
APPENDIX F: SECOND ITERATION PROTOTYPE SCREENSHOTS

Login Page

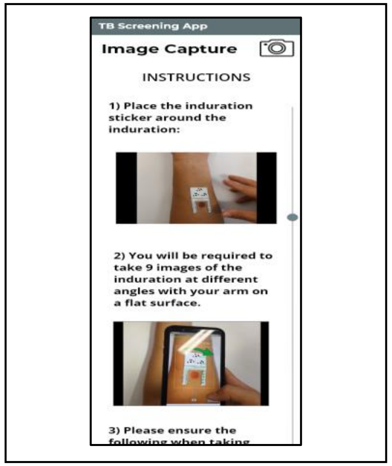




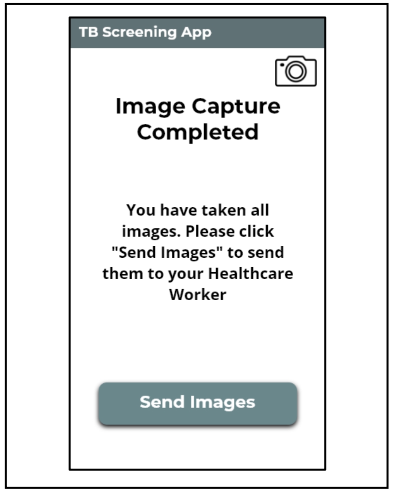
Questionnaire



Instructions



Tutorial



APPENDIX G: PSSUQ RESPONSES

Table 9: PSSUQ responses for student participants.

Questions	Participant Number										Average/Usability Aspect
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	
Q1	4	3	4	3	2	2	3	3	3	3	2,39
Q2	3	2	4	2	1	3	4	2	3	4	
Q3	3	1	3	3	1	1	3	1	4	3	
Q4	2	4	6	3	1	1	3	1	4	1	
Q5	2	3	6	2	1	2	3	2	4	1	
Q6	2	4	4	3	1	3	3	4	2	1	
Q7	1	2	3	2	1	1	2	2	1	1	
Q8	1	4	2	2	1	1	1	1	1	1	
Q9	5	2	4	4	2	1	2	2	1	3	2,20
Q10	4	4	4	3	1	1	2	2	1	3	
Q11	4	3	1	2	1	3	2	4	1	3	
Q12	1	2	1	2	1	2	3	3	3	3	
Q13	2	3	1	2	1	2	3	2	2	3	
Q14	3	2	3	2	1	1	2	1	1	3	
Q15	1	2	1	2	1	4	1	1	2	3	
Q16	1	2	1	2	1	3	1	2	1	3	1,87
Q17	1	2	1	2	1	3	1	2	1	3	
Q18	2	2	1	3	2	3	2	3	1	3	
Q19	2	2	4	2	2	3	2	2	1	3	2,30

Table 10: PSSUQ responses for health worker participants.

Questions	Participant Number										Average/Usability Aspect
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	
Q1	5	2	1	1	1	2	5	1	3	5	2,58
Q2	5	3	1	2	4	2	4	2	2	4	
Q3	4	3	1	1	1	1	2	1	2	4	
Q4	4	1	1	3	7	4	3	7	4	4	
Q5	3	1	1	1	2	4	1	1	3	5	
Q6	3	1	1	1	1	2	3	7	3	5	
Q7	2	1	1	1	2	1	5	1	4	4	
Q8	1	2	1	1	2	1	4	1	4	5	
Q9	1	2		1	1		5	4	3	3	2,29
Q10	1	2	1	1	1	4	1	6	1	4	
Q11	2	3	1	1	1	1	1	2	3	4	
Q12	2	2	1	1	1	1	4	1	4	3	
Q13	2	2	1	1	1	1	6	7	3	3	
Q14	2	2	1	1	7	4	4	4	2	4	
Q15	2	1	1	1	1	1	3	2	3	2	
Q16	2	3	1	1	1	1	1	1	3	3	2,23
Q17	2	3	1	1	1	4	1	3	4	4	
Q18	2	2	1	1	1	1	4	7	4	3	
Q19	2	3	1	1	1	1	1	7	4	4	2,5