

DESIGNING A MULTIMEDIA INTERVENTION FOR ILLITERATE AND SEMI-  
ILLITERATE PREGNANT WOMEN IN DEVELOPING COUNTRIES: A CASE OF  
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**Declaration**

I declare that I have completed the thesis independently using only the aids and tools specified. I have not applied for a doctor's degree in the doctoral subject elsewhere and do not hold a corresponding doctor's degree. I have taken due note of the Faculty of Mathematics and Natural Sciences PhD Regulations, published in the Official Gazette of Humboldt-Universität zu Berlin no. 42/2018 on 11/07/2018.

Jane Katusiime

## **Dedication**

*To my precious daughter Mia, mom  
and dad*

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## **List of abbreviations**

ANC	Antenatal Care
CLDC	Connected Limited Device Configuration
DAC	Discretionary Access Control
IDE	Integrated Development Environment
IDE	Integrated Development Environment
ISO	International Organization of Standardization
MAC	Mandatory Access Control
mHealth	Mobile Health
MIDP	Mobile Information Device Profile
PNC	Postnatal Care
RBAC	Role Based Access Control
SMS	Short Message Service
TBAC	Task Based Access Control
TMAC	Team Based Access Control
UCD	User Centered Design
UNESCO	United Nations Educational, Scientific and Cultural Organization
WHO	World Health Organization

## **Abstract**

Maternal mortality is high in developing countries partly due to indirect factors such as illiteracy and limited access to maternal health information. While literate women can access health information from online platforms, and mHealth apps, illiterate women must get it from health facilities which is often not possible due to lack of transport fees.

Mobile technology has opened opportunities in maternal health care for low resource communities that would otherwise not have benefited from digital technologies. Although used in maternal health, most interventions are not usable by the illiterate, use security models that are not tailored to the developing countries' context, and have not been evaluated to assess their impact on maternal health care.

In this thesis, two (web and mobile) apps that facilitate delivery of multimedia-based maternal health messages, appointment reminders, and calls/ chats were developed. To gather user requirements, a field study in form of semi-structured interviews and focus group discussions was conducted with illiterate pregnant women, health practitioners and developers. Development of a security model (T2RoL) to secure the health information in the apps followed. The apps were then developed following a user-centered design approach.

A second field study in form of semi-structured interviews and surveys was conducted to evaluate the mobile app through a randomized controlled trial with 80 illiterate pregnant women that were followed for 9 months. Overall, results show that the app was acceptable, easy to learn and use. There was improved maternal health knowledge among the intervention group which positively influenced health related decision making and health practices.

## **Kurzfassung**

Die hohe Müttersterblichkeit in Entwicklungsländern ist zum Teil auf indirekte Faktoren wie Analphabetismus und eingeschränkten Zugang zu Gesundheitsinformationen für Mütter zurückzuführen. Während gebildete Frauen auf Gesundheitsinformationen über Online-Plattformen und mHealth-Apps zugreifen können, müssen Analphabetinnen diese in Gesundheitseinrichtungen abrufen, was aufgrund der Transportkosten oft nicht möglich ist.

Mobilfunktechnologie hat in der Gesundheitsversorgung Chancen für ressourcenarme Gemeinschaften eröffnet, die sonst nicht von den digitalen Technologien profitiert hätten. Obwohl Mobilfunktechnologie in der Müttergesundheit eingesetzt wird, können die meisten Maßnahmen nicht von Analphabeten genutzt werden, verwenden Sicherheitsmodelle die nicht auf den Kontext von Entwicklungsländern zugeschnitten sind, und wurden nicht auf ihre Auswirkungen auf die Müttergesundheit hin evaluiert.

In dieser Arbeit wurden zwei (Web und Mobile) Apps entwickelt, die die Übermittlung von multimedialen Nachrichten zur Müttergesundheit, Terminerinnerungen und Anrufe/Chats erleichtern. Um die Anforderungen der Nutzer zu erfassen, wurde eine Feldstudie mit halbstrukturierten Interviews und Fokusgruppendifkussionen mit schwangeren Analphabetinnen, Gesundheitsexperten und Entwicklern durchgeführt. Es folgte die Entwicklung eines Sicherheitsmodells (T2RoL) zur Sicherung der Gesundheitsinformationen in den Apps, die dann nach einem nutzerzentrierten Designansatz entwickelt wurden.

Eine zweite Feldstudie in Form von halbstrukturierten Interviews und Umfragen wurde durchgeführt, um die mobile App in einer randomisierten kontrollierten Studie mit 80 schwangeren Analphabetinnen über 9 Monate zu evaluieren. Die Auswertung zeigte, dass die App akzeptiert wurde sowie einfach zu erlernen und zu benutzen war. Das Wissen über Müttergesundheit in der Interventionsgruppe verbesserte sich, was sich positiv auf gesundheitsbezogene Entscheidungen und Gesundheitsmaßnahmen auswirkte.

## CHAPTER 1: INTRODUCTION

### 1. Introduction

#### 1.1 Illiteracy and maternal mortality in developing countries

##### 1.1.1 Maternal mortality

Maternal mortality is the death of women during pregnancy, childbirth or within 42 days after delivery due to pregnancy related complications[1]. According to UN inter-agency, maternal mortality is estimated at 216 deaths per 100,000 live births globally[2], [3]. Maternal mortality is reducing globally, for instance, between 2000 and 2017, maternal mortality dropped by 38% worldwide[4].

However, maternal mortality is still considered high in developing countries compared to developed countries[3]–[8] due to factors such as poor infrastructure, scarcity of health practitioners and high illiteracy levels among women. The probability of a woman dying due to pregnancy related causes is 1 in 45 in low income countries compared to 1 in 5400 in high income countries[4], [8]. In 2017, 94% of all maternal death occurred in low and lower middle income countries with Sub-Saharan Africa alone accounting for roughly two-thirds of the global maternal deaths[4], [8]. Countries like Nigeria, South Sudan and Uganda have much higher maternal mortality rates in Sub-Saharan Africa. For instance, Uganda has a maternal mortality ratio of 375 per 100,000 live births and it registered six thousand (6,000) maternal death in 2017 compared to countries like Norway and Finland that registered one and two death respectively[9], [10].

##### *Causes and factors that influence maternal mortality in developing countries*

There are several causes and factors that influence the rate of maternal mortality in developing countries. These factors are categorized into direct factors and indirect/ external factors and summarized in a table below based on[7], [8], [11]–[13].

<b>Direct factors</b>	<b>Indirect/ external factors</b>
<ul style="list-style-type: none"><li>• Hemorrhage/ severe bleeding (mostly bleeding after childbirth)</li><li>• Sepsis</li><li>• Pregnancy-induced hypertension</li></ul>	<ul style="list-style-type: none"><li>• Limited information on maternal health</li><li>• Unfavorable policies</li><li>• Poor nutrition before, during pregnancy and after delivery</li></ul>

<ul style="list-style-type: none"> <li>• Complications of unsafe abortion</li> </ul>	<ul style="list-style-type: none"> <li>• Diseases such as anemia, HIV/AIDS and malaria</li> <li>• Poverty</li> <li>• Distance from health facilities</li> <li>• Inadequate services</li> <li>• Cultural practices</li> <li>• Failure and delay in recognizing danger signs</li> <li>• Weak supervision</li> <li>• Illiteracy</li> <li>• Poor or lack of properly functioning health management information systems</li> <li>• High fertility</li> </ul>
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Table 1: Causes and factors that influence the rate of maternal mortality in developing countries.

### 1.1.2 Illiteracy

UNESCO defines illiteracy as the condition of a person who can neither read nor write and literacy is the ability to identify, understand, interpret, create, communicate and compute, using printed and written materials associated with varying contexts[14], [15]. In this thesis, an illiterate is referred to as a person who has no education or does not exceed lower primary (primary three) and semi-illiterate as one that does not exceed upper primary (primary seven).

Illiteracy levels have been reducing globally in the past decades[16], [17]. For instance, literacy rates among youth (aged 15 to 24). Globally, the number of illiterate youth declined from 170 million to 115 million translating to an increase in literacy from 83% to 91% over two decades[16]. However, there are still regional disparities. Literacy is considered low in developing countries compared to developed countries for instance, literacy in North Korea is 100% and that of Germany is 99% while literacy in Niger stands at 19.1% and South Sudan is at 27% [18], [19]. On the other hand, Uganda's literacy stands at 78.4% leaving close to a quarter of its population (21.6%) illiterate[18].

Illiteracy based on gender disparities also still persists and this explains higher levels of illiteracy among women compared to their male counterparts[16], [20], [21]. For instance, young women

account for 59% of the total number of illiterate youths globally[17]. According to world bank data, in sub-Saharan Africa, 59% of adult women(15 years and above) in developing countries are literate compared to 73% of their adult male (15 years and above) counter parts[22], [23]. Considering Uganda, the illiteracy of the population between ages 15 to 49 stands at 32% for women and 22% for males[24]. One contributing factor of high illiteracy among women is the male dominance nature of some cultures whereby the right to education is reserved for the male children especially if there are resource limitations[25].

## **1.2 Mobile technology in developing countries- present and prospects**

Mobile technology continues to gain popularity globally[26], [27]. There were 4.57 billion mobile phone subscribers in 2018 which is estimated at 63.5% of the global population[27]. There is a growing number of mobile phone subscribers observed in developing countries[28], [29]. In 2018, 83% of adults in developing countries had mobile phones[30]. This can be attributed to reduction in prices among other factors. Research shows that the cell phones are widely used in developing countries, but the use of smart phones is also gaining popularity. This is attributed to the continuous reduction of prices of china-made basic smart phones that go as low as 20 dollars. However, research shows that much as more people are acquiring mobile phones globally, there is still gender divide whereby women are less likely to own mobile phones compared to their male counterparts especially in developing countries[31]–[35]. This is even worse in low- and middle-income countries where trends show that even with the surge in acquisition of cell phones, women are 10% less likely to own a mobile than men which translates to 197 million fewer women than men owning a mobile phone as of 2019[36]. In developing countries, 86 % of men have mobile phones compared to 79% of women as of 2018[30]. The mobile phone ownership gap is even wider in the ownership of smartphones whereby males are more likely to own smartphones than women[37], [38].

Internet usage is also affected by gender disparities despite the steady increase in the number of users, from 16.8% in 2005 to 53.6% in 2019[39]. Use of internet is gaining popularity in developing countries but it is also affected by the gender divide with more men having online access than women[25], [33], [38], [40]. For instance, in 2019, 22.6% of women in Africa had access to the internet compared to 33.8% of men[41].



The gender based digital divide is attributed to social economic factors such as illiteracy, cultural influence and gender insensitive resource distribution[35]. This divide forces women to share mobile phones with their male counterparts[25]. The sharing phenomenon may take long to gradually reduce because some of the cultures in these nations are also characterized by sharing resources as a cultural aspect rather than scarcity. In other words, there is communal ownership of resources including technology especially at family level. This poses privacy, security and usability challenges of mobile systems because users are sceptical about using systems that capture sensitive information due to the fear of having their information accessed by the people with whom they share the devices[42]. In some communities, to overcome these challenges, individuals resort to owning personal SIM cards which they use every time they have access to the shared mobile phones. This however leads to quick wear and tear of both the mobile phones and the SIM cards.

Mobile phones in developing countries are mainly used for voice calls, SMS and beeping which refers to calling another mobile phone and hanging up before the call is answered, with the hope of being called back[28], [43]. In addition to strengthening social ties through communication and improving incomes, mobile phones are being used for health purposes such as health related consultations via the mobile phone and reporting emergencies.

### **1.3 Potential of mobile Health in maternal health care**

Despite drawbacks such as sharing of mobile phones and illiteracy, mobile phones have opened opportunities such as mobile banking and mobile health for low resource communities that would otherwise not have benefited from digital technologies[44], [45]. Mobile health (mHealth) systems are gradually gaining popularity regarding patient follow-up, communication, and lifestyle management among others. mHealth refers to practice of medicine and public health supported by mobile devices such as mobile phones, tablet computers and smart watches[46]. The popularity can be attributed to the increased penetration of mobile devices due to their easy mobility, low costs, convenience and ability to be used in remote areas where infrastructure is poor[47].

There have been mobile phone based initiatives in developing countries to support maternal health care such as MomConnect project, the Mobile Alliance for Maternal Action (MAMA) and LigaInan (Mobile Moms) but maternal mortality continues to be a big challenge[48], [49]. MomConnect enables health practitioners to send weekly text messages to pregnant women about their pregnancy and the women can text back, MAMA provides a learning platform where women

participate in mobile-based quizzes about maternal health while Mobile Moms enables health practitioners to broadcast health information to pregnant women. These interventions have registered progress in improving maternal healthcare but they are mainly text based[49]. Therefore they are not usable by illiterate women who are more prone to maternal mortality[50]. The success of these mHealth interventions among literate women may be an indicator that mHealth may also be feasible for illiterates, if their unique design and user requirements are considered

#### **1.4 Security/privacy and Usability in mHealth systems**

In resource constrained settings faced with scarcity of health practitioners, use of mobile technology seems to be a feasible way of improving health care service delivery. However, privacy issues such as eavesdropping and third-party attacks, and usability issues such as memorability and cognition challenges related to authentication remain a challenge to mHealth systems. Social technical factors such as cultural differences, poverty and low literacy levels also contribute to the privacy and usability issues, for instance, illiteracy prevents the illiterate from using conventional authentication methods, and poverty forces them to share mobile devices. Due to the sensitivity of health information, there is an ethical need to equip mobile health systems with adequate security measures to safeguard patient's information. Existing health systems attempt to safeguard client's information by implementing access control security models. However, privacy and usability issues still persist because health systems present a new set of privacy and usability requirements such as the inevitable need for shared access of patients' information. For example, a patient may be examined in one hospital, her case reviewed by experts in another health facility and then treated by health practitioners in yet another different hospital depending on where the required expertise is available. This may be across health facilities within a country or facilities across different countries or continents. This makes health systems largely distributed and complex.

#### **1.5 Access control security models used in healthcare systems**

The most popular security models implemented in health systems are Role Based Access Control (RBAC) model[51], [52], Team-based Access Control (TMAC) model[53] and Task Based Access Control (TBAC) model[54]. There have been efforts to support maternal health by using mobile technology based on these security models. For example, Electronic Patient Record (EPR) systems that implement Role-Based Access Control[55] have been put in place. An example of such systems is PCASSO (Patient Centered Access to Secure Systems Online), which is a research

project and technology demonstration that seeks to provide secure access to highly sensitive patient information over the Internet using the RBAC. In the region of Kedougou in Senegal, mobile phones are used to create a network of community workers who call the nearest health centre in case of an emergency[56]. The system they use is based on TBAC, whereby the communication is initiated only when there is a task to be performed. Another example is Uganda and Kenya, where there is a project initiative based on the TMAC model that aims at supporting maternal health by helping pregnant women contact healthcare providers using mobile phones[57]. These health initiatives have however, registered minimal and slow progress in developing countries[58]. This minimal progress has been partly attributed to the security models used in these projects, which do not adequately safeguard patient's health information[59].

The Role Based-Access Control (RBAC) assigns roles to users, permissions to roles and users get permissions by playing roles. The key strength of this model is that it enables separation of duties[52]. RBAC is also scalable because security can be administered to all users belonging to the same role which reduces administrative overhead cost associated with security administration at individual users, and permissions levels.

However, implementation of RBAC is dependent on the kind of operating system (OS) the device is running. There is no implementation standard for all the operating systems. In addition, RBAC is prone to role explosion whereby the increasing number of different roles make it complex to manage them especially in large organisations.

A Team-based Access Control model is mainly used in collaborative environments and it uses teams whereby access rights are given to groups of users. The advantage of this model is that it is scalable and allows for dynamic management of permissions as tasks progress to completion[53], [60]. The problem of TMAC is that it does not have self-administration capabilities meaning that the team-based permissions must be enabled by an administrator which adds administrative overhead costs.

Task Based Access Control model is based on tasks and permission control is dynamic. The advantage of TBAC is that it supports real time processing of tasks and supports least privilege processes[54], [61]. In other words, permissions change as tasks progress, and authorisations have strict validity and expiration features which gives a chance to all processes to have access. However, in large systems where processes are many, processing time will increase.

Based on the above, it is evident that using a single model poses challenges and some limitations. Moreover, these access control models do not consider the location attribute which is important in cases where there is need for shared access of patients' records or in scenarios where health practitioners are out of health facilities and away from patient records but require access to the records. This raises the need for developing security models that provide secure remote access to patient's information especially for developing countries where mobile clinics/ health camps are common.

## **1.6 Motivation and problem definition**

There is high maternal mortality in developing countries, and this is partly due to indirect/external factors such as illiteracy, cultural practices and limited access to maternal health information. While literate women can access maternal health information from online platforms, search engines and mHealth apps, illiterate pregnant women have no access to information on such platforms. They are forced to go to health facilities to access information which is sometimes not possible due to the long distances to these facilities and the high transport costs which may not be affordable to the women.

In addition, there is a mobile technology boom especially in developing countries and this technology is being used to support healthcare including maternal health care. Unfortunately, most researchers and developers focus on interventions that are only usable by people who are literate leaving the illiterate behind and creating a digital gap. In addition, most of the interventions have limited consideration for balancing the trade-off between security and usability. They use access control models that have been designed without considering the unique requirements of developing countries such as illiteracy and sharing of devices. Moreover, most of the interventions have not been evaluated to assess their impact on maternal health care.

In conclusion, there is limited research on how mobile technology can be used to improve maternal health care for illiterate women. Illiteracy contributes to maternal mortality[62], [63] and with the abundant mobile technology, there is a need to investigate how mobile phones may be used for maternal health care for illiterate and semi-illiterate women. There is also a need to develop reliable access control security models tailored to the low resource context to ensure privacy and security of the interventions.

## 1.7 Research goal

Striking a balance between security and usability of health systems remains a big challenge for designers and developers. Highly secured systems tend to have usability issues whereas highly usable systems tend to have security issues[64]. Developing more reliable security models that ensure usability and address limitations of the current models will go a long way in supporting and improving the efficiency of mobile health systems in developing countries. The main goal of this project is to develop a tool that supports maternal healthcare and is usable by illiterate and semi-illiterate pregnant women, and is based on an access control security model for mobile health care systems that addresses the privacy and usability issues of mobile health systems in developing countries. The access control security model developed can be applied to any mobile health system. However, the thesis is focused on maternal health systems because of the peculiar need by women, especially in male dominant cultures where women are more likely to face privacy challenges as a result of sharing of mobile devices and illiteracy.

## 1.8 Objectives

- i. Determine requirements of an mHealth tool that is usable by illiterate and semi-illiterate people.
- ii. To design an access control security model that is usable in mobile health care systems in developing countries
- iii. To design and develop a tool that supports maternal health care and is also usable by illiterate and semi-illiterate people based on the requirements in (i) and access control model developed in (ii).
- iv. To evaluate the usability, acceptability and impact of the tool developed in iii by key stakeholders in maternal health.

## 1.9 Research contribution

The research contributions are categorized into knowledge, theoretical, **design** and methodological contributions.

### 1.9.1 Knowledge contribution

**Reviewing privacy and usability issues in mHealth systems and determining the relevance and implications of external factors:** A systematic review of privacy and usability issues in

mobile health systems was conducted and the role of external factors towards privacy and usability of mHealth systems was ascertained. It was found that external factors such as cultural differences and illiteracy contribute to privacy and usability issues in mHealth systems especially in developing countries and recommendations for addressing the external factors were discussed.

**Identification of gaps in access control models for health care systems:** Based on the literature review of access control models conducted as part of this thesis, it was ascertained that the available access control models are not tailored for health systems in developing countries because of unique attributes such as sharing of mobile devices, illiteracy and regularity of mobile clinics/ health camps.

**Evaluation of acceptability and usability of mHealth applications by illiterate users:** Evaluation of the usability and acceptability of a multimedia mHealth application by illiterate and semi-illiterate pregnant women was done. The conclusion was that illiterate and semi-illiterate women can use mHealth applications, but the acceptance and usability of the applications requires involvement of these women in every stage of the design process.

**Evaluation of the impact of mHealth applications on knowledge, attitudes and practices:** Evaluation of the impact of a multimedia mHealth application on the maternal health knowledge of pregnant illiterate women, their attitudes and practices was made. It was ascertained that provision of multimedia health messages to pregnant women improved their maternal health knowledge, facilitated health related decision making which positively impacted their attitudes and led to adoption of good maternal and child health practices.

### **1.9.2 Theoretical contribution**

The theoretical contribution is a hybrid access control security (T2RoL) model. Unlike other access control models used in health systems, T2RoL access control security model is designed specifically for health care systems in developing countries. It takes into consideration attributes specific to low resource settings such as sharing of mobile devices, illiteracy and existence of mobile clinics/ health camps. This opens a new window for hybridized security models in mobile health systems.

### **1.9.3 Design contributions**

Requirements for an mHealth tool that supports maternal health care and is usable by illiterate and semi-illiterate pregnant women are presented. Furthermore, requirements for an access control security model for mobile health systems in developing countries are gathered and presented. These requirements may act as a starting point for researchers who want to develop or improve security models for mobile systems in resource constrained settings or software designers/developers who want to develop useable systems for low literacy population respectively.

It is important to note that the requirements, design perspectives and procedures from this study are transferrable to other similar cases of designing for illiterate users.

### **1.9.4 Methodological contributions**

The methodological contribution of this thesis is a workflow that enables the illiterate and semi-illiterate pregnant women to use a multimedia based mHealth application. In the workflow, the women provide picture-based authentication, receive and retrieve multimedia messages (video and audio), set reminders and access the call functionality. The structuring of the workflow was designed and agreed upon with the illiterate and semi-illiterate pregnant women during the design process.

Additionally, using a combination of face-to-face interviews, surveys and focus group discussions, we were able to probe maternal health related knowledge, practices and attitudes of illiterate and semi-illiterate women in more depth than in previous studies. The probing was done in three phases 1) before implementation (baseline), 2) during implementation (midline), and 3) after implementation (endline) with a control and an intervention group.

### **1.10 Thesis structure**

This thesis is organized into eleven chapters namely: introduction, literature review, research methodology, the T2RoL access control security model, results from the first field study, prototype design and development, applications testing and results, application re-design, application evaluation, discussion and limitations, and conclusions and outlook.

Chapter 2 presents review of literature relevant to our area of research as follows:

- 1) Review of the state of mHealth systems for maternal health in developing countries. The literature reveals that there are efforts to use mHealth systems to support maternal health

care. However, the interventions are mainly text-based and are therefore designed for users who are literate leaving out the illiterate and semi-illiterate. The literature further shows that the interventions are not evaluated over a period of time to determine their impact on maternal health care.

- 2) Review of design and social technical issues of mHealth systems in developing countries. The review identifies privacy and usability issues in mHealth systems, and the possible solutions to the issues. It further highlights the external factors that affect mobile health systems. It is noted that there is a small number of documents in the literature combining privacy and usability which is an indicator that less is being done in addressing ways of striking a balance between privacy and usability of mHealth systems. Also, the literature suggests that external factors, which according to the review, influence privacy and usability of mHealth systems are also under researched.
- 3) Access control security models used in healthcare systems. The literature shows that access control models have been used in healthcare systems with some level of success, but they have limitations that have led to persistence of privacy, security and usability issues.

Chapter 3 discusses the research methodology used and it contains:

- 1) Details of the field studies such as the study design and setting, study participants, study procedures, data collection and data analysis.
- 2) Details of design and creation. The user centered approach, an approach suitable for design and creation is explained in detail. Iterative prototyping and the rationale for choosing it for this study are also discussed.
- 3) Model design- Hybridization of the proposed access control model. Details of model integration as the hybridization approach chosen for this research, and model testing are also discussed.

Chapter 4 presents the results from the first field study. The results for this study are user requirements, information preference and design challenges for low resource settings.

Chapter 5 discusses the T2RoL access control model. This chapter contains the integration process of RBAC, TBAC, TMBAC and location, the formal description of T2RoL access control model



and the application example of the model. Limitations of the model are also discussed.

Chapter 6 discusses the prototype design and development. This chapter presents the prototype use case model, the integration of the T2RoL access control security model into the prototype, and prototype development (technologies used and development of prototype functionalities).

Chapter 7 highlights applications testing and results. In this chapter, the applications are tested for functionality and usability, and functionality test results and usability test results are presented in detail.

Chapter 8 presents application re-design in which the application architectural design and the application workflow are discussed.

Chapter 9 discusses application evaluation. The results are categorized into qualitative and quantitative results and they are discussed under baseline, midline and end-line levels.

- 1) Baseline results: Results on participants' access to health information before the study, participant attitudes and practices are presented.
- 2) Midline results: Results based on investigations on facilitating conditions, perceived usefulness of the application, perceived ease of use of the application, norms about using the application and application acceptancy are presented.
- 3) Endline results: Results on the evaluation of the multimedia application (acceptability and usability), participants' knowledge about maternal health, their attitudes and practices are presented.

Chapter 10 contains the discussion and limitations of the study

Chapter 11 is the last chapter and it presents the conclusion and outlook

## CHAPTER 2: LITERATURE REVIEW

### 2. Introduction

A literature review was conducted to determine the state of maternal mortality in developing countries, the potential of mHealth in maternal health in developing countries, the state of the art of access control security models used in mobile health systems in developing countries, and to determine the design (security, privacy and usability) and social technical challenges of mobile systems that support healthcare in developing countries. Possible solutions to the challenges are also discussed.

### 2.1 Study approach

The review was done following the procedures of doing literature review which according to Oates[65] include procedural steps shown in Figure1 below.

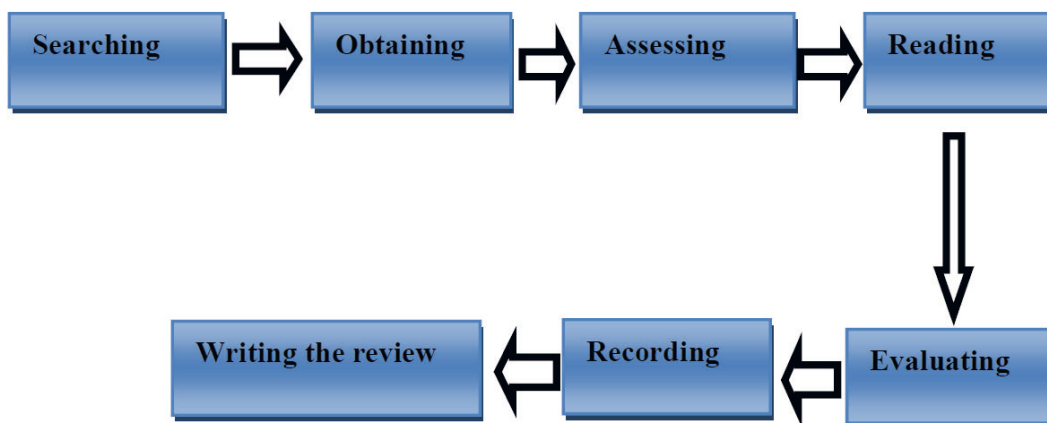


Figure 1: Procedures of doing literature review

#### 2.1.1 Search strategy for identification of papers

An electronic database search of peer reviewed papers, open search on websites of reliable institutions and personal contact to authors working in the field was done. The databases searched were PubMed Central (PMC), ACM, IEEE and IRIS; the digital library of WHO's published material and technical information. Also, an open search was conducted on websites which included World Health Organization (WHO), World Vision International and Vodafone Global enterprise. Personal information request via email to authors of relevant studies requesting for full texts, additional information and expertise were sent out. In addition, reference lists of important studies were checked for additional hints.

Search terms were grouped into seven categories: Mobile technology specific, maternal health specific security specific, privacy specific, usability specific, mHealth systems specific, external factors specific terms and developing countries specific. Each category was used as single terms or as a combination using operators ‘AND’ and ‘OR’. The following combinations are examples of search terms that were used: maternal mortality and developing countries, Privacy issues OR usability issues AND mHealth systems AND external factors.

### **2.1.2 Inclusion and exclusion criteria**

*Inclusion criteria:* Publications about mHealth in maternal healthcare in developing countries, mobile technology in developing countries, access control security models used in mHealth systems in developing countries, privacy issues and usability issues in mobile health systems, external factors that affect privacy and usability, security models used in mHealth systems that are peer reviewed and written in English were included. Reviews of available applications and documentations for systems were also included. Only papers published within the timeframe of 2001 and 2016 were included because our aim was to look out for the current and relevant issues in mobile health technology which excludes papers that are more than fifteen years old due to technological progress except for three papers on access control security that were found relevant.

*Exclusion criteria:* Studies only mentioned through web pages with limited project information, editorial discussions, summaries of literature for purposes of commentary and papers that are not peer reviewed were excluded.

### **2.1.3 Search results**

Publications identified in the search were scrutinised two rounds: First round was aimed at deletion of duplicates and revision of language and titles whereas the second round was based on the inclusion criteria as illustrated in the flow chart below.

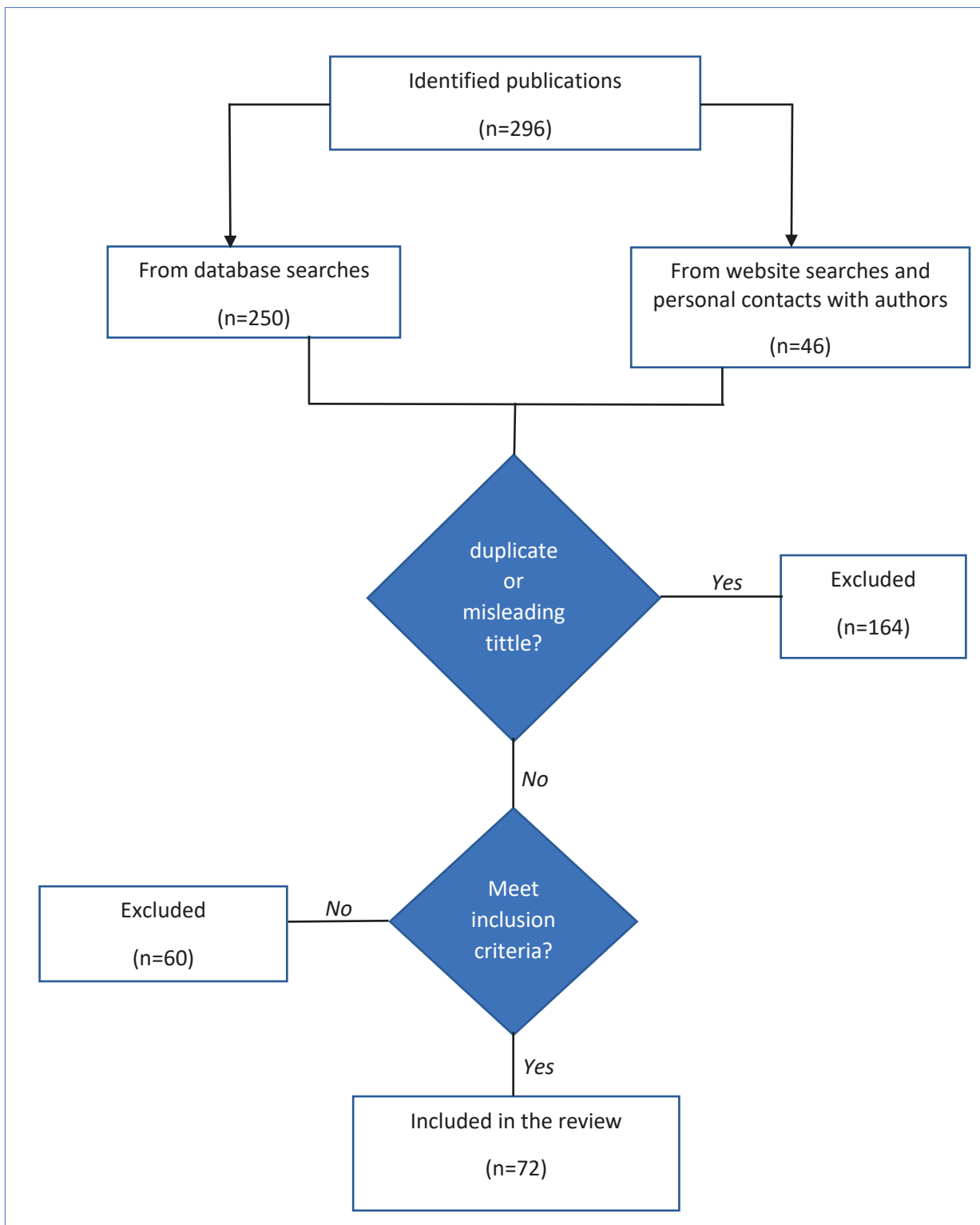


Figure 2: Search results

## **2.2 mHealth systems for maternal health in developing countries**

mHealth apps are being used in maternal healthcare in developing countries to provide support to pregnant and postpartum women such as provision of maternal health related information, consultations, and to support health practitioners and care takers in making follow-ups and decision making among others. This support may be in various forms such as health-related messages, reminders, alerts, voice calls and surveys.

### **2.2.1 Interventions**

#### **Wired Mothers[66]**

The wired mothers intervention consists of an automated short messaging service (SMS) system providing wired mothers with unidirectional text messaging, and a mobile phone voucher system providing the possibility of direct two-way communication between wired mothers and their primary health care providers. The aim of the SMS component was to provide simple health education and appointment reminders to encourage attendance at routine antenatal care, skilled delivery attendance and postnatal care. The wired mothers software was developed to automatically generate and send text messages to registered phone numbers throughout the pregnancy until six weeks after delivery. Based on the gestational age of the women at first antenatal care visit, the wired mothers software creates an individual pregnancy time schedule. A welcome message is sent at registration regardless of gestational age. Thereafter, the content of messages varies depending on individual gestational age. The frequency is two messages per month before gestational week 36 and intensifies to two messages per week from gestational week 36.

The wired mothers intervention was piloted and results from the study claim that the intervention significantly increased the number of pregnant women receiving the recommended four antenatal visits during pregnancy. Findings further show that there was improvement towards receiving preventive health services, more women attending antenatal care and more women with antepartum complications identified and referred.

However, this intervention's usability is tailored to literate women because it only utilises SMS. It also does not implement any access control mechanism to protect the health information sent, making it prone to security attacks.

### **Mobile Midwife[67]**

Mobile Midwife is a mobile application that sends timely messages in local languages to specified clients, mostly expectant mothers and new parents. The messages give relevant information concerning health and notify the client in instances of a missed appointment. Currently, this project is implemented in four regions in Ghana: the upper West, Central, greater Accra, and Volta Regions but it was first implemented in upper East region of Ghana. These regions were rated among the poorest regions, recording the lowest levels in use of antenatal services.

The main findings of this intervention were that combining modern and traditional practices enabled women to gradually gain trust in Mobile Midwife's counselling and attempted to balance between myths and reality regarding nutrition in pregnancy. The intervention further supported women in decision making regarding seeking essential obstetric care and understanding the importance of professional care in pregnancy and childbirth, and recognizing ill health in newborns.

This intervention utilises SMS making it unusable by the illiterate women. It has also not been evaluated to determine its impact on maternal healthcare. There is no mention of utilising any access control to safeguard the health information.

### **RapidSMS[68]**

The RapidSMS is an mHealth system with a two-way communication system between community health workers (CHWs) and health centres. CHWs are the first point of contact with the health system and create a link between communities and health facilities. Each village in Rwanda had three elected CHWs, one of whom oversees maternal and child health, and all of whom could access the system. In brief, CHWs in Rwanda were given mobile phones to report data on maternal and child health indicators using text messages. RapidSMS data were collected during pregnancy, and after birth until the child was 2 years of age, and included several indicators: antenatal care, delivery, maternal mortality, postnatal care, anthropometric measurements and child mortality. The system generated automatic reminders for clinical appointments that were sent to the CHW, including antenatal care, the probable delivery date and postnatal care, with the aim of increasing routine care attendance and the proportion of health facility deliveries. Mothers were not messaged

directly. RapidSMS was also designed to quickly link mothers to emergency obstetric care by notifying ambulance services.

Unlike most interventions, RapidSMS was evaluated in Rwanda between 2012 and 2016 using interrupted time series analysis and data routinely reported monthly by public health care centres. The evaluation was based on four indicators: completion of the four antenatal visits, malnutrition screening, deliveries in a health facility and postnatal care visits.

The findings were that the intervention was successfully implemented due to the high number of messages that community health workers in Rwanda sent (9.3 million messages) using RapidSMS. Findings further found that combining implementation of the RapidSMS with additional support such as training, supervision and provision of equipment increased the use of maternal and child health care services, while implementing the RapidSMS intervention alone was not effective. This suggests that mHealth programmes alone may be insufficient to improve the use of health services. Instead, they should be considered as a part of more comprehensive interventions that provide the necessary equipment and health system capacity to support them.

This intervention implements the conventional username and password to provide access control to health information in the application. However, it is SMS based and therefore it is not usable by illiterate users.

### **MomConnect[69]**

The aims of MomConnect are to connect pregnant women to health services; to encourage pregnant women to attend antenatal clinics as early as possible, preferably before 20 weeks of pregnancy; and to enable these women to interact with the health system. When pregnant women register for MomConnect, the registration is linked to an electronic database and includes several variables: the woman's identification number; her mobile phone number; the estimated duration of pregnancy and a unique clinic identification number. Once registered, women receive free SMS linked to the stage of their pregnancy. They continue to receive messages postnatally, linked to the age of their infant, up to 1 year of age. The women can also rate the system through a survey, ask for additional information around any topic relating to their pregnancy in the form of SMS and log a complaint or compliment about the service that they received, using an SMS message. This intervention has been deployed and registered nearly half of all pregnant women in South Africa.

The findings indicate that the intervention has improved the quality of health care provided to the pregnant women. For instance it has reduced drug shortages and stock-outs, and held managers accountable through the direct complaints made by the beneficiaries of the services via the intervention.

However, this intervention is text based utilising surveys and SMS making it impossible for illiterate women to use it.

### **mHealth expert system[70]**

This mobile application is designed to help care givers in rural India to manage pregnancy related information and to provide pregnancy and childcare advice. The application is embedded with an expert system with an automated advisory component that helps in determining the risk conditions of the pregnancy and suggesting the treatment options. The care givers require minimal medical expertise to use the application which means that the care givers can use it to give assistance to patients before trained health practitioners are available. In addition, the mobile application is not dependent on network availability.

The findings show a reduction in the registration and record retrieval time, reduced waiting time for consultation, and an increase in the clinic's capacity. However, the system is still deployed at the clinic to measure its performance over a period.

This intervention utilises text and voice which makes it partially usable by illiterate users. The illiterate users can use the voice functionalities, but they are unable to use the text-based functionalities of the intervention.

### **Mobile application and patient-held smartcard (Vitira Health platform)[71]**

This is an mHealth platform that provides maternal health data to pregnant women using a smartcard and a mobile phone app. It incorporates a Web-based database, smartcard technology, and a mobile app. The Vitira Health platform encrypts health data in storage and during transmission on the smartcards, the mobile app, and database servers. Health data is input and stored by authorised administrators in a database and the data is encrypted on a Quick Response



(QR) code embedded on the smartcard, which is then given to the pregnant woman/ patient. The mobile app is then used by skilled birth attendants to scan the smartcard (QR code) and view patients' data.

This platform was developed and piloted in a demonstration study and findings show that it is possible to develop a patient-held smartcard and an mHealth platform that captures vital health information which can be accessed at the point of delivery using a mobile phone-based app without an Internet connection. However, it was not evaluated to determine its acceptability and usability by the participants, and its impact on maternal health care.

The intervention utilises text and smartcard. Illiterate users can only own smartcards on which their health information is embedded but they are unable to access that information because the other functionalities of the intervention are text based.

### **Aponjon[72]**

The Aponjon is an mHealth service that provides information about pregnancy, giving birth, newborn care and nutrition to pregnant women and new mothers through text messages and voice messages in Bangla language. The recorded voice messages are limited to one minute whereas the text messages are limited to 161 characters. Each participating woman receives two messages per week, while her nominated family member gets one message per week at 0.02 US dollars per message.

Although initial findings show that low-cost mobile phone educational services may work as catalysts in improving maternal and child health behaviour in resource-limited settings, Aponjon is currently under deployment and its impact on maternal health care is yet to be determined.

The researchers intend to undertake additional research on Aponjon by exploring participants' perceptions and experiences of the Aponjon intervention with the aim of providing information to help develop a national framework for an integrated health system.

The intervention uses text messages and voice messages making it usable by both the illiterate and literate women.

### **mMom[73]**

The mMom intervention is an integrated mHealth system designed to improve maternal and infant health knowledge, and behavior among women in remote areas of Thai Nguyen, Vietnam. It supports community health workers to monitor pregnancy and new motherhood in community women. The intervention consists of two SMS message programs designed to support women's health during pregnancy and new motherhood.

The first SMS program consists of 75 SMS messages focused on prenatal care and offers tips on how to remain healthy throughout pregnancy and promote healthy fetal development. These messages are sent two to three times per week from the 5th week to the 42nd week of pregnancy and cover topics like danger signs, nutrition and antenatal care visits. The second SMS program consists of 71 messages, is initiated once the infant is born and provides information on women's postpartum care and infant development. The messages are delivered one to two times per week for the first year of the baby's life and covers topics like contraception, breastfeeding and immunization for the baby. Both SMS programs were designed to include four types of messages: informational and educational, reminder, interactive, and scanning messages. Informational, educational and reminder messages provided one-way information and reminded women to take critical actions, such as getting a tetanus immunization. On the other hand, interactive or three-way messages requested women to respond to monitoring questions, such as whether they have recently visited the health centre. If women do not respond, or if their responses suggest a risk, the database automatically informs that individual participant's health worker so that they may reach out to the woman. The intervention has not yet been evaluated to ascertain its impact on maternal healthcare.

This intervention is only usable by women who can read and write because it utilises text-based SMS.

### **Baby+[74]**

Baby+ is a localized mobile application designed to support pregnant women in Pakistan by helping them to keep track of their pregnancy and give them more control over it by providing them with relevant information. Baby+ enables the women to customise their personal health records during pregnancy and have them verified by a gynaecologist. The women can record their health records such as weight, track weight gain over time and daily food intake for example the daily intake of

fruits and vegetables. The women can access an exercise plan recommended by the gynaecologist based on the woman's condition and stage of the pregnancy and how to perform the exercises. It also has a section for answering local myths and Islamic FAQs, a section on prayers, Quranic chapters and verses to support the women daily; a push notification system for completing different tasks for instance reminding the women about daily logging in and information about pregnancy weeks; a guide with tips on preventing risky behaviours, and a baby tracker.

Much as most of the users of the application were positive about using it to boost their confidence about pregnancy and increasing their knowledge about maintaining a healthy lifestyle during pregnancy, there were no studies made to determine its impact on the women and maternal health in general. It was rather tested for functionality, visual appeal, and user experience.

The intervention is text and graph based making it unusable by the illiterate women because they are unable to input text-based data or navigate to access information such as FAQs and prayers embedded within the intervention.

### **Short message service advice programme[75]**

This mHealth intervention offers expectant mothers in rural China a free package of short messages regarding pregnancy and childbirth via mobile phones. The intervention comprises of 148 text messages and these messages are tailored to each mother's gestational week. The messages are sent from the time of enrolment until delivery. It also sends reminders for prenatal visits and hospital delivery, messages to encourage the women to take up antenatal care.

The researchers of this intervention hypothesise that SMS might reduce inappropriate weight for gestational age, including small for gestational age (SGA) and macrosomia but the intervention is still in pilot status and therefore its impact is not yet determined.

This intervention is designed for literate women because it is SMS based and can therefore not be usable by women who cannot read and write.

### **mHealth intervention for documentation[76]**

This intervention is designed as a mobile support for community health workers/ Health

Surveillance Assistants in Malawi. The Health Surveillance Assistants received one-way short message services (SMS) from the mHealth coordinator at the National Statistical Office with motivational and data quality content regarding documentation of pregnancies. It is based on the Frontline SMS messaging platform.

The findings of this mHealth intervention indicate improvement in documentation of pregnancies with notable increase in documentation of out-migration and adverse pregnancy outcomes.

This intervention is based on SMS and is therefore it is not usable by users who are unable to read and write.

### **TulaSalud: An m-health system for maternal and infant mortality reduction in Guatemala[77]**

This mhealth intervention aims at supporting community facilitators in rural communities who perform health prevention, promotion and care for pregnant women and children below 1 year of age. This initiative enables the community facilitators to consult when they have questions, receive continuous training, send clinical information related to the cases they attend to and do health related sensitization, emergency transfers and promotion of community health via distance learning sessions in the local languages. The communication is done via free telephone calls, audio-conferencing, and a mobile application. The mHealth application enables the community facilitators to register the demographic and clinical data of the patient and the care provided, transfer, process and visualise the clinical and epidemiological information obtained. It also enables monitoring health information of pregnant and postpartum women, to identify danger signs or risk factors and prevent and treat health problems before they turn into serious complications.

The project reported a statistically significant decrease in maternal mortality and in child mortality in the intervention areas which were selected for their high maternal and infant mortality rates. The maternal and child mortality reduced and became lower than the provincial average (which includes urban areas).

This intervention utilises audio inform of phone calls and audio conferencing, and texts making it partially usable by the illiterate. Whereas the illiterate can use the audio functionalities in the intervention, they are unable to use the mhealth application that requires capturing text-based data.

### **A two-way SMS service[78]**

The intervention is a custom-built, automated software to send and receive messages from pregnant and postpartum women in Kenya. It consists of 14 messages sent at different times. Eight messages are sent during pregnancy at weeks 28, 30, 32, 34, 36, 38, 39, and 40. The remaining 6 messages are sent weekly for the first 6 weeks after delivery. The messages are based on the recipient's gestational age, name, preferred time, date of delivery, desired language, and infant's name. The participants can send SMS, call, or request a call by sending a free 'call back' message.

The findings indicate that text messaging improved maternal attendance at postpartum prevention of mother-to-child transmission (PMTCT) clinic visits and led to higher rates of infant HIV testing. The results further suggest that SMS can be leveraged to bridge gaps in the cascade of care for mother–baby pairs in PMTCT programmes.

Whereas illiterate women make use of calls, the SMS component of the intervention is not usable by them because it is text-based, yet it was reported that the text messaging was the more successful than the calls.

### **mHealth intervention for service delivery[79]**

This intervention is a customised FrontlineSMS based application integrated with a mobile phone system and the central server that enables health extension workers (HEWs) to reach out to health centres in rural Ethiopia. The HEWs fill maternal, child and stock related forms and submit them to the central server which then sends reminders about scheduled date of antenatal and postnatal visits, expected date of delivery, immunization schedule, and vaccine and contraceptive stock status. The intervention further supports management of emergency patients through referrals. HEWs call health centres in emergency referral situations so that the health centres are prepared to receive patients.

The findings of the study show that the SMS based mobile telephone intervention could indeed improve the effectiveness of frontline HEWs in rural Ethiopia, primarily in the area of improving access to antenatal, delivery and postnatal services. The study indicates that the number of antenatal visits, percentage of delivery attended by health workers improved and it also facilitated the work process of health extension workers. No significant impact was observed in the rate of contraceptive utilization and immunization coverage.

The intervention utilises text-based forms, SMS and phone calls which makes it partially usable by the illiterate. The illiterate can make phone calls but are unable to use SMS which is a core functionality of the intervention.

### **Short message service for breastfeeding[80]**

This intervention aims at assessing the effect of short message service (SMS) communication on facility delivery, exclusive breastfeeding, and contraceptive use among women in Kenya. SMS content tailored for maternal characteristics, and pregnancy or postpartum timing are sent to five categories of postpartum women (adolescents, first time mothers, routine, women with a previous caesarean section and those with multiple gestations). The SMS were either educational, motivational or questions (required response from the participant) and covered topics such as antenatal care, pregnancy complications, family planning, infant health, infant immunization and visit reminders.

The SMS intervention resulted into longer exclusive breastfeeding and early use of contraceptives during the postpartum period. These findings suggest that incorporating SMS messaging into maternal, newborn, and child health care has the potential to engage patients and support the use of essential services, and ultimately improve the health of women and infants.

This intervention is SMS based and therefore it is not usable by postpartum women who are not able to read and write.

### **The SUSTAIN application[81]**

SUSTAIN is a smartphone-assisted application designed to assist community health workers in Tanzania with data collection, education delivery, gestational danger sign identification, and referrals during household visits. The community health workers register pregnant women at the village level as soon as they are identified. After registration, the application prompts community

health workers to monitor the status of the women throughout pregnancy and after delivery. During prenatal household visits, the application directs the community health workers to specific health counselling topics, lessons and messages based on the woman's gestational age, and her answers to various diagnostic questions. The application further reminds the community health workers to counsel women on the benefits of seeking antenatal care, developing a birth plan, and seeking skilled birth assistance at health facilities. The application also assists with identifying danger signs, flags women who require immediate referral to health facilities, and reminds community health workers to follow up with women that were previously referred.

The researchers found no significant impact on delivery in health facilities because it was already very high at baseline, but reported significant impacts on use of modern contraceptives, consumption of iron-folate tablets during pregnancy, antenatal care uptake, and several birth preparedness practices that facilitate facility delivery. Previous delivery at the health facility and living close to the facility were stronger predictors of delivering at a health facility.

The SUSTAIN application is text-based making its usability impossible for possible users who are illiterate.

### **2.2.2 Summary of the mHealth apps usage in developing countries**

<b>mHealth app</b>	<b>Support group</b>	<b>Role</b>	<b>Design requirements</b>	<b>Usability by illiterate</b>	<b>Preliminary impact</b>	<b>Country of implementation</b>
Wired mothers[66]	Nursing mothers	To improve antenatal care attendance	SMS based	No	<ul style="list-style-type: none"> <li>• Increased adherence to ANC</li> <li>• Increased referral of antepartum complications</li> <li>• More access to preventive health services</li> </ul>	Zanzibar
Mobile Midwife[67]	Pregnant and nursing mothers	To provide women with advice during pregnancy and after childbirth	Utilise SMS and voice calls	Partially	<ul style="list-style-type: none"> <li>• Women gained trust in mobile midwife counseling</li> <li>• Improved decision making regarding maternal health care.</li> <li>• Balance between myths and reality regarding nutrition in pregnancy</li> </ul>	Ghana
RapidSMS[68]	Community health workers	To inform health centres about the health of pregnant and postpartum women	SMS based	No	<ul style="list-style-type: none"> <li>• Increased use of maternal and child health care services</li> </ul>	Rwanda
MomConnect [69]	Pregnant and postpartum women	To provide maternal health service and improve quality of	Utilise SMS and surveys	No	<ul style="list-style-type: none"> <li>• Improved quality of health care provided to the pregnant women</li> <li>• Reduced drug</li> </ul>	South Africa



		service on health services			shortages and stock-outs	
mHealth expert system[70]	Healthcare workers	Help healthcare workers give relevant pregnancy and childcare advice	Utilise text and Voice	Partially	<ul style="list-style-type: none"> <li>• Reduced registration and record retrieval time</li> <li>• Reduced waiting time for consultation</li> <li>• Increase in the clinic's capacity</li> </ul>	India
Mobile application and patient-held smartcard (Vitira health platform)[71]	Pregnant women	To access prenatal test results through patient-health smart card and mobile application without the need for internet connection	Utilise text and smartcard	No	<ul style="list-style-type: none"> <li>• No evaluation done yet</li> </ul>	Nigeria
Aponjon[72]	Pregnant and postpartum women	To provide health related information to pregnant and postpartum women	Utilise SMS and Voice messages	Yes	<ul style="list-style-type: none"> <li>• Impact on maternal health care not yet determined</li> </ul>	Bangladesh
mMom[73]	Pregnant and postpartum women	To educate women on prenatal and postnatal health	SMS based	No	<ul style="list-style-type: none"> <li>• No evaluation done yet</li> </ul>	Vietnam
Baby+[74]	Pregnant women	Keep track of pregnancies and provide advice	Utilise text and graphs	No	<ul style="list-style-type: none"> <li>• Boosted confidence about pregnancy</li> <li>• Increased knowledge about maintaining a healthy lifestyle during pregnancy</li> </ul>	Pakistan
Short message service	Pregnant women	Inform pregnant women about	SMS based	No	<ul style="list-style-type: none"> <li>• No evaluation done yet</li> </ul>	China

programme[75]		pregnancy and childbirth				
mHealth intervention for documentation [76]	Health assistants	Improve documentation of pregnancies	SMS based	No	<ul style="list-style-type: none"> <li>Increased documentation of out-migration and adverse pregnancy outcomes</li> </ul>	Malawi
TulaSalud[77]	Community facilitators	Enable community facilitators to provide health care services to pregnant women in local communities	Utilise audio (phone calls and audio conferencing) and text.	Partially	<ul style="list-style-type: none"> <li>Decrease in maternal mortality and child mortality</li> </ul>	Guatemala
Two-way SMS service[78]	Postpartum women	Prevention of HIV transmission from mother to child	SMS based	No	<ul style="list-style-type: none"> <li>Improved attendance of postpartum prevention of mother-to-child transmission clinic visits</li> <li>Higher rates of infant HIV testing</li> </ul>	Kenya
mHealth intervention for service delivery[79]	Community health workers	To connect Community health workers to health centres	Utilise text (SMS and forms) and phone calls	No	<ul style="list-style-type: none"> <li>Increased adherence to ANC</li> <li>Increased deliveries attended by health workers</li> <li>No significant impact on contraceptive utilization and immunization coverage</li> </ul>	Ethiopia

SMS for breastfeeding[80]	Postpartum women	To improve exclusive breastfeeding and postpartum contraception	SMS based	No	<ul style="list-style-type: none"> <li>• Longer exclusive breastfeeding</li> <li>• Early use of contraceptives during postpartum period</li> </ul>	Kenya
The SUSTAIN smartphone application[81]	Healthcare workers	To enable healthcare workers to provide healthcare services to pregnant women	Text based	No	<ul style="list-style-type: none"> <li>• Increased use of modern contraceptives</li> <li>• Increased consumption of iron-folate tablets during pregnancy</li> <li>• Increased adherence to ANC</li> <li>• Adoption of birth preparedness practices</li> <li>• No significant impact on delivery in health facility</li> </ul>	Tanzania

Table 2: mHealth apps usage in developing countries

The review of the interventions shows that majority of the interventions are text based and this is a clear indicator that they are designed for users who can read and write making them unusable by the illiterate. In addition, the review further confirms that majority of the interventions have not been evaluated to ascertain their impact on maternal health care.

## 2.3 Challenges of mHealth

It is important to note that some of the contents in this sub-chapter were published in a systematic review paper.

Much as the mobile health systems have registered tremendous progress, they have been faced with several privacy and usability issues such as identity theft, eavesdropping and third-party attacks

among others. Different researchers have come up with solutions such as use of access control security models, user authentication and encryption but the issues persist.

Even though it is fundamental to consider privacy and usability of mobile systems especially mHealth systems that deal with sensitive health information, it remains a challenge to strike a balance between the two. Systems that have emphasized privacy have low usability while on the other hand systems focused on usability are less secure[82]. In addition, it is difficult to strike a balance between privacy of users and the desire to monitor communications by, say governments or attackers looking for individual gains. For instance, the terror attacks in the united states of America led to increased monitoring of communications by the government[83]–[85] thus infringing on the rights of individuals. There is also an issue of the inevitable trade-off between authenticity versus privacy, and anonymity versus accountability.

External factors such as limited application development guidelines and differences in cultures have also contributed to privacy and usability issues in mHealth systems. For instance, in some cultures people consider sharing of mobile devices normal. The sharing phenomenon has reduced the privacy of users which has in turn negatively impacted on system usability. People who share mobile devices tend to avoid use of mHealth systems that capture sensitive information. This is due to the fear that people with whom they share the devices may have access to their private information.

Due to the sensitivity of health information, there is an ethical need to equip mobile health systems with adequate security measures to safeguard patient's information. However, these systems should also be usable by the intended users. Much as some of the available mobile systems try to strike a balance between security of health information and system usability, there is room for improvement.

## **2.4 Design and social technical issues of mHealth systems in developing countries**

### **2.4.1 Privacy and usability issues in mHealth systems**

Findings from the review have been discussed in three categories, namely privacy and usability issues in mHealth systems, possible solutions to the issues and external factors that affect mobile health systems.

#### *Privacy and usability issues*

Literature has confirmed that there is a close link between usability and security of mobile system. This poses a challenge of developing mobile systems that are highly secure and at the same time usable[82]. Results from the review further show that there are a number of privacy and usability issues that affect mobile systems most especially mobile health systems that deal with sensitive patient information. Privacy and usability issues in mobile systems are summarized in the table 3 and table 4 below.

<b>Security and privacy issues</b>	<b>Beach et al.[86]</b>	<b>Arapinis et al.[87]</b>	<b>Treese and Stewart[83]</b>	<b>Adhikari et al.[88]</b>	<b>Arora[89]</b>	<b>Kotz[90]</b>	<b>Bajwa[91]</b>	<b>Vodafone Global enterprises[92]</b>	<b>Zubaydi et al.[93]</b>	<b>Corallo et al.[94]</b>
<i>a) Identity issues</i>										
Indirect anonymity/ K- anonymity problem	X									
Authentication and linkability attacks		X	X					X		
identity loss, theft or sharing	X	X	X	X	X	X	X	X	X	X
<i>b) Access issues</i>										
Direct anonymity	X								X	
Eavesdropping	X	X	X				X		X	
Third party attacks							X		X	
Denial of Service attacks									X	
<i>c) Disclosure issues</i>										
Audit trails			X		X				X	
Data security breaches		X		X	X			X	X	
Unprotected consumer data			X	X					X	X

Table 3: Privacy issues in mHealth systems

The privacy issues have categorized into identity, access and disclosure issues. Identity issues are looked at as challenges that emerge as the users try to prove authenticity for example through provision of usernames and passwords. On the other hand, access issues as challenges that result

as users use the services provided by the system for example unauthorized access and having a third party tapping the information exchange as the user interacts with the system. Unlike identity and access issues, disclosure issues have to do with the personal information of the user for example as the user tries to transmit information.

### **Identity issues**

K-Anonymity as one of the identity challenges which according to Winfield et.al.[86] results from use of information from an anonymous user to identify his personality without consent. For example, use of someone's preferences such as shared pictures, favorite shopping stores, etc to get his identity. Authentication and linkability attacks are another identity issue common to mHealth systems[83], [87], [92]. This has to do with who has access to the information in the system for example in health systems that support voice collaboration, it may be hard to identify if it's the person/patient intended to get the information is actually the one being communicated to. Another identity challenge is identity loss, theft or sharing[82], [86], [89], [91], [95]–[97]. Depending on the situation of the users, their identity may be lost or stolen for example a user may lose a phone with personal information or a notebook in which access information to systems have been written. In some situations, the user may willingly share identity information for example when a user needs information urgently from the system but at that particular time have no access, they may be prompted to share their identity information with another person who is willing to help. All these interfere with privacy of users and the security of the information captured by these systems.

### **Access issues**

Surveys by Winfield et.al.[86] and Fatma et.al.[93] identified direct anonymity as one of the access challenges in mHealth systems. Some applications require users to grant access to their private information such as profile details if they are to access and utilize the services provided through the system. Eavesdropping is another major issue in mobile systems according to researchers[83], [86], [87], [91], [93]. This ranges from stealing a user's ID and masquerading as that user, intercepting conversations to altering user information among others. Third party attacks are also prevalent in mobile system[83], [91], [93]. For example, an mHealth system may be linked to third parties such web servers and insurance companies with whom it shares private patient information, and this may violate the privacy of the user/patient. Sometimes attackers may disrupt the flow of information between users, applications and servers leading to denial of service attack.

According to Ronald et al.[93], denial of service attacks create a bigger negative impact in health monitoring systems whose services need to be available all the time.

### Disclosure issues

According to the reviewed literature, there are three major disclosure issues affecting mobile systems i.e. audit trails, data security breaches and unprotected consumer data[83], [87]–[89], [92]–[94]. Audit trails such as keeping record of who has downloaded the application, ratings of application and billing records may violate the privacy of the users and pose a threat to the security to their information[83], [93]. In some instances, medical personal are able to access and view patient records in the mHealth apps without the consent of the patients[88]. In addition, some applications have trackers that track user behavior[93] and all these are a breach of data security. Most of the applications do not encrypt the data entered by the users[88], for example an intruder can know what the user is suffering from by just looking at what application the user is using and then check out the details in the app. In addition, applications with a voice call function show telephone numbers to call recipients which intruders may use to map to user’s information. Furthermore, transmission of information is often over airwaves that are not protected[94] and all these may lead to disclosure issues in mobile systems.

### Usability issues

Usability issues have been divided and discussed in four categories i.e. accuracy, efficiency, effectiveness and user satisfaction as summarized in the table below.

Usability issues	Vodafone Global enterprise[92]	Zubaydi et al.[93]	Johnson & Willey[98]	Cummings[95]	Brostoff and Sasse[99]	Al-Saadi et al.[100]	Kumar et al.[101]	Mourouzis et al.[102]	Zhang and Adipat[103]
Accuracy issues									
Memorability and cognition challenges related to authentication		X			X				
Input mechanism and size of screen						X	X	X	X
Efficiency issues									

User's understanding of encryption mechanisms		X							
Slow connectivity								X	X
Low processing power								X	X
Effectiveness issues									
Difficult to use user interfaces						X	X		
Size of the screen						X		X	
User satisfaction issues				X					
Un-subjective user assessment		X		X					
Un-secure systems	X	X	X						

Table 4: Usability issues in mHealth systems

According to Ronald et al.[82], usability can be looked at in four categories i.e. effectiveness, accuracy, efficiency and user satisfaction. While efficiency focuses on the amount of time the user takes to complete a task, accuracy is concerned with how accurate the information input in the system is. On the other hand, effectiveness focuses on the ability of the user to do a task while satisfaction looks more into the user's acceptance of the system. There are a number of issues that affect usability of mobile systems as summarized in the table above and discussed below.

### Accuracy issues

One of the major accuracy issues is memorability and cognition challenges related to authentication[82], [99]. In most cases, users are required to input their authentication details such as usernames and passwords with 100% accuracy. Moreover, some systems require use of passwords that are a combination of numeric, text and other complex characters aiming at enhancing the security of user information. However, memorizing such passwords may be difficult especially if the users have many of such systems they are using. This may prompt the user to frequently request for resetting of passwords or write them down which may lead to privacy threats. The screen size and input mechanisms of mobile devices may also interfere with the accuracy of input data[100], [102]. Mobile devices have small screens and, in most instances, have tedious input mechanisms which may interfere with the accuracy of information the user inputs. For example, some mobile devices have small buttons which also have various input functions whereby



a user may mistakenly press two or more buttons at the same time leading to inaccurate data inputs. Moreover, the user may be required to press a similar button many times to get a certain input, in cases where the input is encrypted such as passwords, the user may end up inputting inaccurate data.

### **Efficiency issues**

A slow or fast connectivity may determine the efficiency of a system. Mobile devices often have slow connectivity which is in some cases unreliable[102], [103] and this negatively impacts applications that rely on connectivity, most especially mHealth applications that deal with real time critical information exchange. Also, processing power of a devices may determine the efficiency of the applications it runs. Mobile devices are characterized by low processing power[102], [103] and this increases the amount of time the user takes to complete a task. This may render some applications inefficient and worse still unusable on devices with very low processing power.

### **Effectiveness issues**

In a systematic review of usability and testing challenges in mHealth by Tareq et al.[100], difficult to use user interfaces was ranked as the biggest usability challenge followed by screen size of the devices. User interfaces allow the user to interact with the system and therefore if they are poorly designed, they may render the applications unusable. For instance, if the interfaces have no help function to guide the user on the format of the data required such as dates and no meaningful error correction prompts, the user may find it hard to complete some tasks. In addition, if the interfaces require a lot of data input, bearing in mind the size of the screen and input mechanism of mobile devices, the user may not be able to complete some of the tasks.

### **User satisfaction issues**

User assessment that is not subjective is one of the issues that may hinder usability of an application[82], [95]. Regardless of how effective or efficient the system is, user satisfaction determines whether the system will be used or not. It is therefore paramount for users to do a subjective assessment of the application before it is put into use. In addition, how secure the application is and the ability of the user to identify secure systems also contributes to user satisfaction[82], [92], [98]. Applications that the users perceive as secure are more likely to be

acceptable to users who intend to keep their data private, most especially applications that deal with sensitive patient information.

#### **2.4.2 External factors contributing to privacy and usability issues of mHealth systems**

There are a number of external factors that affect privacy and usability of mobile health systems. Scarcity of mHealth policies, strategies and standard guidelines for development of mHealth applications and failure to enforce the few that are available is one of these factors. Most countries have no mHealth policies and strategies, for instance in a health debate series by Vodafone[104], of all countries worldwide, only one quarter have a national policy or strategy on telemedicine. Enforcement is also lacking. This is evidenced by some developers who tend to ignore privacy measures such as authentication which may be a vital requirement for all mobile systems that deal with sensitive information. For instance, in a review of 20 most popular mHealth applications by Rajindra et al.[88], only two apps (10%) required the user to provide user authentication information before login. In another review of 19 mHealth applications for iOS, Blackberry and android devices by Kharrazi et al.[105] also found that seven of them had no security measures for user authentication. Lack of user authentication may lead to issues like eavesdropping and identity theft among others.

Moreover, some developers share user information with third parties, in some cases without the user's knowledge/consent. In the same review by Rajindra et al. 13 apps (65%) out of the 20 that were review shared user information with third parties such as advertisers. This may lead to data security breaches, increase in third party attacks and linkability attacks among others.

However, some countries with established policies and guidelines for eHealth also have a unique set of challenges when it comes to privacy and usability of mHealth systems. For instance, as a result of frequent terror attacks, some countries have developed national security legislations that may permit surveillance which may go as far as accessing personal information such as health information of individuals in case of suspicion[83], [106], [107]. A good example is in the US where the government can impose a mandatory implementation of eHealth systems in some departments and may have access to health information when the need arises[107]. This increased monitoring by governments violates the privacy of people and may hinder individuals from using

health applications due to fear of having their sensitive health information accessed by the authorities. In addition, some countries have regulations and guidelines that only cover a subset of mHealth applications. For example, the Food and Drug Administration (FDA) in the US only regulates applications that are likely to pose a risk to patients' safety if they do not function as intended[84]. This leaves out applications designed for record archiving, retrieving and sharing. As a result, users may not trust the credibility of these unregulated applications and then avoid using them.

In addition, cultural differences also affect privacy and usability of mobile systems[102], [108]. For instance, in some cultures, sharing of mobile devices is considered normal and as a result of this sharing phenomenon, information sent to or/and stored on a shared device may end up being accessed by people for whom it wasn't intended. As a result, this sharing phenomenon may discourage a user of a shared device from using an application especially if that application captures sensitive information such as health information that the user may prefer to keep private.

Human factors such as age, personality, literacy level and cognitive ability also play an important role in usability of systems[92], [102], [109]. For instance, systems that appeal to the young age brackets may not appeal to the older age brackets. Likewise, the design of systems meant for people with low literacy levels or people with cognitive challenges may have requirements that may not apply to systems meant for people with higher levels of education and good cognitive abilities. For example, a system developed for people who cannot read and write may not utilize text formats but rather use audio, video and pictorial formats while systems meant for literates may utilize text and all the other formats. These human factors determine difficulty or ease with which a user will interact with the application and consequently may influence the acceptability of the application.

Lastly, economic situations and poor infrastructure may hinder usability of mHealth systems[97]. For example, in some rural settings in developing countries, there is limited access to network connection which may limit use of applications that depend on network connection. In addition, poor network hinders implementation of mobile health application, a case in point is the HMRI project in India that had 50% of its services via call centre interrupted due to network issues[110]. Furthermore, some areas are characterized by power shortages. This implies that people in these areas may not be able to charge their mobile devices and use them all the time. In rural areas especially in developing countries where there is no power or power is unreliable, people charge

their mobile devices at charging centres in trading centres or towns that have generators or other reliable power sources. This means that people have no access to their devices during the time when these devices are at the charging centres. This may discourage owners of these devices from using applications that require the user to have access to the device all the time. In addition, applications that deal with sensitive information such as health information may be avoided by these possible users because the security of the information and the devices while at the charging centres may be questionable.

In order to reduce privacy and usability issues in mHealth systems, there is need to address external factors that have been found to have a negative impact as discussed above. This may increase privacy of users and in the long run increase acceptability and usability of mHealth systems.

### 2.4.3 Possible solutions to privacy and usability issues

The solutions have been categorized based on the issues they deal with i.e. Solutions to identity, access and disclosure issues (privacy issues) and Solutions to accuracy, efficiency, effectiveness and user satisfaction issues (usability issues) as summarized in table 5.

Possible Solutions	Beach et al.[86]	Arapinis et al.[87]	Arora[89]	Treese and Stewart[83]	Adhikari et al.[88]	Kotz[90]	Bajwa[91]	Vodafone Glob. Ent[92]	Zubaydi et al.[93]	Corallo et al.[94]	Kaida et al.[82]	Johnson and Willey[98]	Brostoff and Sasse[99]	Al-Saadi et al.[100]	Mourouzis et al.[102]
<i>Solutions to identity, access and disclosure issues</i>															
Encryption		X	X		X	X	X	X		X					
User authentication e.g. passwords			X		X	X		X	X	X					
Erasing identity, Remote wiping and disabling				X	X		X		X						
Access control security models e.g. RBAC				X	X	X									
Avoid unsecured Wi-Fi connections			X		X										

Use firewalls					X		X								
<i>Solutions to accuracy, efficiency, effectiveness and user satisfaction issues</i>															
User involvement and iterative design											X				X
Higher processing power															
Appropriate testing											X			X	X
Password resetting													X		
Better input mechanisms															X
Increase login attempts													X		
Increase screen size														X	
Reduce input to be typed															X

Table 5: Possible solutions to privacy and usability issues in mHealth systems

#### *Solutions to identity, access, and disclosure issues (privacy issues)*

Researchers and developers have come up with solutions to privacy issues[83], [86]–[90], [92]–[94] to the issues discussed above. Among the popular solutions is Encryption[87], [91], [92] which according to Rajindra et al.[88] refers to a method of data protection where by data is converted into a form that unauthorized persons cannot easily understand. Encryption may be used to reduce problems such as eavesdropping and K-anonymity among others. Encryption can be achieved by encryption of the data handled by the system or encryption at the process level. Another popular solution is use of authentication[88]–[90], [92]–[94] such as use of user names and passwords. Some have gone further to use double factor authentication[92] where by more personal information such as favorite pet name is requested from the user to ensure that even when the first level of authentication is broken by a hacker, the personal information may provide a second level of security. This can solve issues like eavesdropping, identity theft and denial of service attacks among others.

According to some researchers[83], [88], [93] erasing identity, remote wiping and disabling may reduce privacy issues in mobile health systems. For example, when the user's phone is lost or

stolen, the user should be able to remotely erase or disable access to the data on that phone. This can go a long way in eradicating issues like third party attacks, audit trails and identity loss, theft or sharing among others. In addition, researchers emphasize access control through use of access control security models such as RBAC (Role-Based Access Control) which limit access to data to legitimate entities using the mobile health systems[83],[88],[90]. This may reduce challenges of eavesdropping, data security breaches and the issue of unprotected consumer data. Use of firewalls and avoiding unsecure Wi-Fi connections may also increase privacy in systems[88], [89], [91]. Unsecured Wi-Fi networks pose a risk of interception from intruders. On the other hand, personal firewalls can intercept and block malicious connections. Aaron et al.[86] also propose use of logic simplification algorithms, anonymous identifiers and identity servers to reduce access threats.

#### *Solutions to accuracy, efficiency, effectiveness and user satisfaction issues (usability issues)*

According to[82], [102], user involvement and iterative design is one of the solutions to usability issues. This involves improving versions of the system based on the feedback of users. They emphasize that subjective assessment of systems by the users in order to increase acceptability. Use of usage scenarios and threat scenarios[82]. These may reduce issues like difficult to use user interfaces. Secondly, appropriate testing could reduce usability issues[82], [100], [102] related to user satisfaction and un-subjective user assessment. A study by Sacha and Angela[99] suggests that increasing the number of login attempts may increase usability. According to the same research, the current policy applied to passwords grants users three false login attempts after which the user is blocked. This may reduce memorability and cognition challenges related to authentication. Secondly, there has been an increase in the screen size of mobile devices in order to improve the input mechanisms[100], [102]. This has been evidenced by the continuous increase in the size of smart phones by the different manufacturers. For instance, the current Samsung smart phones are much bigger than the initial Samsung galaxy S[111]. In addition, reducing the amount of data input may increase usability[102]. Some developers have adapted mechanisms of reducing the amount of data the user has to manually input into the system for example by using drop down menus to make interaction with the system less tasking.

#### **2.4.4 Discussion and conclusion**

The review identified several issues that affect privacy and usability of mHealth systems. It also uncovered some solutions that may be used to minimize these issues as discussed in the previous

sections. However, there also some issues that have no solution yet. The findings show that there is a trade-off between system privacy and usability. Emphasis on privacy leads to development of unusable systems while on the other hand emphasis on usability reduces the security component of the system. There is extensive research on the solutions to privacy and usability of systems compared to the research on striking a balance between privacy and usability. Findings of the review indicate that external factors play a significant role in the design and acceptability of mHealth systems which consequently affect privacy and usability of these systems. For instance, an external factor like literacy levels may influence privacy and usability of mHealth systems as discussed previously. However, there is limited research on how to tackle the factors in conjunction with striking a balance between privacy and usability of mHealth systems. This is evidenced by the limited literature about the same.

All the nine privacy issues identified under identity, access and disclosure issue categories identified had solutions. The solutions range from data and process encryption, user authentication, use of firewalls and access control security models among others. Some solutions could be used to address more than one issue. For instance, use of data and process encryption was shown to reduce privacy issues such as eavesdropping, identity theft and linkability attacks while user authentication such as use of usernames and passwords was shown to reduce denial of service attacks and indirect anonymity problem among others.

On the other hand, the review identifies solutions to usability issues that differ from the ones of privacy. The solutions may be looked at in terms product usability solutions and process usability solutions. Process usability solutions include user involvement, iterative design, appropriate system testing among others while product usability solutions include criteria and guidelines that ensure product usability in terms of reliability, ease to learn, easy memorability and few errors among others. Some solutions also address more than one issue just like the case of solutions to privacy issues discussed above. For instance, User involvement and iterative design may eliminate user interfaces that are not easy to use and increase user satisfaction.

Based on the review, privacy issues and usability issues in mobile systems in general have been widely researched and to some extent have concrete solutions. However, fewer research has focused on mHealth systems specifically. There is limited research on privacy in conjunction with usability in mobile systems and most especially in mHealth systems where these concepts are

fundamental. Moreover, the existing research approaches that tried to address the issue of striking a balance between privacy and usability in mobile systems did not focus on mHealth. The remaining few that look at mHealth systems are based on the context of developed countries. That research cannot often be used as a model for developing countries because of the difference in external factors such as infrastructure and cultural differences among others. For instance, while it may not be common to share mobile phones in developed countries, it is a common practice in low income and middle-income families in developing countries. This sharing phenomenon poses a new set of privacy and usability issues that require solutions different from those applied in developed countries. The limited research poses a challenge of how to develop mHealth systems that are highly secure and at the same time usable most especially in developing countries. More research is needed here.

Much as literature identifies many external factors that affect privacy and usability of mHealth systems and confirms that dealing with external factors may increase usability of mHealth systems and may also improve privacy of the user, it provides few solutions to these issues. As one of our contributions, we propose solutions to deal with external factors.

One of the ways of dealing with external factors is by improving awareness and offering training to users regarding privacy, security, and usability of mHealth systems. For instance, implementation of security measures and letting the users know what, how and where their data is stored may increase acceptance. Secondly, applying principles of user centered design which According to Oates[65] refers to the involvement of users in all phases of system development may also help in avoiding most of the privacy and usability issues. In this case, feedback from users should be put into consideration in the various iterative levels of system development. Involvement of users is more likely to lead to development of applications that are acceptable and increase user satisfaction which in the long run reduces acceptability and user satisfaction issue. In addition, appropriate system testing should also be done. Testing ranging from functionality testing to usability testing using both formal and informal methods need to be emphasized. In addition, all stakeholders ranging from policy makers, manufacturers to health workers among others should be indulged in order to come up with security standards, system development guidelines and infrastructures that support privacy and usability of mHealth systems.



## *Conclusion*

There is considerable research on privacy issues and usability issues in mobile systems in general but relatively fewer in mHealth systems. There are also a number of possible solutions to these issues as discussed in the previous sections. However, with the small number of documents in the literature combining privacy and usability, it appears that less is being done in addressing ways of striking a balance between privacy and usability of mHealth systems. External factors, which according to the review, influence privacy and usability of mHealth systems are also under researched. There is a need for more research on how to increase privacy in mhealth systems while considering usability. There is also need to address external factors especially in the context of developing countries where for instance mobile devices may be shared.

Access control security models such as RBAC have been shown to address some security issues such as eavesdropping which improves security of mobile systems. Much as they have to a greater extent been utilized in mHealth systems, they have major limitations as highlighted by Tolone et al.[59]. To bridge the gap in research on privacy and usability, focus on security models that are currently used to ensure privacy of users and focus on how to improve them to encompass and enhance the issue of usability of the systems especially mHealth systems. Since external factors such as literacy levels and cultural differences have also been sighted to negatively affect security and usability of mobile systems, the thesis is focused on cultural factors and in this regard it is specifically focused on the culture of sharing devices especially in developing countries where this phenomenon is common. The possibilities of developing a security model that can strike a balance between security and usability are explored while taking into consideration the specified external factors.

## 2.5 Access control security models used in healthcare systems

Security models implemented in health systems are mainly access control models. Access control models are more concerned with limiting the behaviour and operations of the user[54]. Commonly used models are RBAC model[52], [112] TMAC model[53] and TBAC model[54]. However, the first access control security models were Discretionary Access Control (DAC) and Mandatory Access Control (MAC). Access control models utilize various access control techniques such as access control matrix, access control lists constrained user interfaces, content and context dependent access control, and rule based access control[113].

MAC enforces access control independent of user operations and controls disclosure of information by assigning and limiting access to objects and subjects at various security levels. It is more concerned with issues of confidentiality than integrity[64], [114]. MAC is considered suitable for military systems and commercial systems such as financial management systems which are highly prone to attacks and therefore are more concerned with confidentiality. However, it is less suitable for healthcare systems because it limits the user's actions and restricts users from controlling their data. On the other hand, DAC controls access basing on the object permission level. It grants users access to objects/ information they own. However, allowing this kind of access makes the system vulnerable to attacks. For instance, limited control of copying privileges by DAC opens way for Trojan attacks. The mentioned limitations of MAC and DAC led to the development of RBAC and later TBAC and TMAC among others.

RBAC incorporates features from both DAC and MAC. It encompasses both integrity and confidentiality but puts more emphasis on integrity. RBAC assigns roles to users, permissions to roles and users get permissions by playing roles and the whole process is managed by a security administrator. Much as users are granted access to roles, they have no rights to transfer permissions assigned to them to other users. With RBAC, access permission is associated to a role and then the role is associated with the user as simplified in the figure below.

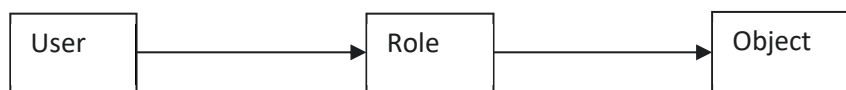


Figure 3: Association between user, role, and objects in RBAC

The key strength of this model is that it enables separation of duties[52]. RBAC promotes system integrity and easy access control in organisations with many users since multiple users can be allocated a single role. However, the need for customised privileges and role inheritance may make administration in large systems based on RBAC unmanageable.

Managing roles and users is difficult especially in cases where roles fluctuate in an organization due to varying organizational needs. In addition, some users may sometimes half-fill multiple roles. Furthermore, RBAC may not easily and quickly subdivide roles into new permissions to new users in cases of emergency. For instance, in a healthcare setting where a doctor is assigned specific patients, absence of this doctor due to emergency situations such as accident would necessitate another medical personnel to immediately take up some or all the roles of the absent doctor. This may call for access of private and sensitive information such as passwords and this would breach the privacy and security component of RBAC which is based on roles. To control crime in such scenarios, some systems are configured to monitor users and permissions they access to keep track of who did what and when. This further interferes with privacy and usability of such health systems.

TMAC model is mainly used in collaborative environments and access control is based on teams whereby access rights are given to groups of users. In this case, a team is a collection of users with individual roles who collaborate with the aim of achieving a specific goal/ task. In TMAC, a user can only access resources allocated to a team in which they belong. However, permissions are granted based on the roles the individual users are assigned to in the team and the activity the team is working on at that moment.

The main advantage of TMAC is that it allows for dynamic management of permissions as tasks progress to completion[53]. It can activate permissions for a particular user based on situation at hand and it is therefore referred to as an active security model[115]. However, the limitation of TMAC is that it does not have self- administration capabilities.

TBAC model is based on tasks and permission control is dynamic. When authorisation is activated, the permissions associated to it are activated too and then the user can then use the permissions to run the task. The user cannot use the permissions unless they have been activated. Tasks in TBAC have time restrictions and therefore the users too have time limitations on the permissions granted to them. Permissions assigned to the user during task processing are withdrawn from the user when the task is stopped or ended.

The advantage of TBAC is that it is dynamic and therefore supports real time processing of tasks, and supports least privilege processes[54]. Access control is not static and it may vary depending on the situation of the task. However, in large systems where processes are many, processing time will increase.

With the persistence of privacy, security and usability issues, more new security models are being proposed. Most of these models are an extension or combination of RBAC, TBAC and TMAC. They include Situation, Team and Role based Access control (STRAC), Context-based Team access control (C-TMAC), Task Role- based Access control (TRBAC), Spatial Role-based access control (SRBAC), Object relationship- based access control (RoBAC), Attribute-based Access control (ABAC) among others. It should however be noted that most of these models are relatively new and have not yet been deployed on a large scale.

STRAC introduces the concept of situations to RBAC and TMAC such as emergencies. In addition to assigning access permissions to users depending on roles and teams, STRAC further assigns situations to users and assigns access permissions to users based on the situations[116]. However, STRAC does not specify the hierarchy structures of situations, teams and roles.

On the other hand, C-TMAC[115] integrates and extends RBAC and TMAC by introducing contextual information such as location where access is requested, time of access, location of the object to be accessed, etc.

TRBAC combines RBAC and TBAC by appointing tasks to roles and permissions to tasks[54]. In other words, the user is appointed to a role, and then the user acquires tasks to carry out based on the role. On the other hand, unlike other access models, RoBAC[117] is based on the relations held among the users and the class relations in the java programming. It is meant for a cloud environment.

SRBAC extends RBAC by adding a spatial component of utilising location information in the definitions of the security policy[118]. In this model, assignment of permissions is dependent on location and therefore a user assigned to a role could have different permissions depending on their location.

ABAC[113] is based on attributes associated with the subject, objects and requested operations. When a user requests access, the access is granted or denied basing on the attributes assigned to

that user, attributes of the object and attributes associated with the operation being requested and in some cases the environment conditions.

### 2.5.1 Limitations of current access control security models

The limitations of the current access control security models are summarised in the table below.

<b>Access permission</b>	<b>RBAC</b>	<b>STRAC</b>	<b>C-TMAC</b>	<b>TBAC</b>	<b>TRBAC</b>	<b>TMAC</b>	<b>SRBAC</b>
Access based on roles (scalable)	√	√	√		√	√	√
Access based on tasks (Dynamic and self-administering)				√	√		
Access based on teams (Dynamic)		√	√			√	
Access based on location			√				√

Table 6: Limitations of the current access control security models

## 2.6 Research gap

Based on the above analysis of the models, it is evident that the available models have limitations in addressing privacy and usability challenges. RBAC, TMAC and TBAC which are commonly used attempt to solve these challenges, but they are limited. RBAC for instance, tries to bridge the security gap by assigning roles to users and granting permissions based on the roles. This implies that all users with the same role have the same permissions. However, this is not practical and makes the model less unusable in real life especially in healthcare settings. For example, even if two nurses have the same role, they may not have access to the same patient records. On the other hand, TMAC tries to solve the collaborative challenges by combining roles and teams' permissions. In this model, members in the same team are assigned the same set of permissions. This is problematic because even if users belong to the same team, they may not play the same role. For example, a doctor may play the role of team manager in one team and a team member in another team.

Mobile health systems pose even more privacy and usability challenges to the available access control security models because they are affected by location of users, an attribute most of the available models are unable to address. This is made more complex in situations where the mobile devices are shared. There are new access control security models such as Context Team- based Access control (C-TMAC) and Spatial Role-based Access Control (SRBAC) that try to address contextual challenges such as location and time. However, they do not specify the hierarchy structures of situations, teams and roles which is a vital component in healthcare.

There is a need to develop more reliable security models for healthcare systems since according to research[119], [120] they are prone to attacks. To address some of the challenges discussed above, we develop a hybrid security model Task- Team- Role based Access Control (T2RoL) model that facilitates sharing of sensitive information while enhancing security of mobile healthcare systems. Location is combined with the scalability attribute of RBAC, self-administering and dynamic attributes of TMAC and TBAC to develop T2RoL model which facilitates hierarchical structuring of tasks, teams and roles while focusing on assigning users to roles, teams and tasks based on their location.

## CHAPTER 3: RESEARCH METHODOLOGY

### 3. Introduction

In this research, we review privacy and usability challenges that are faced by mobile health systems and the effect of social technical factors on the privacy and usability of these systems. We then develop mHealth interventions for illiterate and semi-illiterate pregnant women. To ensure security and privacy of the users of the interventions and address some of the challenges identified, we develop and integrate an access control security model into the applications. Field studies, and design and creation are the two main methods to achieve the research objectives as shown in table 7 below. Details of each method will follow in the next sub sections.

Objectives	Field study	Design and creation
Objective i	X	
Objective ii		X
Objective iii		X
Objective iv	X	

Table 7: Research objectives and their respective research methods

### 3.1 Field studies

Field studies were conducted to achieve objectives i and v. Two main field studies were conducted, and they will be referred to as first field study and second field study. The first field study was aimed at gathering user requirements, information preference and design challenges that may affect design and implementation of the applications (web and mHealth application), and test for proof of concept. The second field study was to evaluate the mHealth application and determine its impact on maternal health care.

### 3.2 Choice of research methods: Mixing Qualitative and Quantitative Methods

The field studies combined qualitative and quantitative methods. Qualitative research includes the use of qualitative data, such as interviews, documents, and participant observation, to understand and explain social phenomena[121] whereas quantitative research is a systematic investigation of phenomena by gathering quantifiable data and performing statistical, mathematical, or computational techniques[122]. Qualitative and quantitative methods are discussed in more detail later in the next subsections.

Research in computing fields is said to have an emphasis on quantitative methods[123]. Despite the ability of quantitative methods to quantify outcomes, they may not be able to properly address social and organisational aspects of research, for instance user experiences and perspectives that arise from implementation of interventions[124]–[126]. Understanding social and organisational aspects in implementation of technological intervention necessitates use of qualitative methods[127]. This indicates that neither the quantitative nor the qualitative method may be effective on its own as confirmed by Hirschheim[125] and Rahman[128]. Therefore, combination of quantitative and the qualitative methods becomes a feasible option. Besides, studies by Venkatesh et al.[129], Silverman[130], Doyle[131], Creswell et al.[132], Kaplan et al.[133], Östlund et al.[134], Tashakori and Teddlie 2002[135], Kaplan and Duchon[136], and Mingers[137] indicate that mixed methods are comprehensive and may be feasible in identifying important insights that might not be identified by a single method.

Therefore, mixed methods were used to conduct in-depth explorations of the social and organisational aspects of the intervention as well as obtaining significance levels of the impacts of the intervention, as a way of complimenting results from both methods. For instance, following the example of Wyatt and Wyatt[138] and Klasnja et al.[139], mixed methods were used in the pre and post intervention study which led to getting an in-depth justification to what extent the impacts identified could be attributed the intervention and how other external factors such as social economic dynamics affected the impacts.

Two approaches of employing mixed methods were followed as suggested by Robson[140] which involve; 1) using qualitative results to identify initial themes that are then quantitatively measured and validated, 2) explaining quantitative results using qualitative approaches.

According to Myers and Avison[121] and Rahman[128], a method may be effective in answering different research questions and therefore it is important to choose a method based on the question to be answered. The criteria for choosing the methods in this study mainly depended on the likelihood of the method to appropriately answer the research questions.



### **3.2.1 Qualitative method**

Qualitative methods are useful in cases where there is need for understanding phenomena or events in depth[141]. Qualitative research has different types such as grounded theory, case study, ethnography, and phenomenology. In this study, the grounded theory which is a type of qualitative research that facilitates development of theories from collected data is used. It follows a systematic and flexible process of collecting and coding data, making connections and generating theories from that data[142]. Grounded theory was chosen because of its ability to make interviews more in-depth, and content analysis more focused. In addition, grounded theory methods have considered to be standard social research methods and have been used in various disciplines[143]. For instance, they have been utilised successfully in research involving technological interventions[144].

Methods of data collection used in grounded theory include interviews, focus groups, participant observation, and study of artefacts and texts[145], [146]. In this study, face to face semi-structured interviews and focus group discussions were utilised.

#### **Why interviews**

Semi-structured interviews were chosen for this due to their flexibility in allowing the researcher to pose follow up questions depending on responses of participants and asking participants for detailed explanations and meanings[147], [148].

To ensure clarity, the initial interview questions were pilot tested by four respondents who were selected purposively. Using the feedback from the respondents, some questions were removed, and others modified to come up with a refined interview guide. Pilot testing of interview guides is an integral part of conducting qualitative research and it is useful in improving the quality of the interview guide[149].

Despite the advantages of face to face semi-structured interviews, it is important to note that they are liable to geographical mobility limitations and they produce large amounts of data that require time to analyse[150].

#### **Why Focus Group discussions?**

A focus group discussion is a data collection method whereby a researcher leads a group of people to discuss a subject of interest[148], [151]. Focus group discussions were chosen because:

1. Compared to other data collection techniques, focus groups yield a shared understanding of the subject and several perspectives of the topic if they are conducted well[152].
2. They facilitate quick collection of data from a big number of participants at the same time[148], [153].

However, literature recommends combining of focus group discussions with other data collection methods instead of using them as the primary data collection method[148]. Focus group discussions were therefore used to supplement the findings from interviews.

### **3.2.2 Quantitative method**

Quantitative research has different types such as surveys or descriptive research, correlational, experimental and causal comparative research[154]. In this study, surveys in form of questionnaires were used because 1) they are convenient in collecting huge amounts of data from many respondents in a short time, 2) they are reliability in obtaining standardised responses which eliminates researcher's biases, and 3) due to the standardisation, there is accuracy in terms of measuring the collected data[150], [155].

The survey questions used to measure the usability and acceptability of the application were derived from the unified theory of acceptance and use of technology (UTAUT). UTAUT is a technology acceptance model formulated with an aim of explaining user intentions to use an information system and the subsequent usage behaviour[156].

UTAUT model suggests that performance expectancy, social influence, facilitating conditions and effort expectancy determine behavioural intention but these constructs are moderated by factors such as age, gender and experience[156]. It is therefore argued that examining these constructs in real life enables assessment of an individual's intention to use a system. The UTAUT model was chosen because it has proved to be reliable in evaluating technological interventions and this can be shown by the large number of interventions that have utilised it successfully[157]. Besides, using previously developed and tested questions ensures reliability of findings[138].

On the other hand, the questions to measure the impact of the intervention on maternal health knowledge, attitudes and practices were structured following the Knowledge-Attitude-Practice

(KAP) model. According to WHO, the KAP Model is based on the idea that increasing personal knowledge prompts behaviour change[158]. The KAP model was chosen because surveys based on it are easy to conduct, and the results are easy to interpret and present[159].

Furthermore, studies by Bano[160], Launiala[161], Vandamme[162], Yezli et al.[163], Tabash et al.[164], Iliyasu et al.[165], Trajman et al.[166] and Liu et al.[167] prove the reliability of KAP surveys in evaluating the knowledge and attitudes in healthcare interventions.

As recommended by Fowler[168], presser et al.[169] and Collins[170], the questions in the survey were tested to ensure that they met their purpose. The survey was tested by five purposefully selected participants whose feedback was used to refine the surveys.

### **3.3 Quality assurance**

#### **3.3.1 Quality assurance in the qualitative study**

The success of a research study is dependent on its quality and it is therefore important to research findings that correctly reflect the phenomena that is being studied[171]. Minimising methodological errors in research is the sure way to ensure quality[172]. The quality of the qualitative components of this research were based on the criteria proposed by Lincoln and Guba[173]. The criteria are based on four strategies which are dependability, credibility, conformability, and transferability.

Dependability looks at the extent to which the results can be trusted and relied on. Following grounded theory procedures[174], the categories and sub-categories were compared and their relationships verified from new incoming data, and were then documented. The validity of the findings was ensured by comparing the results from the self-report data with other studies on the same topic.

Credibility is about demonstrating that the findings have been generated using an appropriate research process. The research methods used in this research were suitable as described and justified in the previous sections. The participants were requested for their consent to participate in the studies and their participation was voluntary. Any digital data capture such as audio recording of the interviews was done after seeking consent from the participant. The data collected was

treated as confidential whereby the paper-based data such as surveys and transcripts were kept in a locked place and reference codes were used instead of names.

Transferability looks at the extent to which the identified results can be generalised. An extensive literature review was done in chapter 2 of this thesis. The findings of this research were compared with the literature, and it was found that some findings confirmed the literature while others added new insights.

Conformability is concerned with the extent to which similar findings would be obtained by a different researcher given a similar context and the same research objectives/ questions. Following a similar systematic documentation of the research, using the research objectives stated in chapter 1, using the data collection sources/ methods mentioned, following a systematic well documented data analysis based on grounded theory, and a user centered design approach in the same exact situation might generate the same findings.

### **3.3.2 Quality assurance in the quantitative study**

Quality of quantitative studies is categorised into internal and external validity. Internal validity looks at whether an experimental condition makes a difference and if there is enough evidence for supporting the claim whereas external validity looks at whether the treatment/ condition outcomes are generalizable[175].

In this research were focus on internal validity by 1) piloting the survey instruments, 2) ensuring reliability of the survey instrument, 3) minimising social desirability and 4) ensuring reliability of the findings.

Piloting the survey instruments: The questionnaire and interview guides were pilot tested before they were officially used for data collection. The pilot test pointed out some ambiguities and repetitions which led to refining of the instruments.

Ensuring reliability of the survey instrument: As mentioned in the previous subsection, questions in the survey instruments were based on UTAUT and KAP guidelines/ models which have been tested over time and have shown predictable reliability.

Minimising social desirability: Social desirability was minimised by using codes instead of participant's names on the questionnaires and informing participants that their answers would be kept private and would only be used for research purposes after which the data would be destroyed.

Ensuring reliability of the findings: Both the intervention group and the control group were pre-tested and post-tested to justify that the findings from the evaluation were solely attributed to the intervention.

### **3.4 First field study: Investigating user requirements, information preference, design challenges, and testing for proof of concept of the maternal health application for illiterate and semi-illiterate pregnant women**

#### **3.4.1 Study design and setting**

To get the user requirements, a field study in form of semi-structured interviews, questionnaires and focus group discussions was conducted. The user requirements were then used to design and develop the prototypes. The prototypes were tested by the women and health care providers using usability and functionality testing.

#### **3.4.2 Study setting and participants**

The study comprised of three kinds of participants: 25 illiterate and semi-illiterate pregnant women, 10 health practitioners in the field of maternal health and 10 designers/ developers of mHealth applications for low resource settings. The women and health practitioners were recruited from the department of obstetrics and gynecology of Mbarara Regional Referral Hospital (MRRH) in southwestern Uganda. MRRH is the largest hospital in rural southwestern Uganda employing 11 gynaecologists/ obstetricians and 22 midwives as of 2019. Annually, MRRH performs more than 10,000 deliveries with a maternal mortality rate of 270/100,000 live birth.

On the other hand, designers/developers were recruited from different parts of the world based on referrals from those who knew about the study.

When women go for the first antenatal visit, their demographics, contacts, and health information are captured and stored in antenatal registers and routine counseling books. Each woman is given an antenatal card locally known as “kipande” which indicates their next appointment date and other

vital information such as biodata. Women must come with these cards during their scheduled visits during which they are marked with the next appointment date. The recommended number of antenatal visits is at least four visits.

Maternal health information is mainly passed on to the pregnant women through group health talks during their antenatal visits. Specific information is given based on categories of women. Women are categorized and appointments given based on these categories. For instance, women coming for antenatal services for the first time are attended to on Mondays after which they are categorized according to their current trimester. Women in their first trimester visit the clinic on Tuesdays; those in the second trimester visit on Wednesdays and those in the third trimester are attended to on Thursdays. Women who miss the health talks have no opportunity to access these talks because the health practitioners have high workloads that do not allow them to repeat the talks for late comers and absentees. Sometimes health talks and advertisements on general maternal health information are aired on radios and television, but the information is not personalized.

On rare occasions, health practitioners sometimes make follow ups on critical cases such HIV positive women, through SMS and sometimes calling but this is unsustainable due to financial constraints and illiteracy.

### 3.4.3 Inclusion criteria for participants

Participants were selected based on the following criteria

<b>Inclusion criteria for participants for interviews</b>		
<b>Women</b>	<b>Health practitioners</b>	<b>Designers/ developers</b>
<ul style="list-style-type: none"> <li>• Illiterate or semi-illiterate</li> <li>• Above 18 years and pregnant</li> <li>• Can speak Runyankole (native language for southwestern Uganda)</li> <li>• Receiving antenatal care services from MRRH</li> <li>• Willing to give consent</li> </ul>	<ul style="list-style-type: none"> <li>• Practitioner in maternal health care at MRRH</li> <li>• Willing to give consent.</li> </ul>	<ul style="list-style-type: none"> <li>• Experience in designing/developing for low resource settings</li> <li>• Willing to give consent</li> </ul>
<b>Inclusion criteria for participants for focus group discussions</b>		
<ul style="list-style-type: none"> <li>• Living within 10km from MRRH (to minimize transport costs)</li> </ul>	<ul style="list-style-type: none"> <li>• Have access to a computer</li> </ul>	<ul style="list-style-type: none"> <li>• Did not participate in the focus group discussions because they were not</li> </ul>

<ul style="list-style-type: none"> <li>• Have access to a basic smart phone (borrowed or owned)</li> <li>• Illiterate or semi-illiterate</li> <li>• Above 18 years and pregnant</li> <li>• Can speak Runyankole</li> <li>• Able and willing to give consent</li> <li>• Receiving antenatal care services from Mbarara regional referral hospital</li> </ul>	<ul style="list-style-type: none"> <li>• Practitioner in maternal health at MRRH</li> <li>• Willing and able to give consent</li> </ul>	considered as part of the users of the applications
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Table 8: Inclusion criteria

#### 3.4.4 Participant selection

Pregnant women were selected based on convenience sampling as they came for antenatal visits until the required number was reached. By virtue of their role as care givers in the gynecology and obstetrics, health practitioners were purposeful selected to provide insights on maternal health procedures in MRRH and requirements for a digital intervention. On the other hand, designers/developers were recruited using snowballing sampling based on referrals from those who knew about the study.

#### 3.4.5 Study procedures

After consenting, each study participant was taken to a private room for a face-to-face interview that lasted utmost 30 minutes. During the interviews, participants for focus group discussions and testing the prototypes were identified and selected based on the inclusion criteria in table 8. The participants who participated in the focus group discussions were grouped beforehand to save time. The pregnant women were divided into two groups to make the group small and more interactive. Each participant was given a phone with the mobile application pre-installed, given a brief training on how to login in, access videos and audios, and use the chat room. They were then allowed to interact with the application and test its functionality and usability for not more than one hour. This was then followed by a focused discussion about the demo. On the other hand, health practitioners were given a brief training on how to use the web application via a web browser on a computer. Each of them tested the functionality and usability of the prototype for not more than one hour, followed by a focused discussion.

### **3.4.6 Data collection**

Between April 2017 and February 2018, we conducted a field study to get information about design perspectives, test for proof of concept using demos and gather user requirements for the prototypes (web and mHealth applications).

This study utilized semi-structured interviews supported by questionnaires (for capturing demographic data), and focus group discussions. Interviews and FGD with women were conducted in Runyankole. During the interviews and focus group discussions, audio was recorded with consent from participants, and questionnaires were also filled.

Interviews and FGD were focused on different aspects. Interviews with pregnant women included questions on access to and usage of mobile technology, information preference and user requirements for the mobile app. Those of health practitioners looked at access to digital technologies, provision of maternal health information and challenges, follow-up of pregnant women, and user requirements for the web application. Designers/developers were interviewed on challenges of designing digital interventions for low resource settings and the possible solutions. On the other hand, FGD addressed the issues of usability and security of the applications, and design improvement.

Audio data files were transcribed using Transcribe[176] -a software plugin for Chrome which enables making notes while listening to the audio. The data collected in Runyankole was translated to English during transcription after which transcripts were later reviewed for consistence. Quantitative data about participants' demographic characteristics, and information preference was also collected.

Data collected was treated with high confidentiality. Text data was stored in files identified by a unique code and kept in a locked drawer that was accessed by only the researchers. The recorded voice data was deleted after data analysis.

### **3.4.7 Data analysis**

In the analysis of the data, thematic content analysis method which, according to Myers and Newman[177] is efficient for analysing semi-structured and open ended interview data was used.

The transcripts were reviewed for content relevant to user requirements, design challenges, information preference among others. Based on this content, a coding scheme was formed, and



data was coded. The coded data was then reviewed and sorted to form descriptive categories together with quotes. Quantitative data was analysed using STATA 16 to describe participants' demographic characteristics and information preference.

#### **3.4.8 Ethical review**

The study was conducted after attaining ethical approvals from Mbarara University of Science and Technology Research Ethics Committee under registration No.16/04-17 and Uganda National Council for Science and Technology under registration No. IS8ES. All participants provided signed/thumb-printed informed consent forms before participating in the study.

### **3.5 Second field study: Evaluating the mHealth application for usability, acceptability, and impact.**

#### **3.5.1 Study design and setting**

The study combines semi-structured interviews and surveys in a parallel mixed methods study design to evaluate usability and acceptability of the mHealth application, and its impact on attitudes, practices, and maternal health knowledge of illiterate and semi-illiterate pregnant women. Like in the previous study, the pregnant women were recruited from the department of obstetrics and gynecology of Mbarara Regional Referral Hospital (MRRH) in southwestern Uganda. Therefore, the study setting of this study is similar to that of the first field study.

#### **3.5.2 Study participants**

This study carried out between January 2019 and December 2019 comprised of 80 illiterate and semi-illiterate pregnant women who were purposively selected and followed throughout pregnancy and 42 days after delivery. The participants had to meet the following criteria to be considered for the study

- 1) Illiterate or semi-illiterate (No education or having an education not exceeding primary seven)
- 2) 18 years or above and pregnant
- 3) Able to speak Runyankole
- 4) Able and willing to give consent
- 5) Living within 20km from Mbarara regional referral hospital

- 6) Receiving antenatal care services from Mbarara regional referral hospital
- 7) In the first or second trimester

The participants were randomly assigned to the intervention arm and the control arm using a random number generator in a ratio of 1:1. Participants in the intervention arm received mobile phones pre-installed with the multimedia mHealth application whereas those in the control arm did not receive the application.

### **3.5.3 Study procedures**

During the baseline phase, women in the intervention arm were given a brief training on how to login in, access messages (videos and audios), set reminders, and use the call functionality of the application. They were then requested to demonstrate how the application works. Each participant was then taken to a private room for a face-to-face interview that lasted between 40 and 50 minutes, in which a survey was filled for all the women in both arms. Details of the development and functionality of the mHealth application are discussed in chapter 8.

In the midline phase, only participants in the intervention arm were considered. They were categorized into two: those that had missed any antenatal visit and those that had adhered to all their scheduled visits. The women who missed visits were interviewed and a survey was also administered whereas those who did not miss any appointments were only interviewed. Just like in baseline, each participant was interviewed face-to-face in a private room for not more than 50 minutes.

In the end line phase, participants in both arms who had already given birth and were within the 42 days of postpartum had surveys filled individually in a face-to-face interview that lasted not more than 50 minutes.

### **3.5.4 Messages (video and audio)**

This study comprised of 30 messages in total (15 audio and 15 video messages) that were developed by a gynecologist and a nutritionist following guidelines from Uganda ministry of health. The women received messages monthly. Categories of messages sent per semester are shown in table 9 below.

### *Message categories per trimester*

Trimester	Category of message sent
<b>1<sup>st</sup> trimester</b>	Diagnosis of Pregnancy
	Antenatal care visits and their timing
	Nutrition
	Danger signs of early pregnancy
	Partner involvement in Antenatal care
	HIV and pregnancy
<b>2<sup>nd</sup> trimester</b>	Prevention of malaria
	Danger signs
	Nutrition
	Exercise during pregnancy
<b>3<sup>rd</sup> trimester</b>	Birth preparedness
	Nutrition
	Delivery
	Breastfeeding
	Postnatal danger signs
	Immunization
	Postnatal care and services

Table 9: Message categories per trimester

### **3.5.5 Sample messages**

Content in the messages was organized into seven categories: 1) preventive care, 2) danger signs, 3) partner support, 4) nutrition, 5) birth preparedness, 6) postnatal care and 7) postnatal services. The table below shows samples of messages in their respective categories.

<b>Message category</b>	<b>Message subcategory</b>	<b>Message content sample</b>
<b>Preventive care during pregnancy</b>	Prevention of malaria	During pregnancy you need to prevent and control malaria through sleeping under insecticide treated mosquito net, ensuring that you destroy all breeding sites for mosquitoes-clean the compound and keep it slashed, remove empty tins from the compound, make sure there is no stagnant water in the compound and close the windows of your house early. Ensure that you receive fansidar at each ANC visit. Seek medical care promptly whenever you develop fever. Do not take unnecessary medications in pregnancy because some may harm your developing baby especially in the first 3 months
	Prevention of mother to child HIV transmission during pregnancy	HIV can be transmitted from an infected mother to her baby. Know your HIV status at the first antenatal visit and repeat the test every 3 months until end of breast feeding. For those who test negative, ensure to remain HIV negative to keep healthy. If you are found HIV positive, ensure to receive appropriate care from your antenatal clinic and ART clinic. You will receive ARVs daily for life to protect your health and prevent transmission of HIV to your baby. Ensure to deliver in the hospital where your baby will receive ARV syrup daily for 6 to 12 weeks. Your baby will be followed up in an exposed infant's clinic where HIV tests for the baby will be done at 6-10 weeks and repeated at 6 weeks after breast feeding. Do all it takes, receive all the recommended care to have an HIV free baby
	ANC visits and their timing	Attend all scheduled ANC visits with a qualified Health worker. Ministry of Health recommends a total of atleast 8 visits, once every month. Ensure the health worker

		provides all recommended services at each visit including tetanus injections, Malarial prophylaxis, physical examination, checking your weight and blood pressure at every visit, laboratory tests like HIV and syphilis, urine analysis, Hepatitis B, Hemoglobin estimation. Ensure you receive a mosquito net on first visit. Return anytime whenever you develop any complication
<b>Danger signs during pregnancy</b>	Danger signs in early pregnancy	Pregnancy may come with some undesirable effects like nausea and vomiting, cravings, constipation, bleeding from your private parts. Report to the health worker for advice in case you experience any disturbance during this period. Ensure to have an early pregnancy ultrasound within the first 3 months to exclude twins and ectopic pregnancy.
	Bleeding in advanced pregnancy	When a woman is pregnant, she stops bleeding. Any bleeding you see when you are or are suspecting to be pregnant is abnormal. In early pregnancy, this could mean you have an ectopic pregnancy or abortion process but in pregnancies after 7 months, it means there is a big problem with the placenta. Bleeding can cause the death of your baby in pregnancy and leave your life in danger. Ensure you receive proper examination by your midwife. A scan may be done to localize the placenta. Always take your iron tablets every day to keep good levels of blood. Have a balanced diet to keep healthy
<b>Partner support</b>	Partner involvement	The father of your unborn baby is as important as you the mother. You are encouraged to involve him in the affairs of this pregnancy. Encourage him to accompany you to the health facility during all scheduled visits where he will test with you for HIV and Syphilis, know his blood group and receive important health education messages

		together, to help you to deliver a healthy baby. Your partner will support you best if he is involved
<b>Nutrition</b>	Balanced diet and frequency of feeding	Like any other person, a pregnant and breastfeeding woman needs to eat a balanced diet at all time to have a healthy baby and she also remains healthy. A balanced diet includes carbohydrates, fats, proteins and minerals/micronutrients. Remember: pregnancy increases all nutritional requirements, hence the need for special attention. Ensure an extra meal from the usual routine, take daily folic acid and iron tablets, deworming using mebendazole. Take iron and folic rich foods like green leafy vegetables, meat, millet
<b>Birth preparedness</b>	Basics	Good pregnancy outcomes come depend on the level of preparation. Be well prepared for the birth of your baby by discussing your plans with your husband and health worker. Be sure of the name and location of the health facility you wish to deliver from. Arrange transport means to your preferred health facility. Be ready for emergency referral in case its necessary. Ask your midwife about items to bring for delivery like maama kit. Have enough personal items like clean clothes, pads, basin and baby clothes
	Modes of delivery	As you know you are coming closer to the day of delivery of your baby. It must be exciting but also full of many uncertainties. The ultimate goal is to deliver a healthy baby and you also remain strong enough to continue offering your baby recommended care. Every mother must discuss with the midwife the mode of delivery of her expected baby. We recommend every woman for a natural birth whenever there is no other reason to prevent it. Remember a natural birth is the best once supervised

		<p>by qualified health worker. For those unable to have a normal delivery, caesarean section (CS) is an option. Whenever you need CS, ensure you get it timely. It's a lifesaving procedure for the mother and the baby. Plan to deliver in a health facility able to offer CS in case you need it or be prepared for urgent transfer to a facility able to do CS without delay. If you have been operated before, you may require another operation before labour begins. Be sure of the mode of delivery of your baby when you are still pregnant to make the correct decisions before costly complications set in</p>
	Care during labour	<p>When labour pains begin you begin a new experience. When you are well prepared you will enjoy the experience. Report to your planned health facility for delivery for initial assessment. The midwife will monitor the progress of labour by repeated examination for you and the baby till delivery. Ensure proper hygiene in labour by shower regularly and use clean sanitary towels. You are advised to have small frequent nutritious meals and teas to keep healthy and well hydrated. Report any undesirable occurrences at any time. A midwife will prepare you for pushing your baby when delivery time comes. After delivery your baby will receive immediate care to help initiate breathing and treat any difficulties. The midwife will ensure you are not bleeding by giving you an injection. The baby will be weighed and immunized before discharge. Deliver under qualified health workers to give your baby a good start</p>
<b>Postnatal care</b>	Postnatal danger signs	<p><b>Mother:</b> Heavy bleeding, swelling of the face, fever, vomiting, smelling vaginal discharge, severe pain in the legs, constant abdominal pains, distention of abdomen,</p>

	(for mother and baby)	General body weakness. Return to the health facility whenever you experience any of the above signs
		<b>Baby:</b> The baby may experience unusual behaviours. Return the baby to the health facility when the baby develops failure to breast feed, yellowing of eyes and the body, convulsions, discharge in the eyes, bleeding from the cord, wet or cord stamp with offensive discharge, failure to pass urine, any injuries and anything that makes you uncomfortable
	Breastfeeding (with or without HIV)	Breast feed your baby for a better future health. Breast milk is the ideal source of nutrition for all babies. Breastfeeding promotes health, helps to prevent disease like diarrhoea, and reduces alternative feeding and treatment costs. The Ministry of health recommends exclusive breastfeeding for six months of life and then supplemented breastfeeding for up to two years or more. During breastfeeding nutrients and antibodies are passed to the baby while it helps to strengthen the maternal bond and love for life. Breast milk has just the right amount of fat, sugar, water, and protein that is needed for proper growth. Consult your health worker in case of any difficulty with breast feeding. Common breastfeeding difficulties include sores on the nipples of your breasts and mouth of the baby
		<b>With HIV:</b> HIV can be transmitted from an infected mother to her baby. Know your HIV status at the first antenatal visit and repeat the test every 3 months until end of breast feeding. HIV can be transmitted during pregnancy and breastfeeding. Babies of HIV infected mothers will breast feed well like any other baby BUT only for one year as long as the baby receives nevirapine



		<p>syrup for 6 to 12 months while the mother takes her ARVs daily for life. Continue breast feeding for 1 year. Take your child for care at special children's clinic where all the care will be given. An HIV test at 6 weeks after end of breast feeding will be done and a confirmatory test at 1 and a half years. Children who will unfortunately be infected will be helped to start HIV treatment early to live longer</p>
<b>Postnatal services</b>	Growth monitoring	<p>It's good for every mother to know whether her baby is growing well. At discharge, the health worker will give you return dates for immunization when the baby will be weighed to determine the development of your baby. Your baby will be weighed at birth and 6, 10 and 14 weeks whenever the child receives immunization. Continue bringing the baby for at 6 months when the baby will also receive Vitamin A and at 9 months during measles immunization. When your baby is found with abnormal growth, you will be advised among other things on how best to feed your bay for proper development</p>
	Family planning	<p>Family planning means having children by choice and not by chance. It's the single most effective means of preventing maternal morbidity and mortality. Let every mother have a child when she is ready and avoid finding yourself pregnant even when you do not feel you want to. Receive family planning information during pregnancy. The majority of women will return to normal fertility by 2 to 6 months following the birth of their baby. You do not have to first experience your monthly period in order for you to become pregnant. Ensure that you are using a family planning method by 2 months after delivery for be</p>

		on a safe side. NO WOMAN SHOULD LOSE LIFE WHILE GIVING BIRTH
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Table 10: Samples of messages in their respective categories

### 3.5.6 Data collection

The second field study was conducted between January 2019 and December 2019 to evaluate a multimedia based mHealth application. This study utilized semi-structured interviews and surveys, all conducted in the local language (Runyankole). During the interviews, audio was recorded with consent from participants, and surveys were also administered.

The data was collected in three phases: at baseline, midline and end line. Baseline data collected was about factors that affect maternal health (demographics and characteristics), knowledge about maternal health, perceptions, and attitudes about using the mHealth multimedia application and practices.

Midline data was collected from participants who missed their scheduled appointments or came for ANC visit outside their appointment time and this was done after two weeks. Data collected covered facilitating conditions, ease of use of the application, perceived usefulness of the application, norms about using the application and application acceptance.

On the other hand, end line data was collected within 42 days after giving birth. This data was collected from participants from both the control and intervention arms. Data collected focused on health knowledge, attitudes, perceptions and practices, and the aim was to compare the data from the two arms and determine if there was a significant difference. Participants' experiences of using the application were also collected to determine its feasibility and acceptability.

The interviews and surveys were conducted in Runyankole. Audio data files were transcribed and translated during transcription.

### 3.5.7 Data analysis

In the analysis of qualitative data, thematic content analysis method as described above in section 3.4.7 was used. However, in this second study, transcripts were reviewed for content relevant to ease of use of the application, perceived usefulness of the application, norms about using the application, experiences of using the application and application acceptance.

Quantitative data collected was analysed using STATA 16 to describe participants' demographics and characteristics, knowledge about maternal health, perceptions, and attitudes about using the mHealth multimedia application.

### **3.5.8 Ethical reviews**

This study was also conducted after attaining a second set of ethical approvals from Mbarara University of Science and Technology Research Ethics Committee under registration No. 30/04-18 and Uganda National Council for Science and Technology under registration No. SS4661. The approvals for this study were attained under the MatHealth project, a collaboration between MUST, MRRH and Humboldt University of Berlin that was sponsored by the German Federal Ministry of Education and Research (BMBF).

## **3.6 Design and creation**

In this research, design and creation approach was utilised to achieve objective iii and iv by developing two artefacts based on build and evaluate procedures i.e., a hybrid access control security model and software tools for testing the model. Design and creation is an approach that involves creation of technological artefacts in form of methods, constructs, models and instantiations such as systems and prototypes[65], [178]. This approach follows several procedures which include building, evaluating, theorizing and justifying[65]. This approach was chosen because it is technology oriented and it enables conceptualization of the idea.

This research is based on the design science methodology which is oriented towards creating new innovative artifacts such as models, constructs and instantiations following a rigorous process[179]. Two artifacts (a web application and a mobile application) were designed and created following a user centered approach and an iterative design process. The iterative process comprised of various phases of pilot and field studies but in this study, the focus was on the two major field studies.

### **3.6.1 User centered design approach**

A user centered design process is followed in this research. User centered design (UCD) is a design process in which designers focus on the users and their needs in each phase of the design process.

International Organization of Standardization (ISO), an organization dedicated to bringing professionals and experts together to set industrial, scientific, and business standards recommends four steps to follow when using the UCD approach[180]. In this thesis, the four steps were followed as shown in figure 4 below.

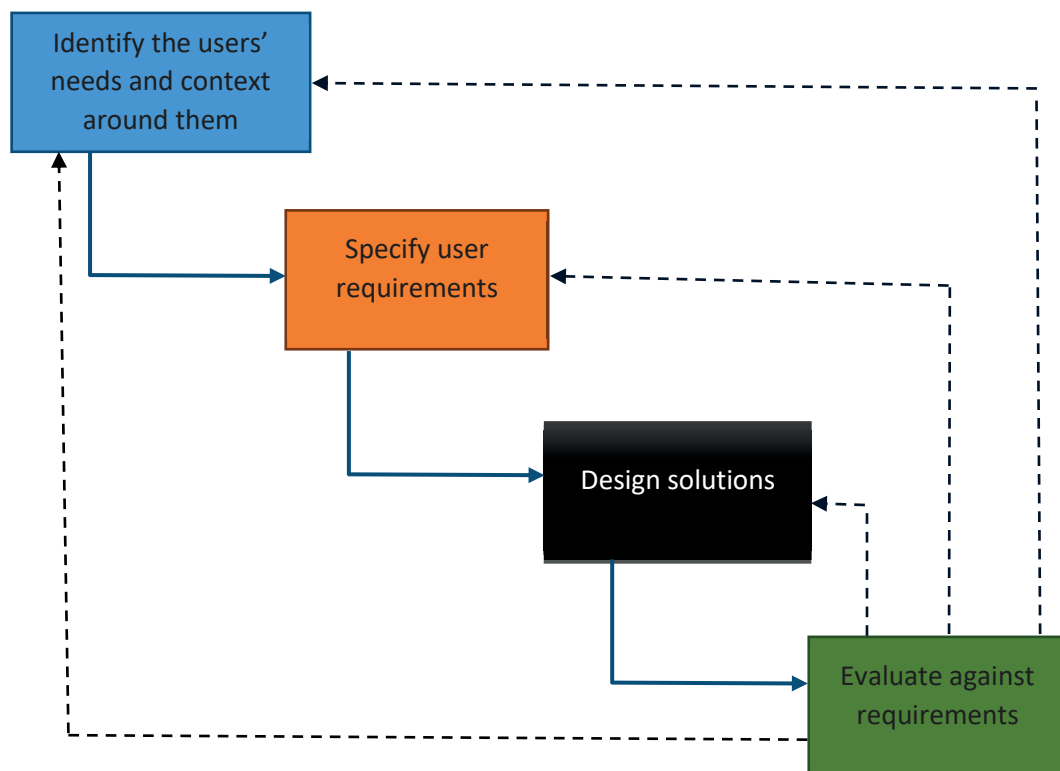


Figure 4: User Centered Design steps

### Step 1. Identify the users' needs and context around them

The first step was to find out everything that needed to be known about the users (illiterate pregnant women and health practitioners) in order to craft a product that satisfies their needs. This required asking and answering:

1. Who will be using the applications?
2. What are the users' problems that the applications will directly or indirectly solve?
3. How are they going to be interacting with the applications?

## **Step 2. Specify user requirements**

The second step was to specify user requirements. This entailed everything the users stand to gain from the design process, and it required answering the question “why is this design beneficial for the user?” This included:

- The problems the design is solving
- Scope of the design.
- The results of successful design

## **Step 3. Design solutions**

Once the users’ needs were identified, it was time to design solutions. This involved building and deciding on the assets to use to address the target users’ issues and the assets included mockups, colors, user flow, images, and icons.

## **Step 4. Evaluate**

The designs in step 3 were analyzed and evaluated against the user requirements while reflecting on the following questions:

1. How are our users responding to the applications?
2. Did the applications solve the users’ issues and pain points?
3. Where can we improve the applications?
4. Where did the process go right? Why?
5. Where was the struggle? Why?
6. What lessons can we take away from this process for future applications?

Whenever the user requirements that were set were not yet met, the user centered design process was repeated, and this is referred to as iterating. Using the knowledge gained in the previous round, changes were made until the users’ needs were met and the application was implemented in practice.

### **3.6.2 User involvement**

In UCD, the users were involved throughout the design process to create a usable and acceptable application for them. We used two investigative methods and tools in the form of surveys and

interviews, and two generative methods, that is brainstorming and focus group discussions to get a clear understanding of user needs.

Research and design techniques for engaging users in the different design phases were used as suggested by Preece, et. al[181], [182] and summarised in the table below

Technique	Purpose	Stage of the Design Cycle
Background Interviews and questionnaires	Were used in collecting data related to the needs and expectations of users; evaluation of design alternatives and prototypes.	At the beginning of the design process
Focus groups	To discuss issues and requirements with the stakeholders (illiterate and semi-illiterate pregnant women, and health practitioners).	Early in the design cycle
Prototyping	Evaluation of designs and gaining additional information about user needs and expectations (prototype evaluation)	Early and mid-point in the design cycle
Usability testing	Collecting data related to measurable usability criteria.	Final stage of the design cycle
Interviews and questionnaires	Collecting qualitative data related to user satisfaction with the artefact	Final stage of the design cycle

Table 11: Users involvement in the design process

It is however important to note that UCD follows an iterative process such as iterative prototyping.

### 3.6.3 Iterative prototyping

This research utilized iterative prototyping. Prototyping refers to rapidly creating a rough draft of a design that can be used to gather feedback. Prototypes were built, tested, and then reworked when needed depending on the users' feedback until an acceptable prototype was achieved.

Unlike other prototyping methods such as parallel prototyping where various prototypes are developed at the same time, in iterative prototyping, one prototype is developed, its success is evaluated through testing and then the feedback is used to make improvements in the next iteration.

The six software development life cycle phases of prototyping were followed as illustrated in the figure below.

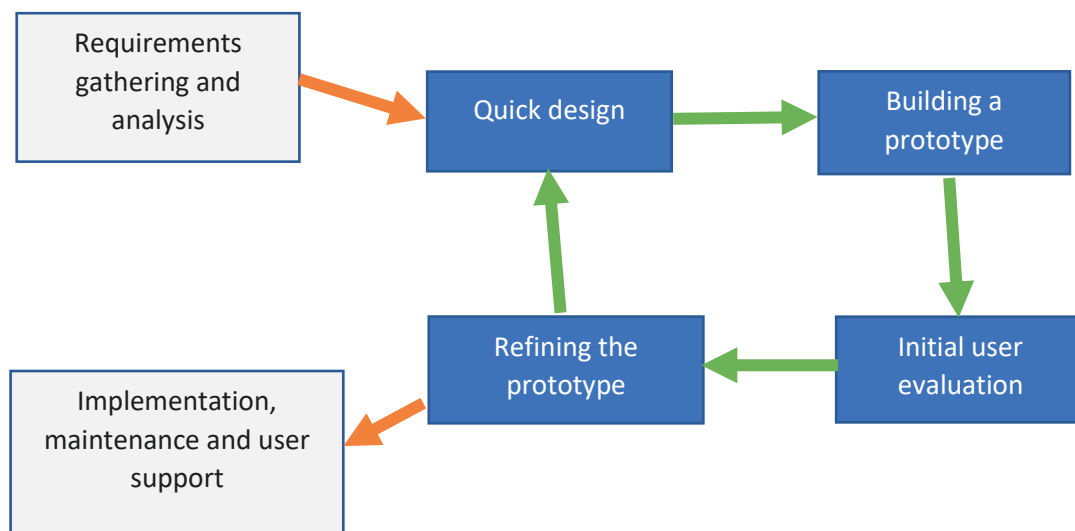


Figure 5: Iterative prototyping cycle

**Requirements gathering and analysis:** In this first phase, user requirements were gathered and analysed. During this phase, the users of the applications were consulted to know their expectations of the applications.

**Quick design:** The second phase of prototyping was to create a simple preliminary design of the applications. This was not a complete design but rather something to give a brief idea of the applications to the user. This quick design helped in the next step of developing the prototype.

**Building a prototype:** An actual prototype based on the information gathered from quick design was designed in this phase. This prototype was a small working model of the required applications.

**Initial user evaluation:** The prototype was presented to the users for an initial evaluation and feedback in form of comments and suggestions. This helped to find out the strength and weakness of the prototype.

**Refining the prototype:** The feedback from the users was used to refine the prototype. This phase was repeated until all the requirements specified by the users were met.

**Implementing the application and providing user support:** The final prototype was thoroughly tested for usability and functionality by the users before it was implemented in practice. Support was also provided to the users in case of training and application failures.

Considering the complexity of designing for illiterate users, iterative prototyping was chosen because it is suitable for refining ideas and discovering previously unknown issues. By testing out different ideas with prototypes, we could improve the designs to meet our illiterate users' needs.

### **3.7 Model design**

In this hybrid model (T2RoL), a fusion of the Role Based Access Control model, TeaM-based Access Control model and Task Based Access Control model is done to harness the integrative synergy of the individual models, while eliminating their weaknesses. Hybridization can be achieved either through a model transformation[183] or full model integration[184]. In this research, we opted for the fully integrated model, which is characterised by assimilation of different components of individual models[184]. The integration process is illustrated in Figure 6.



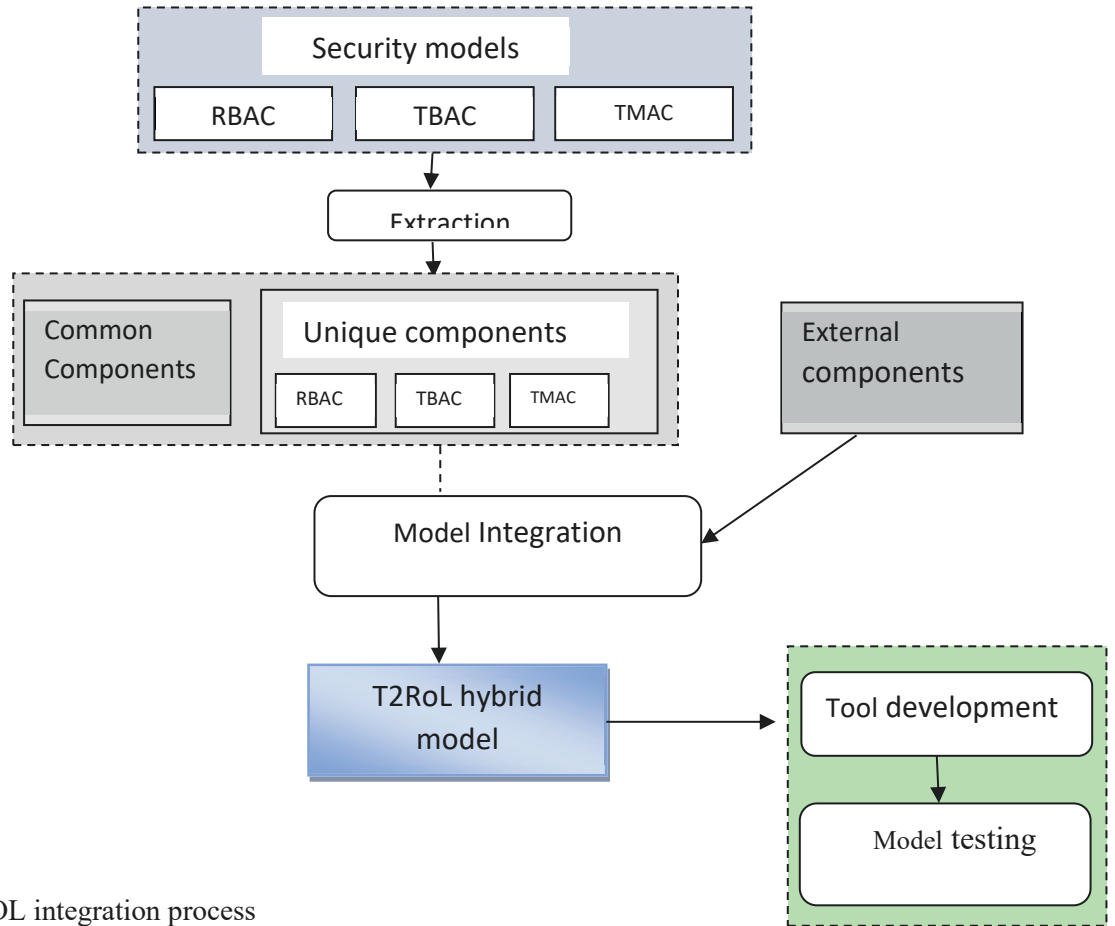


Figure 6: T2ROL integration process

In the T2RoL hybrid model, we extract, isolate, and integrate the common and unique components of RBAC, TBAC and TMAC that enhance their strengths. External components that eliminate the weaknesses of the three security models are integrated into the hybrid model. External components such as location assignments that ensure privacy of users sharing mobile devices and components that enable collaboration between teams are integrated into the model.

### 3.7.1 Model testing

The model is tested using software tools- a web application and a mobile application. The applications are designed to capture the four core attributes of the model namely: task, role, team, and location of the user. The user can only be granted access to the system resources only if the four attributes have been verified.

## CHAPTER 4. RESULTS FROM FIRST FIELD STUDY

### 4. Introduction

This study was aimed at gathering user requirements, information preference and design challenges that may be expected. The results for the study are user requirements, information preference and design challenges for low resource settings.

#### 4.1 Participant characteristics

47 pregnant women, 18 health practitioners and 14 designers/ developers were screened. Then 25(53.2%) pregnant women, 10(55.6%) health practitioners in the field of maternal health and 10(71.4%) designers/ developers of mHealth applications for low resource settings were recruited based on the criteria in table 12 below

Exclusion criteria for interview participants		
Pregnant women excluded (n=22)	Health practitioners excluded (n=8)	Designers/ developers excluded (n=4)
<ul style="list-style-type: none"><li>• Below 18 years (n=5; 22.7%)</li><li>• Unwilling to give consent (n=17; 77.3%)</li></ul>	<ul style="list-style-type: none"><li>• Unwilling to give consent (n=8; 100%)</li></ul>	<ul style="list-style-type: none"><li>• Unwilling to give consent (n=4; 100%)</li></ul>
Exclusion criteria for FGD participants (Screened from interview participants)		
Pregnant women excluded (n=15)	Health practitioners excluded (n=5)	
<ul style="list-style-type: none"><li>• Living more than 10km from study location (n=7; 46.7%)</li><li>• No access to a basic smart phone (borrowed or owned) (n=8; 53.3%)</li></ul>	<ul style="list-style-type: none"><li>• No access to a computer (n=5; 100%)</li></ul>	

Table 12: Exclusion criteria

Participant characteristics are presented in the table 13 below

It is important to note that all the participants recruited participated in their respective categories

<b>Participants for interviews</b>	
<b>Characteristic</b>	<b>n(%)</b>
<b>Pregnant women</b>	<b>25 (100%)</b>
Illiterate	11(44%)
Semi-illiterate	14(56%)
Access to smartphone (owned or borrowed)	15(60%)
Mean age	28
HIV positive	6 (24%)
<b>Health practitioners</b>	<b>10(100%)</b>
Female	6(60%)
Male	4(40%)
Doctors	3(30%)
Nurses	7(70%)
Mean age	32
Access to computer	6(60%)
<b>Designers/ developers</b>	<b>10(100%)</b>
Male	7(70%)
Female	3(30%)
Mean age	27
<b>Participants for FGD and prototype testing</b>	
Pregnant women	10(40%)
Health practitioners	5(50%)

Table 13: Participant characteristics

## 4.2 User requirements

The user requirements are categorized into functional and non-functional requirements. Functional requirements are requirements that explain how the system works and how it should behave based on the input data while non-functional requirements are requirements that define how the system is supposed to behave[185].

#### 4.2.1 Functional requirements

Functional requirement	Description	Example quote
Creating/uploading multimedia messages	The applications should enable the users to create multimedia content (videos, audio, pictures, and text in the native language) and/or upload multimedia messages created externally.	<i>An application that enables me to create and send health related videos and audios to my patients would be feasible for my work. (32 years, female, doctor)</i>
Sending and receiving messages	The users required the applications to receive monthly and/or send multimedia messages.	<p><i>I would be glad to receive information about my pregnancy monthly. This would save me the hassle of going to the hospital to going to inquire. (Semi-illiterate, 28 years, pregnant woman)</i></p> <p><i>When I need to buy unprescribed drugs, I am not sure if they are compatible with my ARVs. It would be helpful to contact my doctor and ask instead of disclosing my HIV status to pharmacists. (32 years, illiterate, pregnant woman)</i></p>
Viewing, retrieving, and deleting messages	The mobile application should enable women to view, retrieve or delete multimedia messages.	<i>I would like the application to allow me view or listen to my previous messages whenever I want to or when I want to show a friend. (Illiterate, 38 years, pregnant woman)</i>

Entering, updating, and deleting patient data	The web application should enable health practitioners to enter, update or delete patient (pregnant women) data.	<i>An application that can enable me to manage my patients' records would make my work more efficient and interesting. (30 years, male, nurse)</i>
Sending and receiving reminders	The applications shall support audio reminders. The pregnant women shall receive audio reminders for their next antenatal visits at least a day before the appointment date.	<i>Sometimes I forget my appointment date because I am unable to record it somewhere for reference. A reminder a day before my appointment would be very helpful. (40 years, illiterate, pregnant woman)</i>

Table 14: Functional requirements

#### 4.2.2 Non-functional requirements

<b>Non-functional requirements</b>	<b>Description</b>	<b>Example quote</b>
Multimedia based	The women were interested in receiving the messages in audio and video formats, but the semi-illiterate ones also showed interest in text messages in the native language.	<i>Videos and audios in Runyankole are convenient for me because I am unable to read and write. (38 years, illiterate, pregnant woman)</i>
Easy to use	The applications should be easy for the users to navigate. The mobile application should have voice-overs explaining what the buttons/ icons do or icons should be of items that women are familiar with.	<i>It is difficult for me to remember all the new things I have seen in the demo. Using items that I know would make it easy for me, for instance the save icon can be replaced with an image of a granary. (40 years, illiterate, pregnant woman)</i>

		<i>I would prefer a voice that tells me what I am about to do when I am using the application. (28 years, semi-illiterate, pregnant woman)</i>
Information security	The applications should provide authentication mechanisms for users before access to information is granted.	<p><i>We deal with a lot of sensitive health information, any intervention that captures this information must be very secure. (45 years, male, doctor)</i></p> <p><i>I fear disclosing my HIV status and losing my marriage and being isolated by my family. I therefore wish to have any information about my condition to remain strictly between me and my doctor. (36 years, HIV positive, illiterate, pregnant woman)</i></p>
Mobile based and free of charge	The pregnant women wanted a free application that would run on mobile phones because they reported having access to mobile phones and no access to other devices such as tablets and computers.	<p><i>Having the information on my phone is appropriate for me because I can access it any time. However, if any money is required, it would be difficult for me since I have no job. (30 years, semi-illiterate, pregnant woman)</i></p> <p><i>I prefer getting the information on my phone because that will guarantee access to the information any time even if I miss a health talk. (33 years, illiterate, pregnant woman)</i></p>

Cheap to implement and maintain	The cost of implementing and maintaining the application should be low and affordable for the health facilities.	<i>We usually run on a very strict budget. Any intervention that is expensive to implement would most likely be rejected.</i> (47 years, female, nurse)
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Table 15: Non-functional requirements

### 4.3 Information preference

We presented to the pregnant women twelve categories of information which we derived from literature and requested them to choose the ones they considered very important. Their preferences are shown in figure 7.

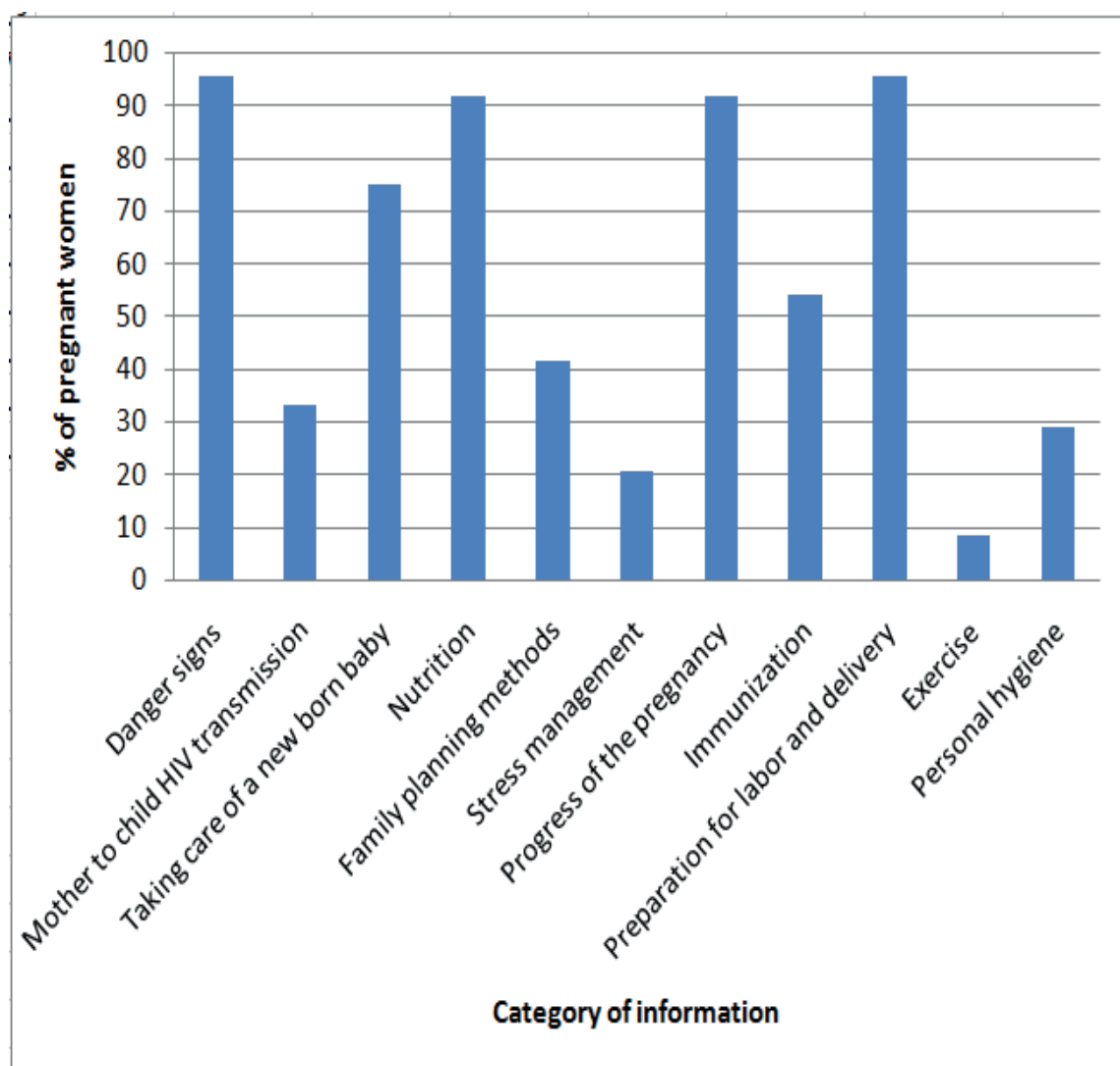


Figure 7: Women's information preference

## **4.4 Design challenges**

### **Illiteracy and poverty**

Participants reported illiteracy and poverty as limiting factors for participation when designing for low resource settings.

*Participants may not afford travel costs to participate in design and training sessions, yet illiterate users have unique requirements that require their involvement. (35 years, female, designer)*

### **Change management and bureaucracy delay implementation.**

Managing changes in design especially when users have not been involved in the initial design phases and bureaucracy were also reported to pose challenges.

*Drastic changes in already made designs, and bureaucratic procedure of logistics delay implementation. However, constant training and involvement of users in all design phases helps. (24 years, female, designer)*

### **Unstable telecom and internet connections**

Participants further reported unstable telecom and internet connections as a design and implementation challenge especially in remote villages.

*Whenever the network connection was bad and field data was needed urgently, we would move in search of a better connection on a nearby hill because raised grounds had better connectivity. (29 years, male, designer)*

### **Power shortages**

Limited access to reliable power makes it difficult for users in low resource settings to charge mobile phones and this hinders interventions that require real time communication and data sharing.

*Some villages have no power connections or are disconnected from the power grid due to power rationing which makes it hard to implement real time interventions. Providing solar chargers helps. (31 years, female, developer)*



It should be noted that the participants emphasized the need for security of the information the applications. To achieve this requirement, the T2RoL access control model was developed and utilized in the development of the applications.

## **CHAPTER 5: THE T2ROL ACCESS CONTROL MODEL**

### **5. Integrating RBAC, TBAC, TMAC and Location**

In RBAC, a user can have access to several permissions assigned to a role which that user is assigned to whereas in TMAC, users have access to permissions available to the team in which they belong. On the other hand, in TBAC, users have access to permissions based on the tasks they are assigned to. As earlier discussed in chapter 2, these models face challenges. In T2RoL, RBAC, TBAC and TMAC were integrated, and location information included in the security model.

#### **5.1 The formal description of T2RoL access control model**

The new model has been developed based on the set theory by Schindler[186] and Model theory by Ebbinghaus and Flum[187]. The model consists of eight components namely users, tasks, roles, teams, permissions, locations, patients, and sessions. Each of these components has been included because of their individual purposes. A user (u) is a mobile subject whose purpose is access and utilizes the system. A task (t) is a unit of workflow. The purpose of tasks in the model is to enable all processes to have access to resources because with tasks, permissions can change as tasks progress, and authorisations have strict validity and expiration features. On the other hand, a role (r) is a job function associated with the responsibility and qualifications of a user to perform tasks. Roles enable separation of duties and enables scalability because security can be administered to all users belonging to the same role which reduces administrative overhead costs associated with security administration at individual users, and permissions levels.

A team (tm) is a group of users with a goal of achieving a given task. The importance of teams in the model is to facilitate scalability and also enable dynamic management of permissions. With teams as well, security can be administered to all users belonging to the same team. A permission (p) is an approval to access data objects and to execute operations. Permissions enable distribution of system resources among the users. A location (l) is an area from where health services are offered and received, and it is categorized into hospital location and mobile location. A hospital location (hl) represents an area identifiable by the system within the hospital premises, mobile location (ml) refers to the area within the mobile clinic outside hospital premises. The importance of location is to restrict access of system resources in inappropriate locations that may jeopardise the privacy of the patients' information. A patient (pa) is a person who accesses health services from the hospital location or mobile location. The patient is required in the model to provide consent to access patient

records. A session (s) is a duration during which a user utilises system resources. Sessions enable tracking of users and their utilisation of the system resources (who used the system resources, when, and for how long).

A user can be assigned to tasks, roles, teams, patients, and location. Much as the scalability enabled by roles and teams is important, if not well managed, it may lead to running of too many processes and slow down the system especially in big health facilities with many employees. One way to overcome this is use of high processing power computers/ servers. Since this model is meant for developing countries that may not have high processing power computers and servers, we restrict users to have one role and one team in each session. However, a user can switch to a different role and team in a different session. On the other hand, the user can have more than one task in a session because in a health care setting, the role has many tasks involved that may be required in a single session. For instance, in a session, a user may need to view the patient records, update the records, order a lab test, etc for the same patient in that session.

Another attribute of the models is that the user must be in one location (either hospital location or mobile location) because logically, it is not possible to be in the hospital and be in the mobile clinic at the same time. Secondly, it enables security of patient information since authentication mechanisms are linked to the location, for instance, the patient and the user need to be in the same mobile location.

It is important to note that unlike users, patients do not actively access and use the system resources during the session which is why they are not associated with the session and permissions but rather associated with the users. Finally, there is an assumption that every session has only one patient associated to it because in real life settings, the health practitioner attends to one patient at a time.

The model is based on two conditions,

1. Permissions are given based on tasks, roles, teams, the location of the user in hospital location and the patients assigned to the user.

Users in a hospital location are granted access when there is an active session and, in that session, 1) the user has at least a task assigned in which case permission is assigned to the

task, 2) the user has a role and permission is assigned to that role, 3) the user belongs to a team and permission is assigned to the team, 4) the user is assigned a patient and permission is assigned to the patient. In this case the patient does not necessarily have to be in the same hospital location for the user to access patient data, for instance if the data is accessed for research purposes, and 5) the user is assigned a hospital location and the permissions are assigned to that location.

In this model, we assume that the location of the user in the hospital can be identified and verified by the network based on the underlying network architecture.

2. Permissions are given based on tasks, roles, teams, and the mobile location of the user and patient. Both the user and the patient must be in the same location in the mobile location for access to be granted. Just like in condition 1, users are assigned tasks, roles, and teams in condition 2, and permissions are assigned to these attributes. In summary, for a user to have permission to access the resources outside the hospital, there must be an active session, and in that session, the user must be assigned a task (t), a role (r), a team (tm) and a mobile location (ml).

The model is made up of finite sets:

(U, T, R, TM, L, HL, ML, P, PA, S, UT, UR, UTM, UL, UHL, UML, PL, PEMPL, UPA, PPA, PT, PR, PTM, SU, SUT, SUR, SUTM, SUL, SUP) where

- U is a set of users,
- T is a set of tasks,
- R is a set of roles,
- TM is a set of teams,
- PA is a set of patients,
- L is a set of locations
- HL is a set of hospital locations,
- ML is a set of mobile clinic locations
- P is a set of permissions, and
- S is a set of sessions.

Where assignments

- $UT \subseteq U \times T$  is a many-to-many relation assigning users to tasks,
- $UR \subseteq U \times R$  is a many-to-many relation assigning users to roles,
- $UTM \subseteq U \times TM$  is a many-to-many relation assigning users to teams,
- $UL \subseteq U \times L$  is a many-to-many relation assigning users to locations,
- $UHL \subseteq U \times HL$  is a many-to-many relation assigning users to hospital locations,
- $UML \subseteq U \times ML$  is a many-to-many relation assigning users to mobile clinic locations,
- $PAML \subseteq PA \times ML$  is a many-to-many relation assigning patients to mobile clinic locations,
- $UPA \subseteq U \times PA$  is a many-to-many relation assigning users to patients,
- $SU \subseteq S \times U$  is a many-to-many relation assigning sessions to users,
- $PT \subseteq P \times T$  is a many-to-many relation assigning permissions to tasks,
- $PR \subseteq P \times R$  is a many-to-many relation assigning permissions to roles,
- $PTM \subseteq P \times TM$  is a many-to-many relation assigning permissions to teams,
- $PPA \subseteq P \times PA$  is a many-to-many relation assigning permissions to patients,
- $PL \subseteq P \times L$  is a many-to-many relation assigning permissions to locations.

And where assignments

- $SUT \subseteq S \times UT$ : Users with assigned tasks are assigned a session in a many to many relation
- $SUR \subseteq SU \times R$ : Users in the session are assigned roles in a many to one relation
- $SUTM \subseteq SU \times TM$ : Users in the session are assigned teams in a many to one relation
- $SUL \subseteq SU \times L$ : Users in the session are assigned locations in a many to one relation
- $SUP \subseteq S \times U \times P$ : Users are assigned permissions within a session and that session is assigned in a many to many relation

For condition 1, the following applies

$$\forall s, \forall u, \forall p (((s, u, p) \in \text{SUP}) \leftrightarrow$$

$$(\exists t((s, (u, t)) \in \text{SUT} \wedge (p, t) \in \text{PT})$$

$$\wedge \exists r(\text{SUR}(s, u) = r \wedge (u, r) \in \text{UR} \wedge (p, r) \in \text{PR} )$$

$$\wedge \exists \text{tm}(\text{SUTM}(s, u) = \text{tm} \wedge (u, \text{tm}) \in \text{UTM} \wedge (p, \text{tm}) \in \text{PTM})$$

$$\wedge \exists \text{pa}((u, \text{pa}) \in \text{UPA} \wedge (p, \text{pa}) \in \text{PPA})$$

$$\wedge \exists l(\text{SUL}(s, u) = l \wedge (u, l) \in \text{UHL} \wedge (p, l) \in \text{PL}))$$

For all sessions (s), users (u), permissions (p), (s, u, p) is an element of SUP if and only if all the following five conditions hold.

- a. There exists a task (t) assigned to a user (u) in that session such that (s, (u, t)) is an element of SUT and (p, t) is an element of PT. A user can have more than one task in the same session.
- b. There exists a role (r) assigned to a user (u) in that session such that (u, r) is an element of UR and (p, r) is an element of PR. A user can have only one role in a session.
- c. There exists a team (tm) assigned to a user (u) in that session such that (u, tm) is an element of UTM and (p, tm) is an element of PTM. A user can belong to only one team in a session.
- d. There exists a patient (pa) assigned to the user (u) such that (u, pa) is an element of UPA and (p, pa) is an element in PPA.
- e. There exists a location (l) assigned to the user (u) in the session such that (u, l) is an element of UHL and (p, l) is an element of PL.

For condition 2, the following applies

$\forall s, \forall u, \forall p ((s, u, p) \in \text{SUP}) \leftrightarrow$

$(\exists t((s, (u, t)) \in \text{SUT} \wedge (p, t) \in \text{PT}))$

$\wedge \exists r(\text{SUR}(s, u) = r \wedge (u, r) \in \text{UR} \wedge (p, r) \in \text{PR})$

$\wedge \exists \text{tm}(\text{SUTM}(s, u) = \text{tm} \wedge (u, \text{tm}) \in \text{UTM} \wedge (p, \text{tm}) \in \text{PTM})$

$\wedge \exists \text{pa}((u, \text{pa}) \in \text{UPA} \wedge (p, \text{pa}) \in \text{PPA})$

$\wedge \exists l(\text{SUL}(s, u) = l \wedge (u, l) \in \text{UML} \wedge (p, l) \in \text{PAML} \wedge (p, \text{pa}) \in \text{PPA}))$

For all sessions (s), users (u), permissions (p), (s, u, p) is an element of SUP if and only if all the following four conditions hold

- a. There exists a task (t) assigned to a user (u) in that session such that (s, (u, t)) is an element of SUT and (p, t) is an element of PT. A user can have more than one task in the same session.
- b. There exists a role (r) assigned to a user (u) in that session such that (u, r) is an element of UR and (p, r) is an element of PR. A user can have only one role in a session.
- c. There exists a team (tm) assigned to a user (u) in that session such that (u, tm) is an element of UTM and (p, tm) is an element of PTM. A user can belong to only one team in a session.
- d. There exists a patient (pa) assigned to the user (u) such that (u, pa) is an element of UPA and (p, pa) is an element in PPA.
- e. There exists a location (l) assigned to the user (u) in the session such that (u, l) is an element of UML, and (p, l) is an element of PAML, and (p, pa) is an element of PPA.

## 5.2 Application Example of T2RoL model

Due to poor infrastructure that makes it hard for women to frequently travel long distances to the hospital to access maternal health related services, a referral hospital decides to temporarily extend its maternal health services to remote villages by operating mobile clinics. The hospital dispatches teams of health experts and medical lab scientists but realizes the need for the teams to have access to the health records of the patients (women in the villages they are going to) which are securely kept on the server in the hospital. The teams decide to carry mobile devices that have an app

installed to enable them to access patients' records but there is a need for a secure mechanism to access the records. In this example, the referral hospital represents the hospital location whereas the mobile clinic represents the mobile location.

In this example John, Sarah, David, Mary, and Barbra are users belonging to different collaborating teams with different tasks and roles. Apart from Barbra, the others are operating outside hospital premises in what we may refer to as a mobile clinic and using mobile devices to access patient data from the hospital. John later relocates to the hospital location and assumes a different role in a different team in a different session.

$U = \{\text{John, Mary, Sarah, David, Barbra}\}$

$PA = \{\text{Joyce, Betty, Alice}\}$

$R = \{\text{gynecologist, medical lab scientist, cardiologist}\}$

$T = \{\text{update patient records, fill results form, give consent}\}$

$TM = \{\text{Health experts, medical lab team}\}$

$L = \{\text{hospital, mobile clinic}\}$

$P = \{\text{access patient records, access lab results form, access consent method}\}$

$S = \{s1, s2\}$

$PT = \{(\text{access patient records, update patient records}), (\text{access lab results form, fill results form}), (\text{access consent method, give consent})\}$

$UR = \{(\text{John, gynecologist}), (\text{John, medical lab scientist}), (\text{Sarah, gynecologist}), (\text{Mary, medical lab scientist}), (\text{David, medical lab scientist}), (\text{Barbra, cardiologist})\}$

$PR = \{(\text{access patient records, gynecologist}), (\text{access lab results form, medical lab scientist}), (\text{access patient records, cardiologist})\}$

$UTM = \{(\text{John, Health experts}), (\text{John, medical lab team}), (\text{Sarah, Health experts}), (\text{Mary, medical lab team}), (\text{David, medical lab team}), (\text{Barbra, Health experts})\}$



PTM = {(access patient records, Health experts), (access lab results form, medical lab team)}

UPA = {(John, Joyce), (Sarah, Betty), (Mary, Joyce), (Mary, Betty), (David, Joyce), (David, Betty), (David, Joyce), (Barbra, Alice), (John, Alice)}

PPA = {(access consent method, Joyce), (access consent method, Betty), (access consent method, Alice)}

PL = {(access patient records, hospital), (access lab results form, hospital), (access consent method, hospital), {(access patient records, mobile clinic), (access lab results form, mobile clinic), (access consent method, mobile clinic)}

SUP = {(s1, John, access patient records), (s1, Sarah, access patient records), (s1, Mary, access lab results form), (s1, David, access lab results form), (s2, Barbra, access patient records), (s2, John, access lab results form)}

SUT = {(s1, (John, update patient records)), (s1, (Sarah, update patient records)), (s1, (Mary, fill results form)), (s1, (David, fill results form)), (s2, (Barbra, update health records)), (s2, (John, fill results form))}

SUR = {((s1, John), gynecologist), ((s1, Sarah), gynecologist), ((s1, Mary), medical lab scientist), ((s1, David), medical lab scientist), ((s2, Barbra), cardiologist), ((s2, John), medical lab scientist)}

SUTM = {((s1, John), Health experts), ((s1, Sarah), Health experts), ((s1, Mary), medical lab team), ((s1, David), medical lab team), ((s2, Barbra), Health experts), ((s2, John), medical lab team)}

SUL = {((s1, John), mobile clinic), ((s1, Sarah), mobile clinic), ((s1, Mary), mobile clinic), ((s1, David), mobile clinic), ((s2, Barbra), hospital), ((s2, John), hospital)}

PAML = {(Joyce, mobile clinic), (Betty, mobile clinic), (Alice, hospital)}

### 5.2.1 The assignment process condition 1 of the model (in the hospital location)

Using Barbra, John and Alice as examples

**Step1 - Detecting task:** From the assignment  $SUT = \{(s2, (Barbra, \text{update patient records})), ((s2, \text{John}), \text{fill results form})\}$ , Barbra and John's tasks are detected in session 2 and task permissions assigned via the assignment  $PT = \{(\text{access patient records}, \text{update patient records}), (\text{access lab results form}, \text{fill results form})\}$ .

**Step 2 – Detecting role:** Using assignment  $SUR = \{((s2, Barbra), \text{cardiologist}), ((s2, \text{John}), \text{medical lab scientist})\}$ , Barbra and John's roles are detected in session 2 and role permissions assigned via the assignment  $PR = \{(\text{access patient records}, \text{cardiologist}), (\text{access lab results form}, \text{medical lab scientist})\}$ .

**Step 3 - Detecting team:** From the assignment  $SUTM = \{((s2, Barbra), \text{Health experts}), ((s2, \text{John}), \text{medical lab team})\}$ , Barbra and John's teams are detected in session 2 and team permissions assigned via the assignment  $PTM = \{(\text{access patient records}, \text{Health experts}), (\text{access lab results form}, \text{medical lab team})\}$ .

**Step 4 - Detecting patients assigned:** From the assignment  $UPA = \{(Barbra, Alice), (John, Alice)\}$ , Barbra and John's patients are detected, and patient permissions assigned via the assignment  $PPA = \{(\text{access consent method}, Alice)\}$ .

**Step 5 - Detecting location:** Using the assignment  $SUL = \{((s2, Barbra), \text{hospital}), ((s2, \text{John}), \text{Hospital})\}$ , Barbra and John's locations are detected in session 2 and location permissions assigned via the assignment  $PL = \{(\text{access patient records}, \text{hospital}), (\text{access lab results form}, \text{hospital})\}$

**Step 6 - Granting permissions:** For Barbra to access Alice's health records, permissions from step 1 - 5 must be granted. In other words, Barbra must be assigned a task to update patient records, a role as a cardiologist, assigned to the team of Health experts, be assigned Alice as her patient,

and be in the referral hospital before any access privileges are granted to her. The same steps apply for John.

### **5.2.2 The assignment process for condition 2 of the model (in the mobile location)**

(Using John, Mary as users, and Joyce, Alice and Betty as patients). It is important to note that John's tasks, role, team and location are different from the ones he had in session 2 above.

**Step1 - Detecting task:** From the assignment  $SUT = \{(s1, (John, update\ patient\ records)), (s1, (Mary, fill\ results\ form))\}$ , John's task of updating patient records and Mary's task of filling results form respectively are detected in session1, and task permissions assigned to them via the assignment  $PT = \{(access\ patient\ records, update\ patient\ records), (access\ lab\ results\ form, fill\ results\ form)\}$ .

**Step 2 - Detecting role:** Using assignment  $SUR = \{((s1, John), gynecologist), ((s1, Mary), medical\ lab\ scientist)\}$ , John's role a gynecologist and Mary's role as medical lab scientist are detected in session1 and role permissions assigned to them via the assignment  $PR = \{(access\ patient\ records, gynecologist), (access\ lab\ results\ form, medical\ lab\ scientist)\}$ .

**Step 3 - Detecting team:** From the assignment  $SUTM = \{((s1, John), Health\ experts), ((s1, Mary), medical\ lab\ team)\}$ , John's team and Mary's team are detected respectively in session1 and team permissions assigned via the assignment  $PTM = \{(access\ patient\ records, Health\ experts), (access\ lab\ results\ form, medical\ lab\ team)\}$ .

**Step 4 - Detecting patients assigned:** From the assignment  $UPA = \{(John, Alice), (John, Joyce), (Mary, Joyce), (Mary, Betty)\}$ , Mary and John's patients are detected, and patient permissions assigned via the assignment  $PPA = \{(access\ consent\ method, Alice), (access\ consent\ method, Joyce), (access\ consent\ method, Betty)\}$ .

**Step 5 - Detecting location:** Using the assignment  $SUL = \{((s1, John), mobile\ clinic), ((s1, Mary), mobile\ clinic)\}$ , John's location and Mary's location are detected in session1. From the assignment  $PAML = \{(Joyce, mobile\ clinic), (Betty, mobile\ clinic), (Alice, hospital)\}$ , Joyce, Alice and Betty's

locations are detected and permissions are then assigned to them via the assignment  $PPA = \{(access\ consent\ method, Joyce), (access\ consent\ method, Betty), (access\ consent\ method, Alice)\}$ . John, Mary, and the patients (Joyce and Betty) are in the same location (mobile clinic). Alice on the other hand is in a hospital location.

**Step 6 - Granting permissions:** For John to access Joyce's or Alice's health records, permissions from steps 1 - 5 must be granted. In other words, John must be assigned a task of updating patient records, a role as a gynecologist, assigned to the team of Health experts and be in the same location (mobile clinic) as Joyce and Alice before any access privileges are granted to him. The same applies to Mary, permissions from steps 1 – 5 must be granted before she is granted access privileges. Much as Alice is assigned to John, she is in the hospital location which means that John is unable to access her health records while in the mobile clinic.

### 5.2.3 Cases of access denial

**Case 1:** Due to the increasing number of patients, Barbra- one of the doctors from the hospital decides to spend her day off by volunteering at the mobile clinic. She is assigned a task to update patient records, a role as a cardiologist and belongs to the Health experts team in the hospital but since she is not assigned to the role of a gynecologist working in the mobile clinic, she is denied access to records of patients handled in the mobile clinic.

**Case 2:** The medical lab team in the clinic seems to be remaining with many tests to carry out. John who was a medical lab scientist before becoming a gynecologist decides to help to do some of the lab tests. However, John is denied access to permissions meant for medical lab scientists such as results entry forms because he was not assigned the task of filling results form and the team of medical lab scientist

It is important to note that access control and denial of access permissions is crucial in health care systems that capture sensitive patient information. However, if strict access control is not carefully handled, it may slow down workflow processes. To address this trade off, remote assignment of tasks, roles, teams and locations can be enabled by an administrator in the hospital before the session.

## **CHAPTER 6: PROTOTYPE DESIGN AND DEVELOPMENT**

### **6. Introduction**

The prototype comprises of a mobile application (for pregnant women) and a web application (for health practitioners). Both applications are designed based on the functional and non-functional requirements.

### **6.1 Choice of technologies**

The initial prototypes were developed on opensource platforms: the mobile application was built on MITapp inventor whereas the application was built on Bubble.is and the information from these applications was stored on a cloud server. However, the mobile application was later redesigned into a native app using Android studio for the front end, java for the backend and SQLite as the database. The interface application was also developed on these technologies whose details will be discussed in chapter 8.

#### **6.1.1 Why opensource technologies?**

Opensource platforms are those whose source code is publicly accessible for people to share and/or modify. As explained below, opensource platforms were chosen due to their advantages and suitability for prototyping as emphasised by Bonnaccorsi and Rossi[188], Scacchi[189] and West[190].

- Opensource platforms provide free libraries and frameworks requiring no licencing fees which reduces the cost of software development.
- Opensource platforms provide flexibility and agility in developing software, and they are thus convenient for prototyping and testing the feasibility of information systems in a short time, with the ability to mature to a large scale, fully supported implementation.
- Opensource platforms and software are known for their solid information security due to the swift responsiveness of the opensource community when information security problems arise, and the availability of tested code whose problems have already been identified and fixed.

- Besides, there are numerous successfully implemented web, mobile, and cloud solutions that were predominantly built on opensource infrastructure.

### **6.1.2 Why MIT app inventor?**

App Inventor is a visual programming development environment developed by MIT that provides a blocks programming interface that enables design and implementation of fully functional mobile apps on the Android operating system. Unlike other integrated development environments such as Eclipse, NetBeans and Visual studio, App Inventor was chosen because of its in-built programming blocks. These blocks facilitate quick development of apps making it suitable for prototyping and development of applications, since instead of focusing on language syntax, the developer focuses on design and programming logic[191].

In addition, App inventor does not go through the compile-load-run cycle that is typical of mobile app development, and this makes it suitable for iterative app development [192]. Besides, there is evidence that App inventor can be used to develop powerful applications, for instance, Sanskrit Essay[193] that was developed using app inventor is a popular app with over 100,000 downloads on Google Play.

### **6.1.3 Why bubble.is?**

Bubble.is is a combination of a programming tool and a cloud platform whereby the programming tool is for building the applications while the cloud platform hosts and runs the developed applications. Applications built on Bubble require no external deployment because they are hosted on Bubble's cloud infrastructure. Unlike other platforms such as webflow, Wix, and wordpress that are good for developing websites, bubble.is can be used to develop web applications such as health applications, e-commerce applications, and complex content management systems due to its custom logic and backend/ database capabilities[194], [195].

Bubble was also used due to its flexibility in design and workflows which facilitates development of responsive applications, its scalable infrastructure which is not only good for prototyping but also for development of complete fully functional applications, its ease of connecting to APIs and plugins, and its robust infrastructure that handles deployment and hosting[196].

In addition, Bubble has been used to build robust applications such as Qoins and Plato's tracking systems[197].

#### **6.1.4 Why cloud server?**

A cloud server is a virtual server that is built, hosted, and delivered via a cloud computing environment via the internet in a cloud computing environment. The researcher opted to use a cloud server because:

1. Cloud servers require no IT infrastructure or purchase of expensive hardware and maintenance on the side of the user. This being a PhD study with no budget to purchase expensive IT infrastructure, a cloud server was the only option since the health facility that the researcher worked with did not have the necessary infrastructure such as an in-house server.
2. Besides, cloud platforms have advanced, high-level security features such as data encryption and automatic routine backups, thus providing better data security than that of an in-house server. All data stays secure within the cloud minimizing data losses in disaster situations[198], [199].
3. Cloud servers are scalability, meaning they can adapt in size according to the increase and decrease in workload[200].
4. Cloud Storage is a service where data is remotely maintained, managed, and backed up. The service is available to users over a network, which is usually the internet, and backup and restore can be initiated from anywhere[201].

#### **6.1.5 Why android?**

Android is an open source mobile device platform based on Linux that includes an operating system, middleware and key applications whereby all the applications are written in Java programming language[202].

The mobile application was developed for android due to two factors:

1. Android operating system is part of the Open Handset Alliance meaning that most of the leading handset manufacturers in the world have Android phones making it the most widely used operating system[203]. Over the years (since 2012 to date), Android has held the

highest Mobile Operating System Market Share Worldwide[204], [205]. For instance, Android's market share stood at 85.9% in the second quarter of 2018 while iOS was at 14.1% [206].

2. Android is open source making it developer friendly which increases the chances of developing useful apps[207].

## **6.2 Prototype use case model**

The applications enable user authentication and handling of multimedia content. Figure 8 illustrates the use cases of the data administrator, the health practitioner, and the pregnant woman.



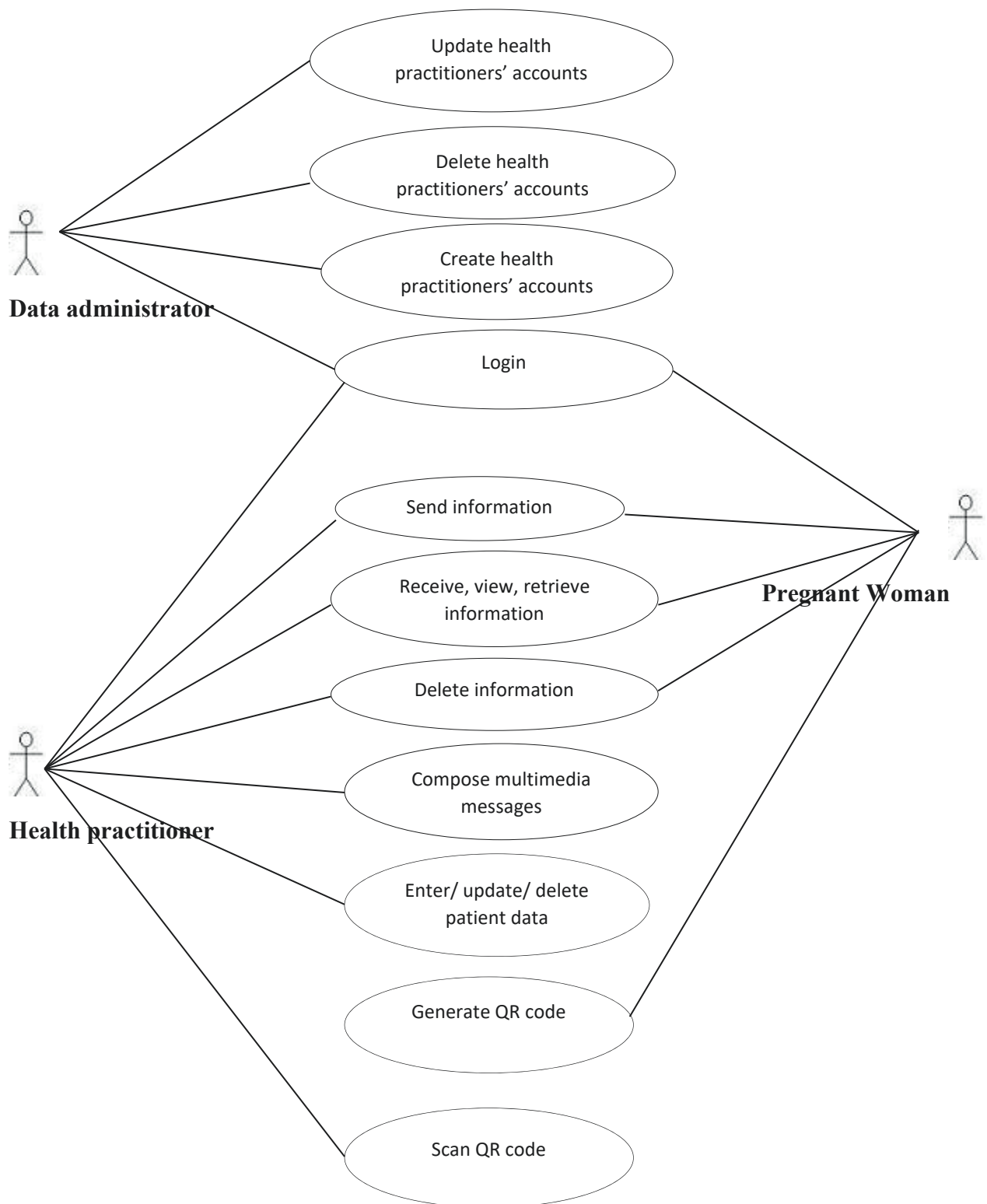


Figure 8: Use case diagram

## **6.3 Integration of the T2ROL access control model into the prototype**

### **6.3.1 Location based authentication**

According to Talasila et al.[208] and Roland van Rijswijk-Deij[209], location based authentication can be implemented in three methods:

1. Knowledge based authentication- in this method, the user already knows the attributes to use, for instance a pin and password.
2. Object- based authentication- this involves use of tokens that the user already has which may be physical such as smart cards or digital such as QR codes.
3. Identity-based authentication- this method utilizes the user's biometric attributes such as fingerprints and voice.

Choice of a location-based authentication method depends on the device, for instance choosing the identity-based method requires hardware that can capture biometric information. It is also important to compare the strength and vulnerabilities of the methods as highlighted by Boonkrong and Vongsingthong[210], Zirjawi et al.[211], and Shafique et al.[212].

For instance, use of pins and passwords is user friendly, but they are prone to various attacks such as Brute Force; use of physical tokens like smart cards are safe from software-based attacks but they can be stolen. It is therefore advisable to use a combination of different methods to minimise the vulnerabilities and ensure security[210], [213].

In this thesis, the T2RoL model was implemented by combining knowledge-based authentication in the form of username and password, and object-based authentication in the form of QR codes as the token.

The role, task and team authentication attributes of the T2RoL access control model are implemented in the web application and the multimedia mobile application. On the other hand, the interface app implements the location authentication part of the model.

Health practitioners within the hospital premises access the patient records in the web through provision of individual roles, tasks, and teams in the authentication module. When the health workers are in mobile clinics away from the hospital, they must get permission from the patients before accessing the patient records. The interface app is used by the health practitioners to scan

the QR code that is generated on the multimedia application by the patients. Alternatively, the patient can input her password on the interface application for the health practitioner to access her health records. This implies that the patient and the health practitioner must be in the same location (mobile clinic).

## 6.4 Prototype development

The mobile app and the web application were developed first before the interface app was later integrated because the core functionalities of the mobile and web applications are not affected by the interface application.

### 6.4.1 Development of mobile application and web application

Initially the mobile application was developed on the MIT app inventor platform while the web application was developed on the bubble.is platform for purposes of rapid prototyping but were later developed using Java, Android Studio and SQLite. The applications are developed based on the design summary in the figure below.

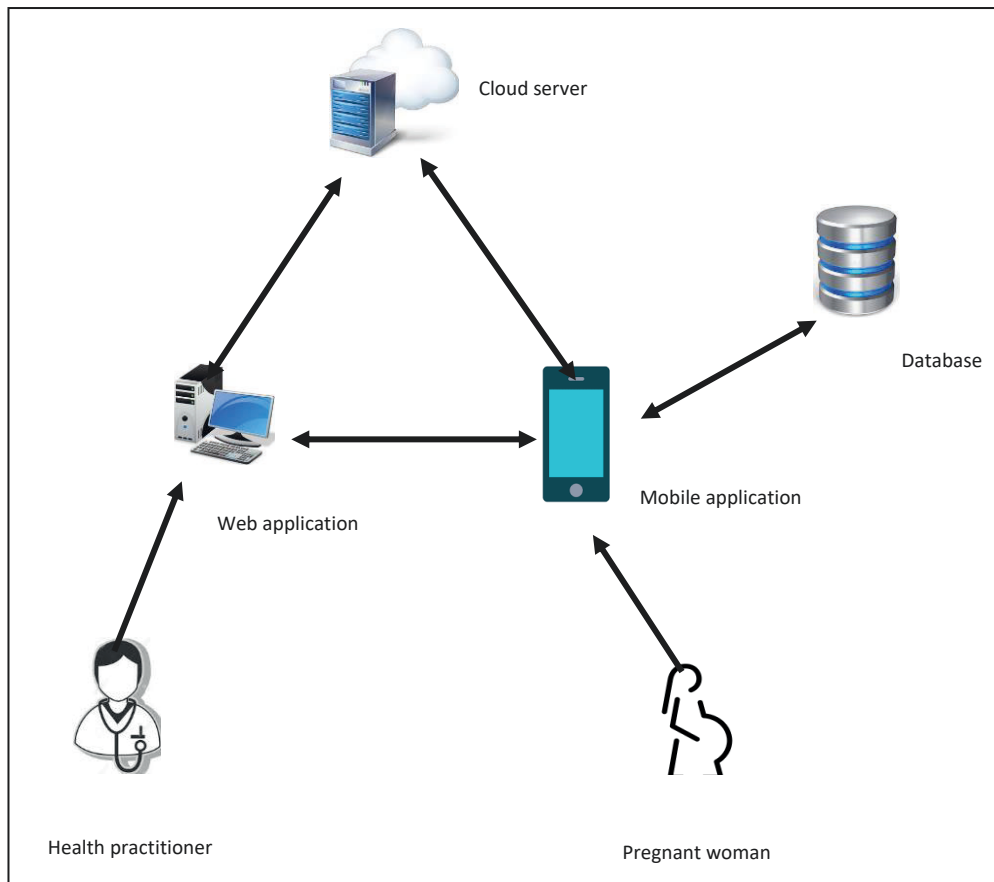


Figure 9: The general design structure of the applications

### 6.4.2 Authentication mechanisms

The non-functional requirement of security was addressed by creating a login function for each application. The web application provides the standard username and password user authentication mechanism. The mobile application has a pictorial login function to enable users who are illiterate to provide a pictorial password. This password is a pre-set combination of pictures that the user must tap before being granted access to the application.

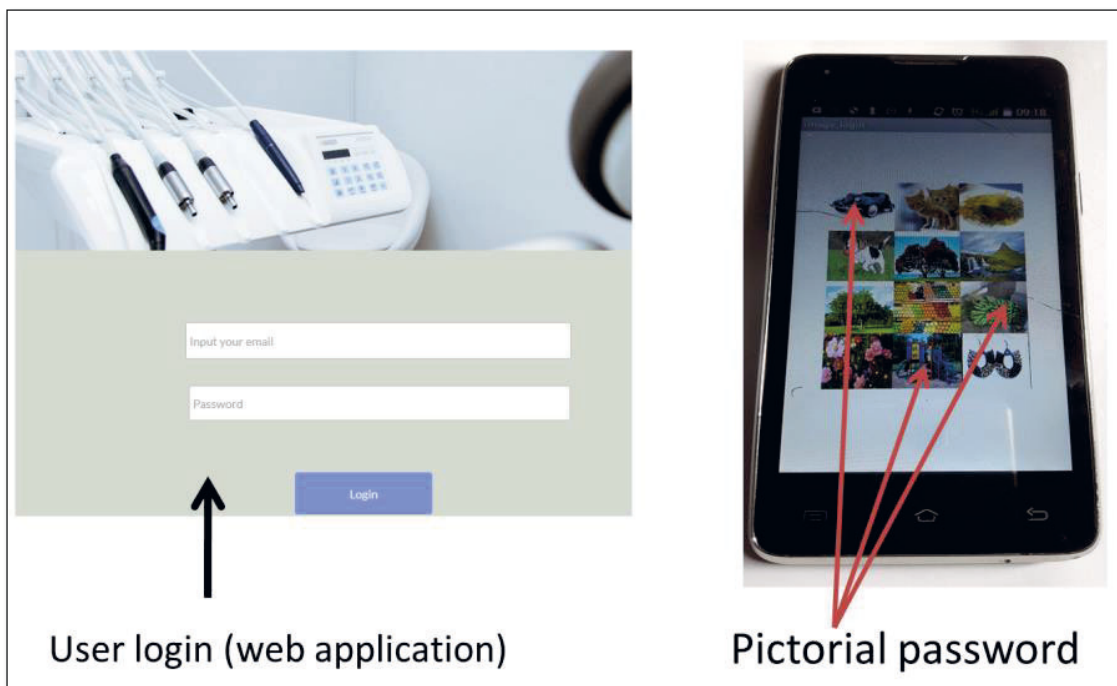


Figure 10: Login options

### 6.4.3 Information exchange and storage

An administrator registers and creates user accounts for health practitioners based on their roles, tasks, and teams. Using individual accounts, the health practitioners can then access the web application.

When the pregnant woman visits the antenatal clinic for the first time, maturity of her pregnancy is determined and captured in the web application together with the date of the visit. The mobile application is then installed on the woman's phone with a pre-set pictorial password of her choice. Multimedia messages tailored to the maturity of her pregnancy are sent monthly from the web application to her mobile phone via the mobile application.

The multimedia messages can be created directly using the recording and capture functions of the web application or they can be uploaded from external sources into the messenger function of the application. The woman can only access the messages in the mobile application after logging in with her pictorial password. Through the messenger function of the mobile application, she can also create multimedia messages such as inquiries by recording herself (audio or video), taking pictures or typing (if semi-illiterate) and sending the messages to the web application which are then accessed and responded to by the health practitioners.

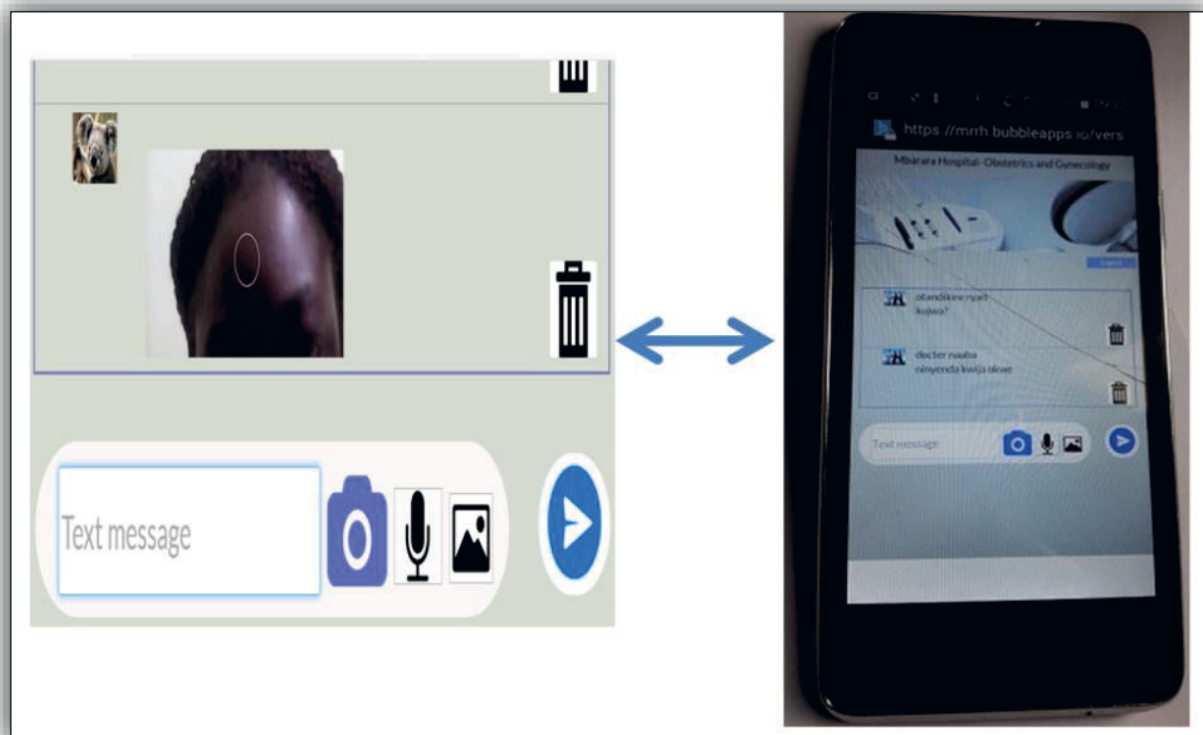


Figure 11: Communication between the applications

The information captured by the web application is currently stored on a cloud server provided by the bubble.is platform. The information on the mobile application is stored in an in-built database but a copy of the communication in the messenger function is kept on the bubble.is server.

#### 6.4.4 Reminder functionality

When the pregnant woman goes for her antenatal visit, a date for her next appointment is set and captured in the web application. The calendar embedded in the web application automatically counts down and sends the woman an audio reminder a day before her appointment. The audio

message is generalized with a message “*Your next antenatal appointment is tomorrow, please do not forget to go to the hospital*” in the native language. This message can either be recorded with in the messenger component of the web application or uploaded as an external file. The reminder is triggered to play continuously as soon as it is received in the mobile application until the user stops it.

#### **6.4.5 Help functionality**

Voice-overs have been added for the login, record, send, delete and logout icons that play when the icon is hovered to explain the action that the user will perform when they tap the icon. For instance, when the user hovers the delete icon, an audio sound plays explaining that tapping the icon will permanently remove the message. A new button was also added for de-activating the audio explanations for users who may no longer need them.

#### **6.4.6 Location authentication**

In this research, location authentication is implemented via extension of a mobile application to include a functionality of generating QR codes and an interface app. The main purpose of the interface app is to provide a mechanism for health practitioners to access patient records when they are in mobile clinics, away from the hospital.

The patient can grant access to the individual health records to health practitioners by generating a QR code, using the conventional authentication method of inputting username and password, or using a pictorial password for patients who are illiterate. Generate QR code functionality is integrated into the mobile application (summarized in figure 12 below) while scan QR code and the option of using username and passwords form the interface app. The QR code generated via the mobile application is scanned via the interface app to grant access to health practitioners.

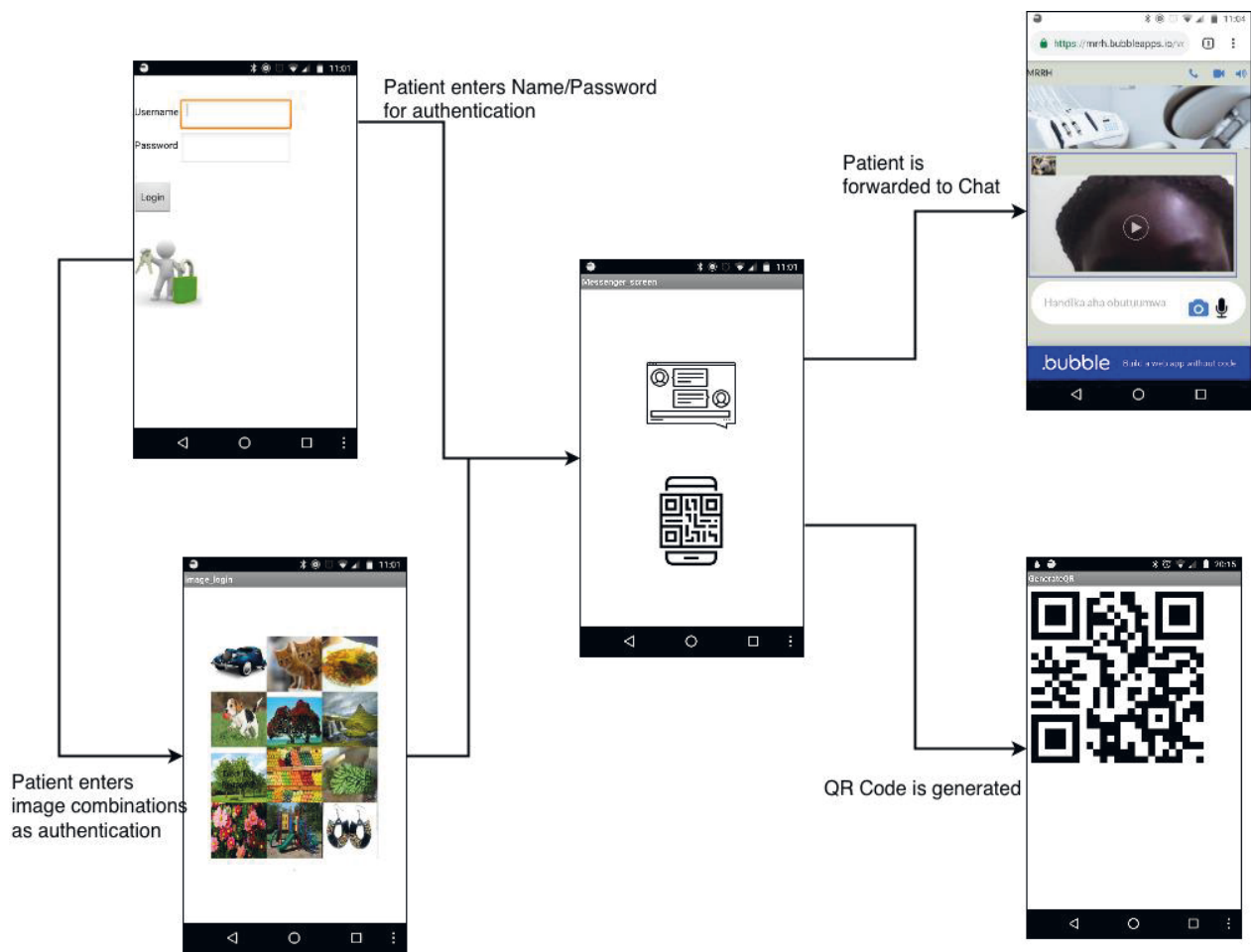


Figure 12: Extension of mobile app to include QR code generation[214].

The patient logs in with either a username and password, or a pictorial password (a combination of three pictures). After successful login, the patient is directed to a screen with two options where they choose to either go to the chat functionality or generate a QR code. Selecting the chat icon takes the patient to the chat window where they can chat with the health practitioner. They can also access the multimedia health messages sent to them from the web application.

On the other hand, when the patients tap on the generate QR code button, a QR code is automatically generated and is then presented to the health practitioner for scanning.

## 6.5 The interface app

The interface app enables the health practitioner to scan the QR code, or to present it to the patient to input the username and password, or a pictorial password in order to access the patient health

records as summarized in the figure below. It is important to acknowledge that the interface application was implemented under a master's thesis [214] but fully under my supervision and guidance.

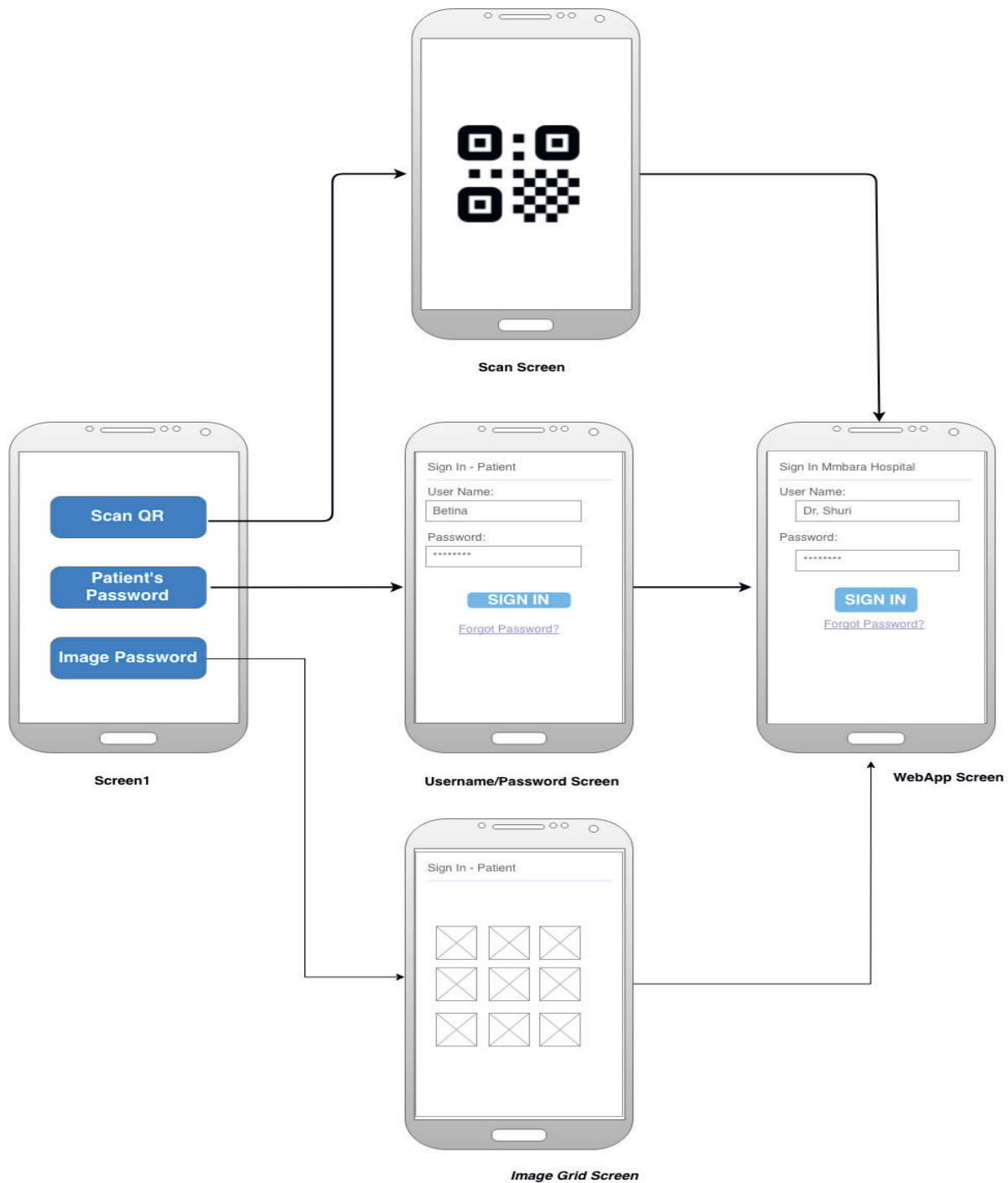


Figure 13: Means of patient consent to their health records[214].



### **6.5.1 Scanning the QR code**

Tapping on the Scan QR button opens the camera of the device instantly which is then used to capture the QR code. After successful scanning, the health practitioner is directed to the login page of the web application where they login and are then able to access the patient records.

### **6.5.2 Login with password**

Alternatively, the health practitioner can present the login screen for the patient to provide a password. When patient's password button is tapped, a login screen appears where the patient can then input a username and password. For illiterate patients, tapping on the picture password button takes them to screen with pictures where they select their pictorial password. Upon successful login, the health practitioner is directed to the login page of the web application where they can login and access patient records.

## **CHAPTER 7: APPLICATIONS TESTING AND RESULTS**

### **7. Introduction**

A field test was conducted in which the applications were tested for functionality and usability by the participants (pregnant women and health practitioners).

#### **7.1 Functionality testing**

Functionality testing is a process for ensuring quality assurance that is characterised by testing functionalities by feeding them input and examining the output[215], [216]. Functionality testing is conducted to determine whether the system or a system component is compliant with the specified functional requirements[217]. In other words, functionality testing describes what the system is supposed to do.

Functionality testing is categorised into eight types as suggested in literature[218] and shown in the figure below

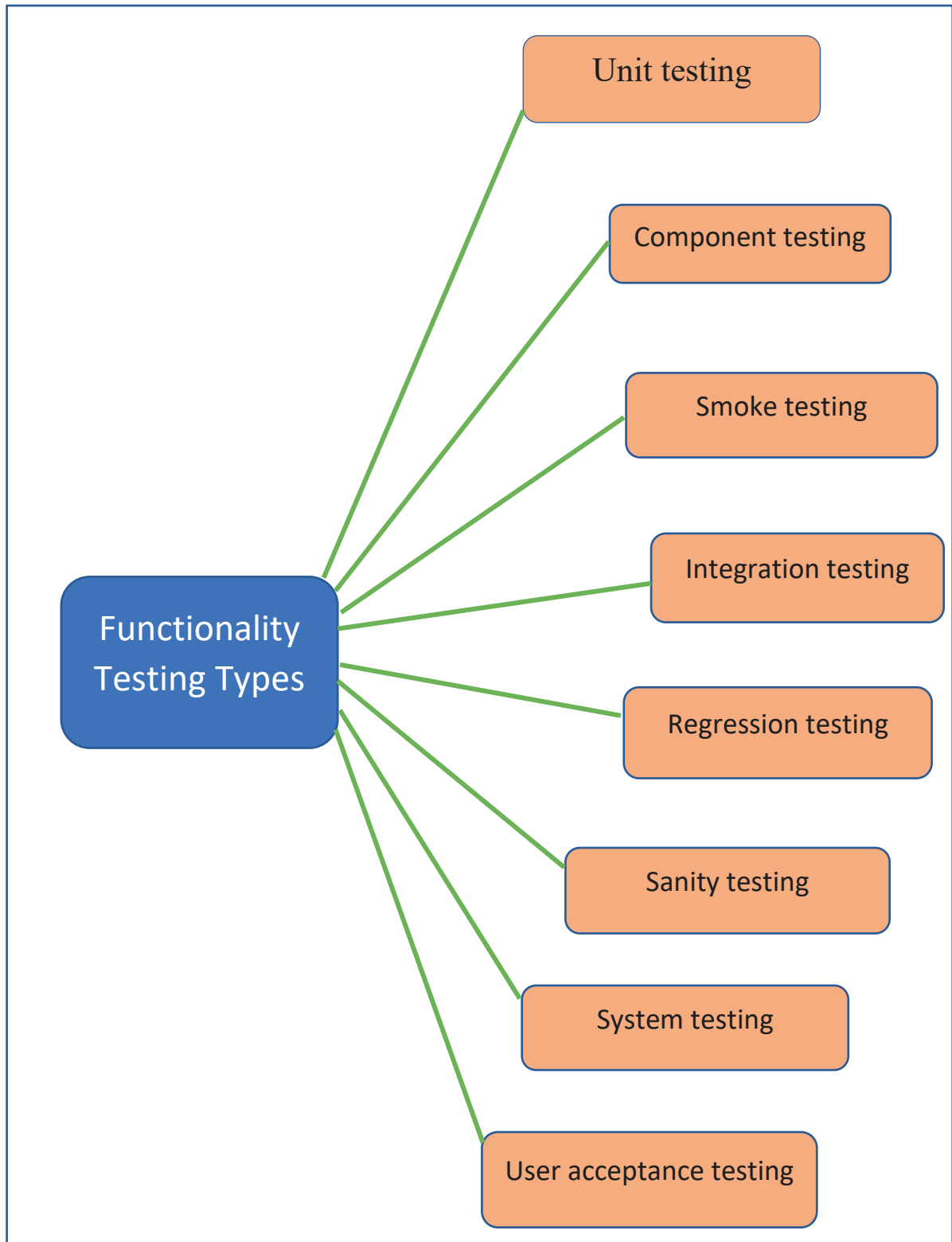


Figure 14: Functionality testing types

### *Unit testing*

The purpose of unit testing is to ensure that each system component delivers the desired output. The testers only look at the interface and the component specifications. Each unit of code is tested thoroughly before proceeding to another unit.

### *Component testing*

Component testing is where a module or component is tested independently to verify if it gives the expected output. Component testing is mainly done to verify the functionality and/or usability of a component. An example of a component may be a piece of code, a screen, a web page, or a smaller system inside a bigger system.

### *Smoke testing*

Smoke testing is not aimed at performing exhaustive testing, but rather to verify that the critical functionality of the system is working well. In smoke testing, the most important functionality or component is chosen and tested to verify if it is working or not. If the component passes the Smoke test, the system is considered stable but if it fails, it has to be sent back to the development team to fix its issues.

### *Integration testing*

Integration testing is an automated form of testing where individual components are tested to verify if they function properly individually and show no bugs when integrated. This type of testing is convenient if the system has been developed as separate modules/ individual components which need to be integrated to form the whole system.

### *Regression testing*

Regression testing is necessary when there are changes or modifications in the functionality/feature of the system. It is done to check whether the changes have not broken the existing functionalities and to verify if the additions exhibit expected behaviour. Therefore, the main purpose of this testing is to find bugs that could have been accidentally introduced into the existing system and to ensure that previously removed bugs don't come back.

### *Sanity testing*

Sanity testing is a subset of regression testing that is done when there are minor changes/modifications in the system. In such a case, instead of running a thorough regression test, a sanity test is performed. It determines whether the modifications have not caused any issues.

### *System testing*

System testing is the testing done on a complete, integrated system to verify if it meets the specified requirements. System testing is done by independent testers who have not played any role in developing the system. This testing verifies that the system meets the requirements that were set by the stakeholders.

### *User acceptance testing*

In user acceptance testing, the users test the software/ application to make sure it meets the user requirements, and it can handle the required tasks in a real-life setting. It is based on users' stories/ experiences with the software and how well their requirements are met.

In this study, component testing was carried out to test the usability and accessibility of user interfaces (screens and web pages), tested for functionality by inputting data and observing the output, for instance testing the login with valid and invalid credentials. User acceptance testing was also carried out.

## **7.2 Usability testing**

According to International Organisation for 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[219].

Usability is important in ensuring the quality of applications and it is applied to general presentation and behaviour of the system, such as the interface design, choice of the colours and icons, interaction, and navigation style[220]–[225].

De Angeli et al.[226], Zhang and Adipat[227], and Kaikkonen et al.[228] propose usability factors and how they can be measured during usability testing. We measured these factors empirically and repeatedly with the users (participants) throughout the testing process.

The mHealth application and interface application were tested on TECNO phones running the android operating system whereas the web application was tested on Windows operating system.

### **7.2.1 Usability qualities and considerations for the mHealth application**

The mHealth application and the interface applications were designed and tested considering the nature of mobile phones which are characterised by mobility, limited input and processing power, and small display screens. The testing of the applications was based on usability guidelines as proposed in literature and discussed below.

1. The interfaces are appealing to a wide range of users with varying skills and expertise[229].
2. The system is presented in an easy to follow hierarchical structure that enables users to browse and understand information of interest[229], [230].
3. The system is designed in such a way that it requires minimal effort from the user, by providing interfaces with simple and straight forward dialogues, short and concise information[231].
4. The menus are designed and presented to enable users to easily reach the desired information[232], [233]. Menus clearly and consistently utilize icons to facilitate easy navigation, memorability and learnability of the system by the users[234]. Easy memorability can also be ensured by using short list choices/menus, and providing backtrack mechanism and easy navigation to previously accessed pages/screens[235].
5. The content for each page/screen is fitted so that there is no need for scrolling in search of information[229].

### **7.2.2 Usability tests for the applications**

Nielsen and Molich[236] propose four ways of evaluating user interfaces, 1) using automatic computerized procedures, 2) formal analysis technique, 3) looking at the interfaces and judging them based on one's own opinion, and 4) empirically by having users experiment with them. However, they report that evaluation of interfaces achieves good and thorough results if empirical and/or heuristic evaluations are used. Therefore, in this study, we chose to evaluate the applications empirically.

#### *Test for the mHealth application*

During the testing of the mHealth application, participants were required to carry out the following tasks:

**Task 1:** Log into the application using a pictorial password or username and password (for the semi-illiterate)

**Task 2:** Access and view the available multimedia messages

**Task 3:** Record/capture/ type in the local language (for the semi-illiterate) multimedia messages (video, audio, picture) and send them to the health practitioner via the chat functionality.

**Task 4:** Generate QR code

#### *Test for the interface application*

The participants (health practitioners) were required to complete the two tasks

**Task 1:** Scan the QR code

**Task 2:** When directed to the web application, login and access patient records

#### *Test for the web application*

The participants (health practitioners) were required to complete the following tasks

**Task 1:** Log into the application using username and password but specify their role, task and team

**Task 2:** Add, delete, modify patient accounts and records

**Task 3:** Upload and send multimedia messages (audio and video) to a patient (pregnant woman)

**Task 4:** Record/capture/ type in the local language multimedia messages (video, audio, picture, text) and send them to the patient via the chat functionality.

## **7.3 Test results**

For details on participant demographics and characteristics, refer to table 16.

### **7.3.1 Functionality test results**

The pregnant women were able to log into the mobile application, receive multimedia messages and send feedback in form of multimedia messages through recording audio and video, taking pictures and typing text in the local language (semi-illiterate women).

*After login, I found a message from the doctor, and I was able to reply by recording an audio message and sending it following the steps that were given in the training. I was surprised to receive a response after a few minutes. (29 years, illiterate, pregnant woman)*

Participants showed concerns about their inability to afford internet and recommended that a standalone version should be developed.

*I would gladly use the application, but I cannot afford internet. I would prefer an internet independent version. (26 years, semi-illiterate, pregnant woman)*

The health practitioners were able to log into the web application, create or upload maternal health related multimedia messages and send them to the mobile application. They however reported that video and audio files exceeding 8MB were taking long to upload.

*I tried to upload 20MB video file and I had to wait for about two minutes, which I think is a bit long. (38 years, male, doctor)*

Overall, the participants showed interest in using the applications throughout pregnancy and a few weeks after giving birth.

## **7.4 Usability test results**

### **Prototype usability**

Participants found the prototypes easy to use

*The voice-overs that explain what the buttons do are very helpful! I don't have to worry about remembering the navigation procedures. (31 years, illiterate, pregnant woman)*

*The ability to upload multimedia files from external sources into the application makes it easy for me to re-use them. (36 years, female, doctor)*

## **7.5 Conclusion**

In addition to sending/receiving scheduled monthly messages, the applications have a chat functionality that enables the users to record and exchange multimedia messages in form of video, audio, pictures, and text in the local language. Using the applications require less memorability due to the few and simple navigation steps, which makes them easy to learn and use.

The results suggest that the users, especially the illiterate and semi-illiterate pregnant women are likely to face challenges due to limited access to the internet, network issues and lack of reliable



power for charging the phones. This would challenge our aim of empowering these women with maternal health information. Therefore, the mobile application was re-designed to make it a standalone application that can be used to access maternal health information whenever the women get access to the phone, without requiring an internet connection.

## **CHAPTER 8: APPLICATION RE-DESIGN**

### **8. Introduction**

The application was developed using Java as the programming language and SQLite as the database for storing the multimedia messages. The application was designed for the Android platform using Android Studio which is the official IDE (Integrated Development Environment) for Android that is based on IntelliJ IDEA.

#### **8.1 Why Android Studio?**

Much as Android Studio is designed for Android, other IDEs such as Eclipse can be used to develop applications for android. However, Android Studio was chosen because of two key advantages as highlighted by researchers and developers and discussed below:

1. Android Studio enables instant run whereby changes in the code can be tested in the emulator or physical device in real-time without building a new APK (Android Application Package file) or restarting the app, which makes app development faster and easier compared to other IDEs[237], [238].
2. Android studio has a cloud test lab integration making it possible to check the compatibility and performance of the application on various physical Android devices from within Android Studio[239], [240].

#### **8.2 Why Java?**

Besides Java being an object-oriented programming language designed to have few implementation dependencies, there are other reasons why java was considered suitable for developing the mobile application and they include:

1. It provides a platform that facilitates development of applications that are executable on resource constrained devices such as mobile phones[241].
2. It enables development of applications that utilize a wide range of content formats such as video, audio, text and XML[242].
3. It is platform independent making it possible to execute applications on any device supporting Connected Limited Device Configuration (CLDC) / Mobile Information Device

Profile (MIDP) regardless of the underlying operating system, any software or Java compatible browser[242].

4. It enables generation of graphics locally without bandwidth demand making it suitable for implementation of interactive applications with rich graphics thereby offering enhanced user experience[243].
5. It is robust with security integrated into its design. Java's run-time system performs checks and makes sure that programs transmitted over a network are not tampered with[244], [245].
6. It enables synchronization between the mobile application and the server[243].

### **8.3 Why SQLite?**

SQLite is an open source database that is embedded into Android, that supports standard relational database features such as SQL syntax and transactions[246]. Unlike Client/server SQL database engines that strive for centralization through implementation of a shared repository of enterprise data, SQLite strives for independence by providing local storage of data for individual applications and devices[247].

Despite SQLite being embedded in Android, there are other databases that may have been used for the multimedia application such as Realm and Berkeley databases. However, SQLite was more suitable due to two reasons:

1. It has been proved to be reliable and efficient and this is evidenced by the extent in which it is extensively used. SQLite is the most deployed SQL database in the world with over one trillion databases in active use[247], [248].
2. SQLite is a transactional database engine that requires small memory and occupies a small amount of disk storage making it suitable for creating databases for mobile phones on various operating systems like Android and iOS[246].

### **8.4 The Architectural Design**

The architectural diagram below presents the different modules that make up the application.

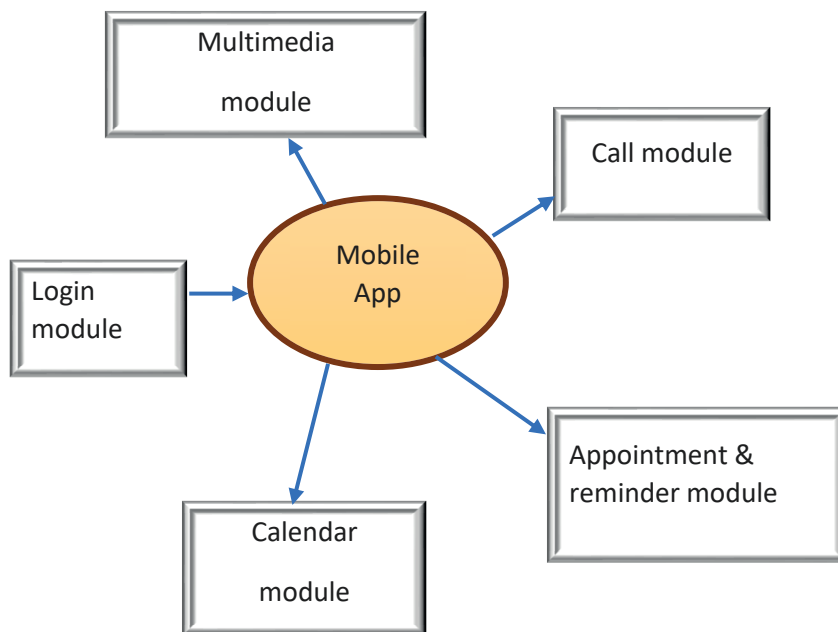


Figure 15: App architectural design

The architecture of the app comprises of four modules- the login, multimedia, appointment & reminder, and the call modules.

#### 8.4.1 The Login module

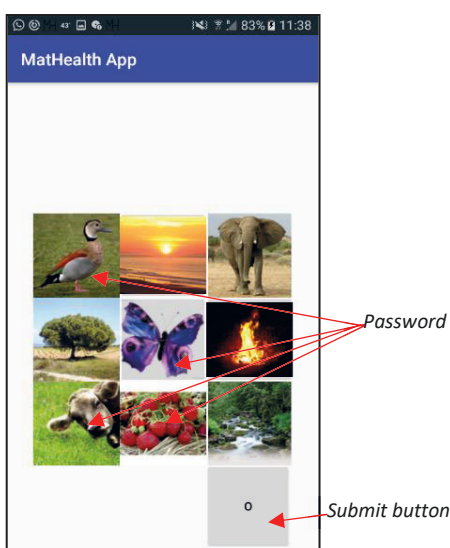


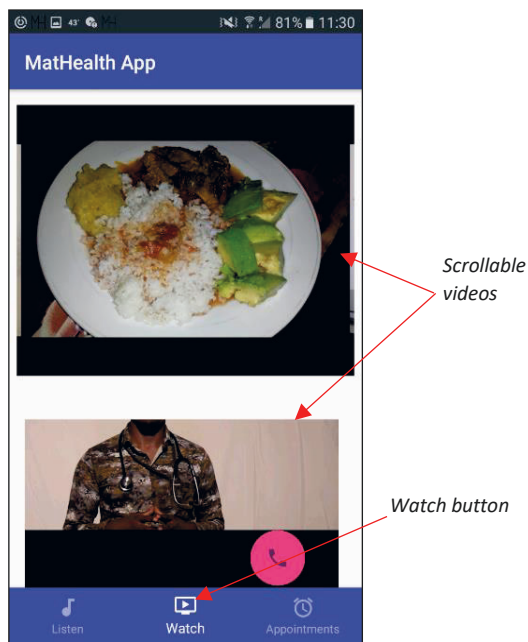
Figure 16: Login screen

The login module facilitates logging into the app using a pictorial password. It is made up of a user interface with images from which the user taps a combination of four images (password) to login. Provision of a wrong password triggers a vibration to indicate that the password is wrong.

### 8.4.2 The multimedia module (audio and video)

The multimedia module comprises of two components- the audio and the video components as discussed below.

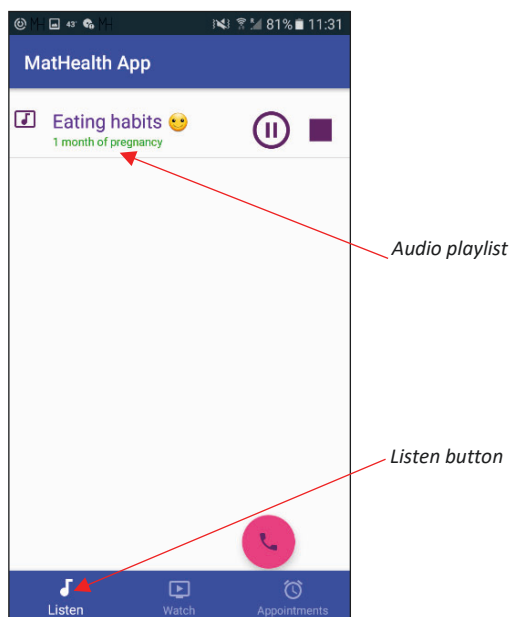
#### *Video component*



Videos are accessible via the watch button. Tapping the watch button takes the user to the saved videos which are presented as scrollable thumbnails. Each video is one to two minutes in length.

Figure 17: Video screen

#### *Audio component*



Audios are accessible via the Listen button. Tapping the Listen button takes the user to the list of the saved audio files. Audio files are saved with emojis to indicate the content of each file. Each audio is one to two minutes

Figure 18: Audio screen

## *The calendar*

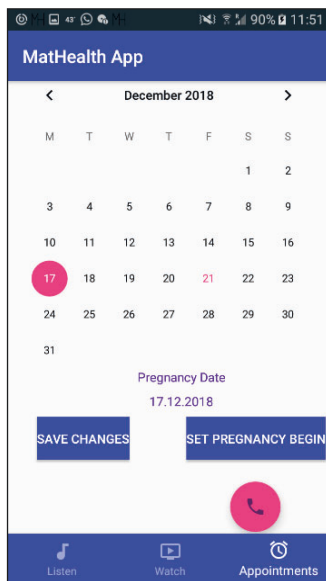


Figure 19: Calendar screen

### **8.4.3 The appointment & reminder module**

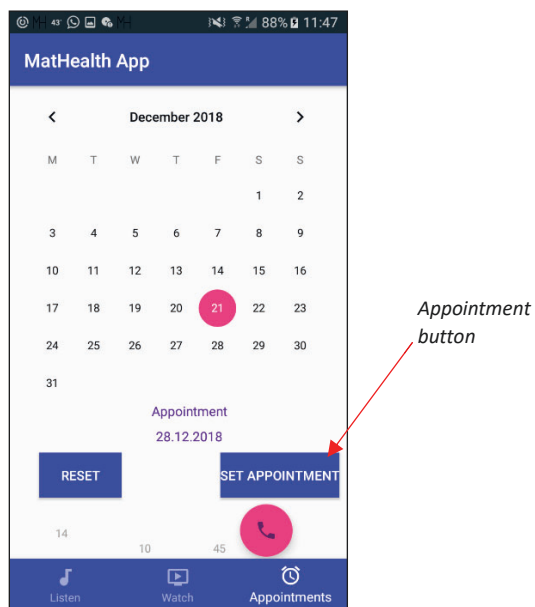


Figure 20: Appointment screen

The calendar comprises of twelve months. When the pregnant woman visits the maternal clinic for the first time, the maturity of her pregnancy and due date are determined. The pregnancy begin date is then set in the calendar. The app starts counting down and after one month, it pops up a video and/or audio tailored to the current maturity of her pregnancy.

The appointment and reminder module enables the users to set appointment date and receive reminders. During the maternal clinic visit, the next appointment date is decided. This date is input into the app via the calendar module. The day before the appointment date, the app triggers an audio reminder reminding the woman to go for her appointment.

#### 8.4.4 The Call module

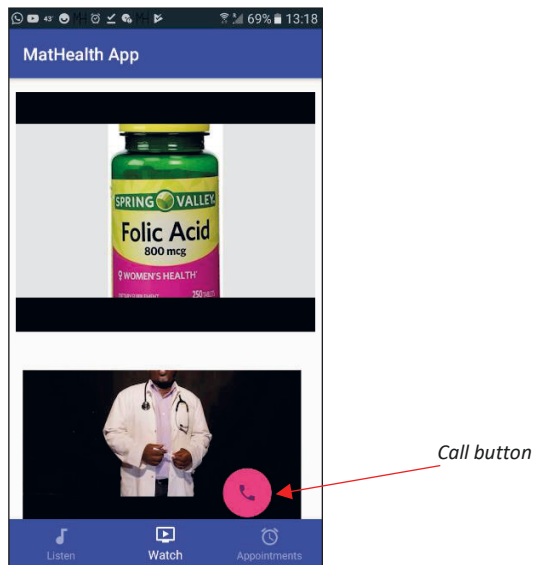


Figure 21: Appearance of call button

The module enables the pregnant women to call the maternal clinic and talk with their health care providers. The app has a call icon which the woman can tap and her call is directed to the health care provider. If the call is not picked, the woman can leave an audio message for the health provider who can then respond within twenty-four hours. The call button appears on all the app screens for easy accessibility.

#### 8.5 App workflow

The process diagram below presents the workflow in the app

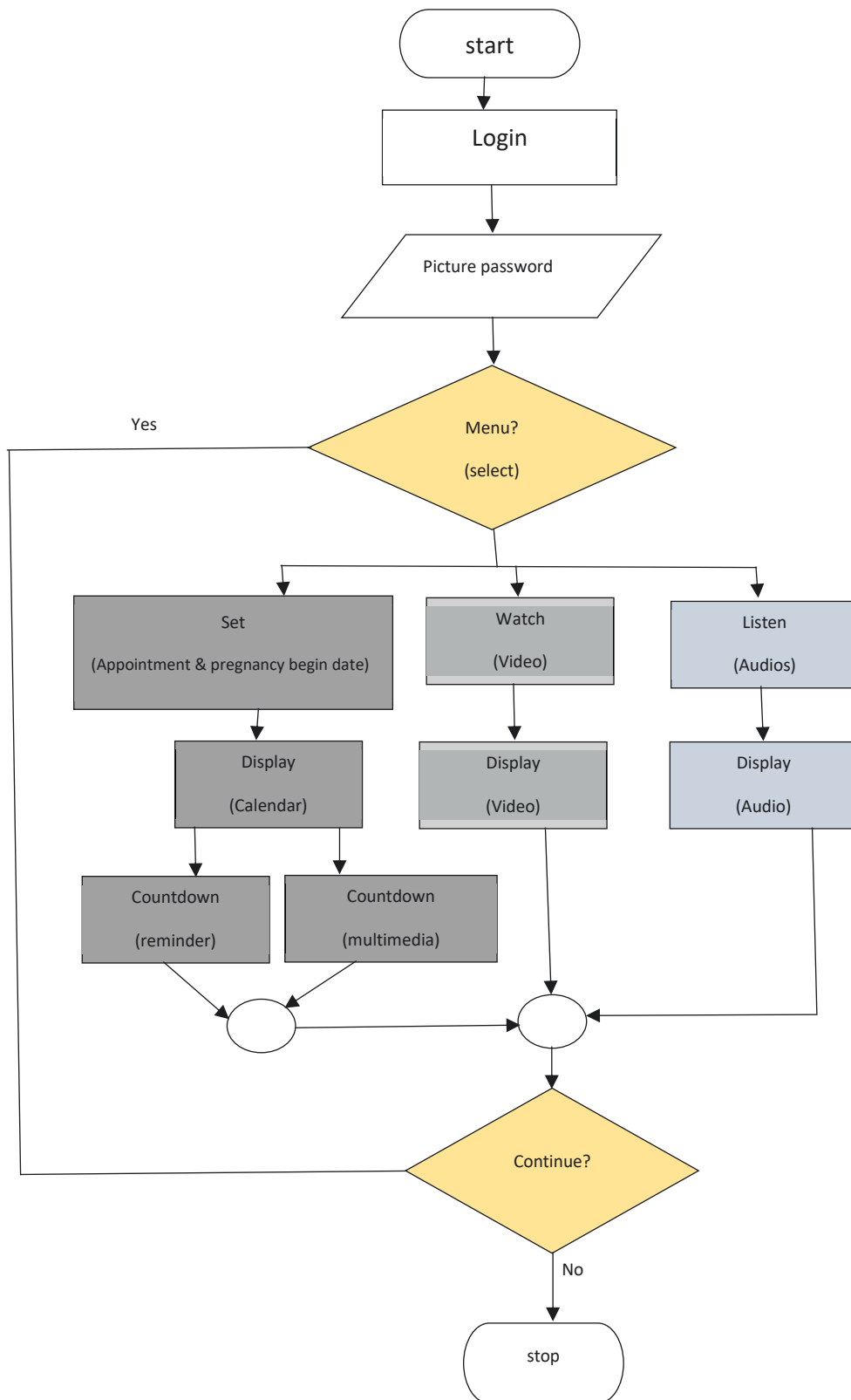


Figure 22: App flow diagram



Tapping the app icon on the phone screen represents the start of the processes in the app. This is followed by the prompt to login after which the user has access to the app menu. The menu is representative of the modules explained under app design in section 8.4. Navigating away from the app stops the app processes.

## CHAPTER 9: FIELD EVALUATION OF THE MHEALTH APPLICATION

### 9. Introduction

Evaluation is an attempt to assess the value of an innovation or technology to end users[249]. It can also be defined as the systematic determination of the quality or value of the system[250]. Evaluation is a phase of system design that focusses on usability of the system and user's experiences when they are interacting with the system[251]. Gould and Lewis[252] recommend studying the learnability and ease of use of the system before reviewing and demonstrating it to users in order to avoid misleading results.

The participants were given the mHealth application and followed for 9 months. Evaluation was done in three phases: 1) at baseline (pre-test) immediately after recruitment, 2) at midline in case of missed ANC appointment, and 3) at endline (post-test) within 42 days after giving birth. We categorise and present the results as baseline, midline and endline results.

It should be noted that some results in this chapter have been published

#### 9.1 Baseline (Pre-test) results

All the participants (both in the control group and the intervention group) were interviewed and given questionnaires at the beginning of the study and therefore the results below are representative of all the 80 participants.

##### 9.1.1 Participants' demographics and basic health

Age	Total number of respondents(n)	n(%)
18 – 28	80	51(63.8%)
29 – 39		28(35.0%)
40 – 50		1(1.2%)
Marital status		
Married	80	70(87.5%)
Cohabiting		1(1.2%)
Single		4(5.0%)

separated		5(6.2%)
Education		
None	80	4(5.0%)
Lower primary (up to P3)		11(13.8%)
Upper primary (up to p7)		65(81.2%)
Gestation age (trimester)		
First trimester (up to 12 weeks)	80	42(52.5%)
Second trimester (12-24 weeks)		32(47.5%)
HIV status		
Negative	79	70(88.6%)
Positive		9(11.4%)

Table 16: Participant demographics

### 9.1.2 Quantitative results

#### Access to health information before the study

	Total number of respondents(n)	n(%)
Current source of information about pregnancy		
Friends and relatives	80	8(10.0%)
Healthcare providers		63(78.8.0%)
Internet		1(1.2%)
Mass media (Radio/TV)		8(10.0%)
How often information about pregnancy is received		
Per day	80	10(12.5%)
Per week		20(25.0%)
Per month		50(62.5%)
Form of receiving information about pregnancy		
Word of mouth	80	78(97.5%)
Video/audio		2(2.5%)

Table 17: Access to health information before the study

### Participant Attitudes before the study

	Attitude	Total Number of respondents (n)	Response	n(%)
1.	It is not necessary for pregnant women to go for antenatal visits throughout their pregnancies as long as they are feeling okay.	80	Disagree	3(3.8%)
			Strongly disagree	76(95.0%)
2.	It is okay for pregnant women to consult traditional health personnel instead of modern health professionals	80	Disagree	2(2.5%)
			Strongly disagree	77(96.2%)
3.	Delivering from a traditional birth attendant is safer than delivering from the hospital	80	Disagree	1(1.2%)
			Strongly disagree	79(98.8%)
4.	Sleeping under a treated mosquito net when pregnant might cause miscarriage due to the insecticide used in treating the net	79	Strongly disagree	79(100%)
5.	It is more reliable to get pregnancy related information from peers than getting it from health professionals	80	Disagree	2(2.5%)
			Strongly disagree	78(97.5%)
6.	Spouses should not escort their wives for antenatal visits or during delivery since pregnancy only concerns wives	80	Disagree	2(2.5%)
			Strongly disagree	78(97.5%)
7.	Immunizing the baby is not necessary since immunization contains substances that may be harmful to the baby	79	Strongly disagree	79(100.0%)

Table 18: Participant attitudes

### Participants' practices before the study

Practice	Total number of respondents (n)	n(%)
First antenatal examination		
Before 3 months	79	43(54.4%)
After 3 months		22(27.8%)
After 4 months		10(12.7%)
After 5 months		4(5.1%)
Antenatal visits done so far (at baseline)		
One visit	76	50(65.8%)
Two visits		13(17.1%)
At least four visits		10(13.2%)
Eight visits		3(3.9%)
How often iron tablets have been taken during the pregnancy		
Daily	80	43(53.8%)
Never took		35(43.8%)
Intentions to breastfeed		
Intend to exclusively breastfeed the baby for six months	79	78(98.7%)
Have tested for HIV		
Yes	79	76(96.2%)
No		3(3.8%)
Intentions for delivery		
Intend to deliver the baby from a clinic/hospital with the help of a qualified birth attendant	80	80(100.0%)
Intentions to attend antenatal clinic		
Yes	80	80(100.0%)
Number of visits intended to attend		
Four	76	49(64.5%)
Eight		22(28.9%)

Table 19: Participant attitudes

## 9.2 Midline results

Midline results were from participants in the intervention group that missed any of their appointments. Interviews and questionnaires were given to determine factors that may have led to missing the appointment, whether the mobile application was being used properly and if it was fulfilling its intended use.

### 9.2.1 Quantitative results

Total number of respondents (n) = 29

Facilitating conditions		Number of respondents n(%)	Response	Frequency n(%)
1.	Possess mobile phone with app installed on it	29	Yes	29(100%)
2.	Phone successfully receives reminders	28	Yes	23(82.1%)
			No	5(17.9%)
3.	Have electricity/solar for charging the phone	29	Yes	10(34.5%)
			No	19 (65.5%)
4.	Have reliable telephone network to communicate with health practitioner	27	Yes	24(88.9%)
			No	3(11.1%)
Perceived usefulness of the app				
1.	App has been useful in acquiring knowledge about maternal health	29	Strongly agree	25(86.5%)
			Agree	4(13.8%)
2.	App has been useful in reminding me to attend antenatal appointments	28	Strongly agree	17(60.7%)
			Agree	3(10.7%)
3.	App has been useful in making decisions regarding pregnancy	29	Strongly agree	22(75.9%)
			Agree	6(20.7%)
4.	App has been useful in communicating with health practitioner while away from the clinic	28	Strongly agree	17(60.7%)
			Agree	4(13.8%)

5.	App has positively affected the way they feel about pregnancy	29	Strongly agree	23(79.3%)
			Agree	5(17.2%)
6.	Reminders helped them to remember to go for antenatal visits	28	Strongly agree	13(46.4%)
			Agree	6(21.4%)
7.	App helped to reduce communication costs	29	Strongly agree	14(48.3%)
			Agree	11(37.9%)
8.	App improved patient-health practitioner relationship	29	Strongly agree	18(62.1%)
			Agree	7(24.1%)
Perceived ease of use of the app				
1.	Easy to access multimedia messages in the app	29	Strongly agree	24(82.8%)
			Agree	5(17.2%)
2.	Easy to learn how to access reminders for antenatal appointments	28	Strongly agree	14(50%)
			Agree	3(10.7%)
3.	Easy to initiate communication with the health practitioner	28	Strongly agree	18(64.3%)
			Agree	3(10.7%)
4.	Easy to understand the information in the multimedia messages	29	Strongly agree	23(79.3%)
			Agree	6(20.7%)
5.	Easy to remember to go for antenatal appointments	28	Strongly agree	18(64.3%)
			Agree	7(25.0%)
6.	Overall, app is easy to use	28	Strongly agree	18(64.3%)
			Agree	8(28.6%)

Norms about using the app				
1.	Caretaker thought the app should be used	29	Strongly agree	22(75.9%)
			Agree	6(20.7%)
2.	Behavior influencer thought the app should be used	28	Strongly agree	22(78.6%)
			Agree	6(21.4%)
3.	Important people thought the app should be used	29	Strongly agree	20(69.0%)
			Agree	9(31.0%)
4.	App users have a high social status	28	Strongly agree	22(78.6%)
			Agree	1(3.6%)
App acceptance				
1.	Have been using the app consistently	28	Strongly agree	21(72.4%)
			Agree	2(6.9%)
2.	Have been using reminders consistently	28	Strongly agree	10(35.7%)
			Agree	3(10.7%)
			Disagree	13(46.4%)
3.	Have been using the communication function to contact health practitioner when needed	28	Strongly agree	11(39.3%)
			Agree	4(14.3%)
			Disagree	12(42.9%)
4.	Would like to continue using the app in next pregnancies and would recommend it to a friend/ relative	29	Strongly agree	28(96.6%)
			Agree	1(3.4%)

Table 20: Midline quantitative results



### 9.2.2 Qualitative results

The participants reported that the multimedia based mHealth application enabled them to 1) identify danger signs and act accordingly, 2) prepare for birth, 3) remember attending clinic appointments, 4) communicate with health practitioners, 5) adhere to attending the recommended number of antenatal visits, 6) have future reference to maternal health information and 7) adopt other good maternal health practices. The participants further reported that the application was easy to use, and it enhanced partner involvement. However, they cited several challenges that affect the implementation of the intervention.

#### Helps in identifying danger signs

The participants reported that the mHealth application helped them to identify danger signs and seek professional help in time.

*When I started feeling pain, I remembered the video I watched talking about challenges that can happen when pregnant, I rushed to the hospital and went to scan to know why I was feeling pain". MT0030, pregnant mother, 21 years*

*What I remembered was about bleeding, the doctor was saying that in case a pregnant woman starts bleeding she should rush to the hospital". MT001, pregnant, 33 years*

#### Preparing for birth

The participants reported that the application taught them the importance of preparing for birth and how to prepare for the arrival of the baby, for instance, saving money for transport, buying baby clothes, and acquiring a mama kit<sup>1</sup>.

*The doctor in the video told us that we should get prepared with mama kit and the baby's clothing to remain set for the day of delivery, and I did it because I have already bought some clothes for the baby plus mama kit so I am set for delivery now. MT024, pregnant mother, 42 years*

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<sup>1</sup> A Mama Kit is an all-in-one kit that contains everything needed to help provide a clean and safe delivery.

*These videos have helped me because with the first kids I never bought for them baby covers not even one of them but with this one because I have been so much touched with the videos, I have tried to buy some baby covers. MT001, pregnant woman, 33 years.*

### **Reminds about attending clinic appointments**

Participants reported that the application reminded them to go for their scheduled antenatal appoints, something they found challenges to do before the application.

*With the previous pregnancy I didn't attend all the antenatal visits and the few times I attended I didn't attend with in the medical appointment schedule. I could only go when I wanted but with this pregnancy, I have attended all the prescribed antenatal visits so far within the medical appointment schedules. MT001, pregnant, 33 years*

*With my first pregnancy I used to forget antenatal visits even when I had money for transport. I would remember when a day had already passed but with this app, there is a reminder functionality, and even if I don't use that reminder functionality, the mere fact that I was given a phone keeps me alert that I have to fulfil the purpose for which this phone was given to me. MT007, pregnant mother, 23 years*

### **Facilitates communication with health practitioners**

Participants reported using the calling function of the application to call health practitioners for pregnancy related inquiries. Some further reported that this improved their patient-health practitioner relationship

*It has been more helpful because when I call a doctor, he tells me what to do. when I started feeling pain, I called the doctor and he told me to rush to the hospital. MT0030, pregnant mother, 21 years.*

*The application improves communication and relationship between health workers and pregnant mothers because whenever I call someone for help during the time of challenge and he helps me, that will push me to create friendship with that person. MT007, pregnant mother, 23 years.*

### **Adherence to antenatal visits**

Some participants reported that receiving the video and audio messages motivated them to attend their hospital visits regularly.

*I have not been attending antenatal for my first kids but after giving me this phone and sending me the videos and audios, that is why I put in more efforts to make sure I visit the hospital regularly. MT043, pregnant, 28 years*

*I even learnt the purpose of attending antenatal visits as recommended by health workers, which I have been doing. MT018, pregnant mother, 29 years*

### **Enables future reference to maternal health information**

Some participants reported that the application avails them an opportunity to access the maternal health information and remind themselves about the content by replaying the videos and audios whenever they want.

*Another thing is learning from the videos we watch, yes in the hospital they tell us some of these things we hear from videos but in the hospital they don't normally go to details and there are chances of forgetting what we have been told in the hospital after some days but with this application a doctor is trying to explain so much and I can't forget because whenever I want to know, I play my videos and watch, I can replay as many times as I want. MT007, pregnant mother, 23 years.*

### **Improved nutrition**

Participants reported that the application taught them how to feed well during pregnancy and the importance of eating a balanced diet especially during pregnancy and when breastfeeding.

*Videos have helped me to understand what I should do with my pregnancy for example they talk about the best way of feeding, so I try to eat what I can afford. I used to eat anyhow but I have tried to get some sensible food like fish, and whenever I eat it, I feel my baby*

*kicking a bit better within the uterus. Before I heard these videos about feeding, I didn't care about feeding in anyway. MT016, pregnant mother.*

### **Adoption of good maternal and child health care practices**

Participants further reported that the application enabled them to adopt good maternal and child health care practices such as prevention of malaria and mother to child HIV transmission, delivery under the care of health practitioners, saving money, healthy feeding and taking the recommended supplements.

*I have always tried to do what I can afford to do, for example there is a certain video in which a doctor was telling us that we should do scanning to know whether our babies are well-positioned in the uterus or to know whether one is carrying twins. I went for that scan after hearing about it in a video. Another message was in audios that we should always take iron tablets in order to maintain our blood levels, I also started taking iron tablets after hearing it in an audio. MT018, pregnant mother, 29 years*

*These videos have been so helpful because one video was talking about malaria prevention through clearing the bushes around our homes and sleeping under a mosquito net, another taught me how a pregnant mother is supposed to eat which helped me to know what to eat and when to eat it. Another video talked about avoiding hard work which was also helpful because I have been doing some simple work to help my baby and I. MT019, pregnant mother, 24 years.*

### **Application is easy to use**

The participants reported that the application is easy to use because the procedures in the application were explained to them in the beginning and they are easy to follow.

*I don't have any problem with accessing videos, it is easy because I play a certain video and keep scrolling down to see whether there are more videos. MT016, pregnant mother.*

## **Encourages partner involvement**

Some participants reported that after showing the messages or telling their partners about the contents in the messages in the application, the partners became supportive and more involved in the wellbeing of their pregnant women and unborn babies.

*There are some challenges in implementation but not as much as they would be if he didn't watch these videos. When they talked about fruits, my partner started bringing them. They talked about the effects of hard work on a pregnant woman, and since then he stopped me from doing heavy work, he does it himself.* MT028, pregnant mother, 21 years

*I don't have a big problem with my pregnancy but at times I used to feel some pain and discomfort in the lower abdomen, then I called medical workers about the issue, they gave me some medication and told me that I should stop bending a lot. When I told my husband about the issue, he started helping me with work, so I stopped bending and now I no longer have the pain.* MT016, pregnant mother

*There is a very big change because I had never attended more than two antenatal visits before. Even my husband likes it now, whenever I tell him that I want to go for antenatal check-up, he gives me transport money.* MT024, pregnant mother, 42 years

## **Challenges**

### **Financial challenges**

Some participants reported that much as they would like to implement what is recommended in the videos and audios such as eating a balanced diet, buying requirements for delivery and attending antenatal care appointments, they lack financial capacity to do so.

*The videos recommend that a pregnant woman is supposed to eat well, some foods are mentioned but I don't have money to buy the recommended food or even buy what my heart desires. I find myself eating whatever I get, whether I like it or whether it is useful or not.* MT019, pregnant mother, 24 years.

*I mean I am unable financially because he was talking about shopping for child delivery, but I haven't managed to buy all that would be necessary for child delivery because I don't have money. Though, I have managed to buy a few of them and if it wasn't finances, I would have bought everything that was mentioned in a video. MT001, pregnant, 33 years*

### Technology related challenges

Some participants reported challenges of charging their phones due to unreliable power options. Some opted to charge the phones at the charging centres but were forced to stop because of illegal use of their phones by the people in the charging centres.

*Sometimes I get battery problems because we use solar loan and when we don't pay in time, they disconnect us, so it has been a big challenge. MT010, pregnant, 31 years*

*The application is very nice but when it comes to battery, it consumes a lot of battery. The solar charger you gave to me for charging has a less capacity. When the sunshine is not much, I charge a very small percentage of the battery, yet they told me that if I keep on charging it half way, I will destroy my battery. It needs a very sharp sunshine for it to charge a phone fully. MT007, pregnant, 28 years*

## 9.3 End line results

### 9.3.1 Quantitative results

	Total number of respondents	Response	n(%)
Loss to follow-up	78	No	73 (93.6%)
		Yes	5 (6.4%)
Had a miscarriage	73	Not ticked	68 (93.2%)
		Ticked	5 (6.8%)
Premature birth	72	Not ticked	71 (98.6%)
		Ticked	1 (1.4%)

Figure 23: Complications and cases lost to follow-up

Some participants that were recruited at baseline were lost to follow-up due to factors like shifting to new areas, some got miscarriages while one gave birth prematurely. In total, 69 participants out of the 80 participants that were recruited at baseline responded at endline as shown in the pie chart below

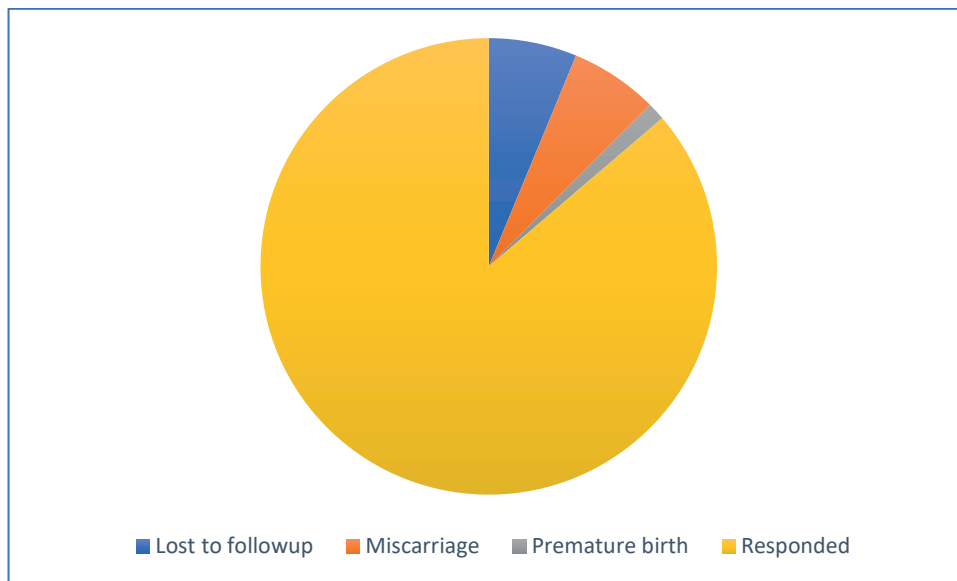


Figure 24: Respondents at endline and problem cases

### Evaluation of the multimedia application

Likert-type questions with four response alternatives (strongly agree, agree, disagree and strongly disagree) were used to determine the perceived usefulness, and ease of use of the application, social norms about using the application and application acceptancy. Studies indicate that the Likert-type approach has been successfully used in collecting data about healthcare technologies such determining perceptions on ease of use, acceptability and other usability attributes[253]–[255].

### Facilitating conditions

Facilitating conditions (n = 32)		Response	Frequency n(%)
1.	Possess mobile phone with app installed on it	Yes	32(100%)
2.	Phone successfully receives reminders	Yes	26(81.3%)
		No	6(18.8%)
3.	Have electricity/solar for charging the phone	Yes	27(84.4%)

		No	5 (15.6%)
4.	Have reliable telephone network to communicate with health practitioner	Yes	28(87.5%)
		No	4(12.5%)

Table 21: Facilitating conditions

Successful implementation of the application was dependant on facilitating conditions such as availability of reliable power for charging the mobile phones. Overall, the participants reported having favourable conditions as indicated in table 21.

### Perceived usefulness of the app

Total number of participants (n = 32)

Usefulness		Response	Frequency n(%)
1.	App has been useful in acquiring knowledge about maternal health	Strongly agree	28(87.5%)
		Agree	3(9.4%)
		Disagree	1(3.1%)
2.	App has been useful in reminding me to attend antenatal appointments	Strongly agree	23(71.9%)
		Agree	4(12.5%)
		Disagree	5(15.6%)
3.	App has been useful in making decisions regarding pregnancy	Strongly agree	24(75.0%)
		Agree	8(25.0%)
4.	App has been useful in communicating with health practitioner while away from the clinic	Strongly agree	17(54.8%)
		Agree	8(25.8%)
		Disagree	6(19.4%)
5.	App has positively affected the way they feel about pregnancy	Strongly agree	25(78.1%)
		Agree	6(18.8%)
		Disagree	1(3.1%)
6.	Reminders helped them to remember to go for antenatal visits	Strongly agree	21(65.6%)
		Agree	5(15.6%)
		Disagree	6(18.8%)
7.	App helped to reduce communication costs	Strongly agree	14(43.8%)
		Agree	12(37.5%)



		Disagree	6(18.8%)
8.	App improved patient-health practitioner relationship	Strongly agree	22(68.8%)
		Agree	9(28.1%)
		Disagree	1(3.1%)

Table 22: App usefulness results

Table 22 describes participants' perceived usefulness of the multimedia application. The table demonstrates that the application helped them to acquire new maternal health knowledge, make decisions regarding pregnancy, reminded them to go for antenatal appointments and communicate with health practitioners. 96.9% of the participants reported to have acquired new maternal health knowledge.

### Perceived ease of use of the app

Total number of participants (n = 32)

Learnability		Response	Frequency n(%)
1.	Easy to access multimedia messages in the app	Strongly agree	27(84.4%)
		Agree	4(12.5%)
		Disagree	1(3.1%)
2.	Easy to learn how to access reminders for antenatal appointments	Strongly agree	18(56.3%)
		Agree	5(15.6%)
		Disagree	7(21.9%)
		Strongly disagree	2(6.3%)
3.	Easy to initiate communication with the health practitioner	Strongly agree	15(48.4%)
		Agree	8(25.8%)
		Disagree	6(19.4%)
		Strongly disagree	2(6.3%)
4.	Easy to understand the information in the multimedia messages	Strongly agree	27(84.4%)
		Agree	4(12.5%)
		Disagree	1(3.1%)
5.	Easy to remember to go for antenatal appointments	Strongly agree	20(62.5%)
		Agree	11(34.4%)

		Disagree	1(3.1%)
6.	Overall, app is easy to use	Strongly agree	21(65.6%)
		Agree	9(28.1%)
		Disagree	2(6.3%)

Table 23: App learnability results

The evaluation of perceived ease of use of the multimedia application gave satisfactory results as shown in table 23. Majority of the participants (93.7%) reported that the application was easy to use. Overall, the results confirm that the participants found the application easy to learn, use, navigate and understand the contents of the multimedia messages.

### Norms about using the app

Total number of participants (n=32)

	Norm	Response	Frequency n(%)
1.	Caretaker thought the app should be used	Strongly agree	22(68.8%)
		Agree	10(31.3%)
2.	Behavior influencer thought the app should be used	Strongly agree	23(71.9%)
		Agree	8(25.1%)
		Disagree	1(3.1%)
3.	Important people thought the app should be used	Strongly agree	21(65.6%)
		Agree	10(31.3%)
		Strongly disagree	1(3.1%)
4.	App users have a high social status	Strongly agree	17(54.8%)
		Agree	11(35.5%)
		Disagree	2(6.5%)
		Strongly disagree	1(3.2%)

Table 24: Results about participants' norms

Participants reported positive results regarding norms of using the application, for instance, all the participants reported that their health caretakers thought it was good to use the application. The results in table 24 indicate that stakeholders in the health of the participants were in support of

participants using the application. 28 (90.3%) reported that using the application gave them a higher social status compared to those who were not using the application.

### Application acceptance

Total number of participants (n=32)

Statement		Response	Frequency n(%)
1.	Have been using the app consistently	Strongly agree	23(71.9%)
		Agree	4(12.5%)
		Disagree	4(12.5%)
		Strongly disagree	1(3.1%)
2.	Have been using reminders consistently	Strongly agree	11(34.4%)
		Agree	6(18.8%)
		Disagree	12(37.5%)
		Strongly disagree	3(9.4%)
3.	Have been using the calling function to contact health practitioner when needed	Strongly agree	9(28.1%)
		Agree	12(37.5%)
		Disagree	8(25.0%)
		Strongly disagree	3(9.4%)
4.	Would like to continue using the app in next pregnancies and would recommend it to a friend/ relative	Strongly agree	28(87.5%)
		Agree	4(12.5%)

Table 25: App acceptance results

Table 25 demonstrates that the multimedia application was acceptable to the participants. All the participants were interested in using the application in their next pregnancies and recommending it to friends and relatives, and 84.4% of the participants reported using the application consistently throughout the study.

### Impact of the application on participants' attitudes

The evaluation was done using the Mann-Whitney U, a non-parametric test efficient in comparing two independent samples on three, four or five point scaled variables especially when samples are not normally distributed[256], [257].

Baseline (Pre-test)					Endline (Post-test)			
	Intervention (n=40)	Control (n=40)			Intervention (n=31)	Control (n=37)		
Attitude	MR	MR	U	P	MR1	MR1	U1	P1
It is not necessary for pregnant women to go for antenatal visits throughout their pregnancies as long as they are feeling okay.	39.54	41.46	761.5	0.327	34.71	34.32	567.0	0.860
It is okay for pregnant women to consult traditional health personnel instead of modern health professionals	39.99	41.01	779.5	0.549	35.45	33.70	544.0	0.570
Delivering from a traditional birth attendant is safer than delivering from the hospital	40.00	41.00	780.0	0.317	35.61	33.57	539.0	0.505
Sleeping under a treated mosquito net when pregnant might cause miscarriage due to the insecticide used in	40.50	40.50	800.0	1.000	34.21	34.74	564.5	0.822

treating the net								
It is more reliable to get pregnancy related information from peers than getting it from health professionals	40.50	40.50	800.0	1.000	36.21	33.07	520.5	0.287
Spouses should not escort their wives for antenatal visits or during delivery since pregnancy only concerns wives	40.50	40.50	800.0	1.000	35.29	33.84	549.0	0.589
Immunizing the baby is not necessary since immunization contains substances that may be harmful to the baby	40.50	40.50	800.0	1.000	35.87	33.35	535.5	0.465
It is not necessary to attend postnatal appointments if the mother & baby are well					33.27	35.53	535.5	0.465
<ul style="list-style-type: none"> <li>MR = Mean rank at baseline, U = Mann-Whitney U at baseline, P = Probability value at baseline.</li> <li>MR1 = Mean rank at endline, U1 = Mann-Whitney U at endline, P1 = Probability value at endline.</li> <li>Mann-Whitney U values were rounded off to one decimal point.</li> </ul>								

Table 26: Results on the impact of the application on participants' attitudes

Table 26 shows a comparison between the intervention and control groups at baseline and endline regarding attitudes. Much as there are differences in the Mann-Whitney U values and mean rank values especially at endline, these differences are not statistically significant, and this is shown by P values that are greater than 0.05. The graph below shows a sample of descriptive results inform of frequencies showing differences in attitudes between the intervention and control groups at endline.

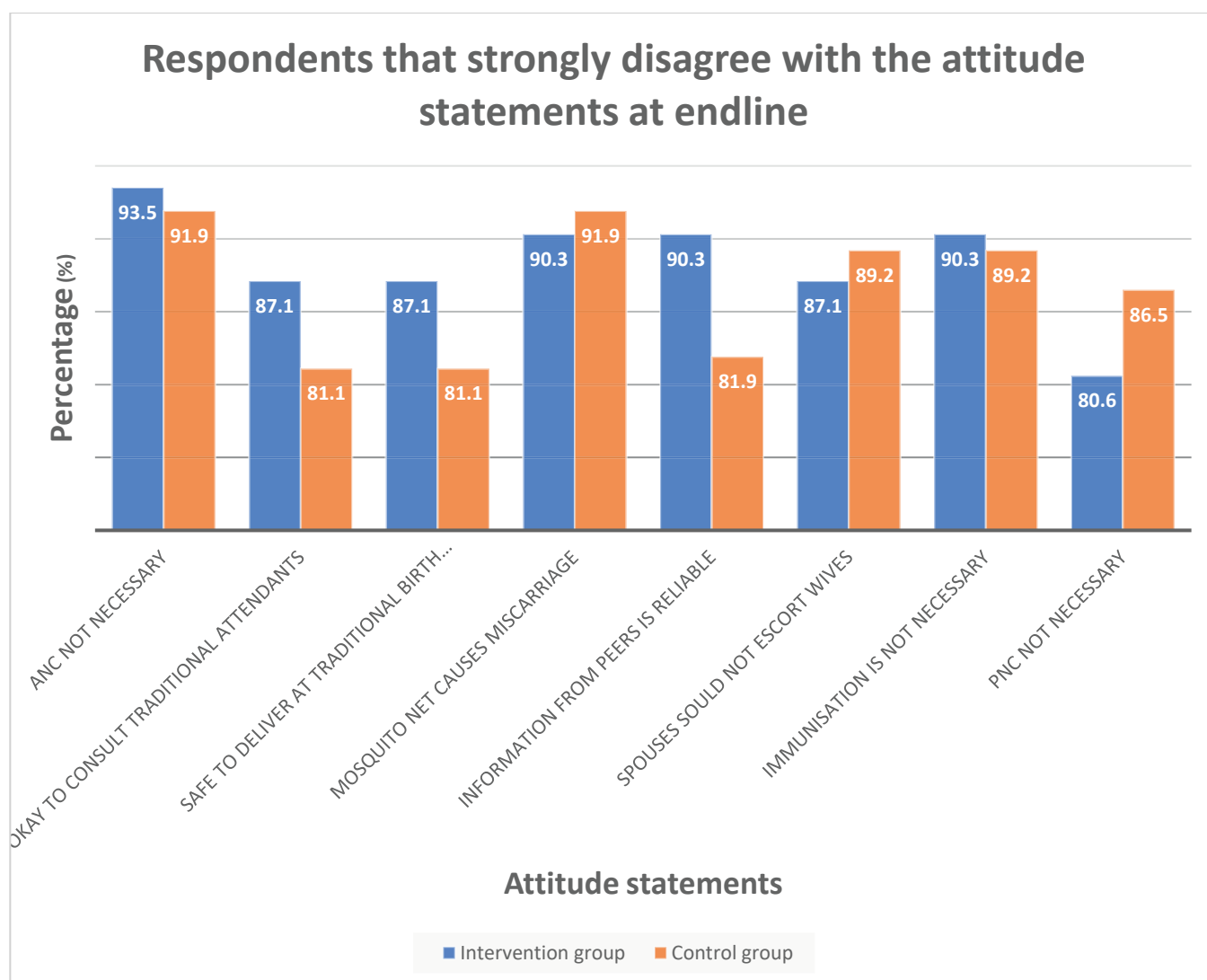


Figure 25: Respondents' response about attitude statements

### Impact of the multimedia application on participants' practices

The results were got from analysing the relevant data using descriptive statistics in the form of frequencies.

	Intervention group		Control group	
Practice	Total number of respondents	Frequency n (%)	Total number of respondents	Frequency n (%)
Number of antenatal visits done				
At least four visits	32	18(56.3%)	37	22(59.5%)
How often iron tablets have been taken during the pregnancy				
Daily	32	29 (90.6%)	37	35(94.6%)
Place of delivery				
Delivered from a clinic/hospital with the help of a qualified birth attendant	32	27(84.4%)	37	36(97.3%)
Delivery				
Gave birth to normal baby without complications	34	26(83.9%)	37	31(83.8%)
Intentions to breastfeed				
Intend to exclusively breastfeed the baby for six months	32	31(96.9%)	37	31(83.8%)
Diets taken				
Proteins	32	31(96.9%)	37	36(97.3%)
Carbohydrates fats		30 (93.8%)		33(89.2%)
Fats		13 (40.6%)		19(51.4%)
Attended PNC				
Yes	32	22 (88.0%)	37	29(78.4%)
Preparation for delivery				
Saved transport funds	32	29(90.6)	37	26(70.3%)

Had Mama kit	30	19(63.3%)	37	27(73.0%)
Had someone to escort to the facility	32	31 (96.9%)	37	32(86.5%)
<b>Complications</b>				
Had complications during pregnancy	35	5(12.5%)	37	12(32.4%)

Table 27: Results on the impact of the application on participants' practices

Endline results show that more participants in the control group (32.4%) had complications during pregnancy compared to 12.5% in the intervention group. More participants in the intervention group (96.9%) intended to breastfeed exclusively for 6 months compared 83.8% in the control group. Much as majority of the participants in both groups delivered from the hospital, more women (97.3%) in the control group than in the intervention group (84.4%) reported to have delivered from the hospital. This may be attributed to distance from the health facility and other social economic factors such as availability of transport funds and means to the facility at the time of labour.

### **Impact of the multimedia application on participants' knowledge about maternal health**

Part of the evaluation was done using descriptive statistics in form of frequencies and the other part with P values was done using the Wilcoxon signed ranks test. The Wilcoxon signed ranks test is a non-parametric test that is suitable for comparing two related samples. In this case, the maternal health knowledge of participants in the intervention group at baseline is compared with their knowledge at endline.

	Baseline (n=40)	Endline (n=32)	
Knowledge	Frequency n(%)	Frequency n(%)	P(2-tailed)
<b>Danger signs during first trimester</b>			
Persistent cramps	29(72.5%)	18(56.3%)	0.275
Nausea	26(65%)	14(43.8%)	0.029
Poor appetite	26(65%)	16(50%)	0.166
Persistent bleeding	17(42.5%)	26(81.3%)	0.000
<b>Causes of anemia during pregnancy</b>			



Lack of exercise	12(30%)	9(28.1%)	0.739
Lack of foods containing iron	37(92.5%)	26(81.3%)	0.317
Poor sleep	4(10%)	3(9.4%)	0.655
<b>Prevention of anemia during pregnancy</b>			
Eating food containing iron	40(100%)	30(93.8%)	0.157
Having enough sleep	7(17.5%)	4(12.5%)	0.317
Doing exercises	10(25%)	5(15.6%)	0.156
<b>Which is the main source of calcium for pregnant women</b>			
Water	30(75%)	22(68.8%)	0.782
Milk	26(65%)	19(59.4%)	0.782
<b>Main reason why pregnant women need calcium</b>			
Prevents heartburn	4(10%)	6(18.8%)	0.480
Source of good skin	5(12.5%)	12(37.5%)	0.090
Hardening bones	38(95.0%)	27(84.4%)	0.257
<b>Which of the following are labor signs</b>			
Slimy vaginal discharge	31(77.5%)	30(93.8%)	0.317
Regular increasing pains in the uterus	15(37.5%)	20(62.5%)	0.275
Rapture of membranes	7(17.5%)	12(37.5%)	0.491

Table 28: Results on the impact of the application on participants' knowledge about maternal health

Table 28 indicates shows statistically significant differences between intervention participants' knowledge about danger signs during pregnancy and this is shown by P values  $< 0.05$ . For instance, participants learnt that persistent bleeding is a danger sign, and this is shown by an increase of participants that thought it was a danger sign from 42.5% at baseline to 81.3% at endline, reflected by  $P = 0.000$ . Much as most P values are greater than 0.05, there are increases in the number of participants that gained maternal knowledge. For instance, there is an increase in the number of participants from 37.5% at baseline to 62.5% at endline who think that regular increasing pains in the uterus is a sign of labour despite a  $p = 0.275$ . It is important to note that the results may have been affected by social desirability since data collected was based on self-reporting. Literature and

studies by Grimm[258], Krumpal[259], Holtgraves[260] and van de Mortel[261] show that social desirability may influence results.

### **9.3.2 Qualitative results**

The participants reported that the multimedia based mHealth application, 1) taught them how to take care of the baby, 2) how to improve nutrition, 3) facilitated communication and other social benefits. The participants further cited challenges that affect the implementation of the intervention and gave recommendations for dealing with the challenges.

#### **Taking care of the baby**

Participants reported learning how to take good care of their newborns such as proper breastfeeding techniques, recommended breastfeeding duration and its importance, and when to introduce babies to other foods.

*I changed the way I was doing things with my first kids, especially the way I used to breastfeed them. I could just put a breast in a baby's mouth and let him deal with it by himself without even holding for him as I continue doing some other things such as eating or preparing G.nuts. I couldn't mind about watching him to see whether he is swallowing or not, whether he is satisfied or not, sometimes I could find the breast out of his mouth yet I thought he was sucking but after watching this video I totally changed according to how I was taught. MT007, breastfeeding mother, 28 years*

*..... hold him and insert the nib of the breast properly and see him swallow to satisfaction, MT021, breastfeeding mother, 28 years.*

*I learnt to breastfeed the baby without any supplement up to six months and then continue breastfeeding while giving other foods up to two years. MT021, breastfeeding mother, 28 years.*

#### **Facilitates communication and other social benefits**

Some participants reported that their status in the community was elevated due to ownership of the smartphones that they received and the use of the multimedia application.

*Those who didn't get phones wish to get them as well because they admire us, a village woman to own a smart phone is very surprising. MT007, breastfeeding mother, 28 years*

*I always want people to find me watching or holding my phone because it makes me feel proud and respected, people in villages think these phones are only owned by rich people, so I have no issue people seeing me using this application. MT016, breastfeeding mother, 34 years*

Others reported using the phone to call their friends and relatives which improved their social wellbeing. Calling was also beneficial in cases of emergencies.

*It helped me so much because one time I called the doctors when I was going to give birth and it also helped me in calling my friends, for example when I was going to give birth, I called them and they came and helped me in the hospital. MT007, breastfeeding mother, 25 years*

Others reported that in addition to being educative, the videos were interesting to watch, and they therefore re-watched them for stress relief.

*It also helped me take away my stress because every time I got stressed, I opened my phone and watched my videos, so it has helped me to take away my stress. MT016, breastfeeding mother, 34 years*

There were further reports of using the phone for mobile money which made it easy for the women to make financial transactions.

*It helped me during delivery because if I never had this phone I would have probably delivered from home and even alone but since I had this phone, I used it to call someone who helped me. I called and even they sent me money on this very phone, now how would they have sent money to me if I didn't have this phone. MT054, breastfeeding mother, 22 years*

### **Improved nutrition**

Some participants reported that the multimedia messages taught them the importance of eating a

balanced diet especially when pregnant and taught them how to balance their diets.

*The application has taught us to eat foods rich in proteins, calcium and others which has helped me to remain healthy throughout my pregnancy. Actually, I used to fall sick every time I was pregnant but with this one, I never felt sick which I think was due to better feeding and sleeping under a mosquito net, courtesy of this application. MT013, breastfeeding mother, 29 years*

*Even when I would not feel like eating greens and fruits but due to the applications' teachings, I would be forced to eat them for the benefit of the child inside me. Unlike before, when I felt that I didn't want any food I would not bother eating it, MT008, breastfeeding mother, 27 years*

## **Challenges**

Some participants reported that they found difficulties in identifying the nutritional value of the readily available local foods that were not included in the messages and therefore found it hard to substitute foods in the messages that were hard to get.

*The foods we were being taught to eat rich in iron, vitamins, proteins, and the like, I would sometimes find it hard to find them. So, I would substitute them with other local, easily reachable foods. Even then understanding which local foods contained vitamins, iron, fats, so on was not easy to know. MT013, breastfeeding mother, 29 years*

Others reported the challenge of sharing their mobile phones with their spouses and not being able to access their messages whenever they wanted to.

*My husband used to disturb me by taking away my phone but when I came to your offices, some lady talked to him, and he no longer disturbed me like before. He put his line but at least I would give him the phone when someone calls him. MT016, breastfeeding mother, 34 years*

## **Recommendations**

Some participants recommended dedicating time to talking to pregnant women, involving spouses in such projects, and educating them about their responsibilities towards their pregnant partners.

*Always get time and talk to pregnant mothers and our husbands because most of the times when we become pregnant, men abandon us, they don't want to know what we pass through. Tell them their responsibilities as men. ... and also teach men how to care for their pregnant women (wives) by giving them transport and helping them do some work at home. MT002, breastfeeding mother, 25 years*

*I think you should always tell us to come with our husbands, for example when am with my husband and you tell us these things when we are together, it might surely open his eyes and he changes the way he does his things. MT043, breastfeeding mother, 32 years*

Others recommended buying food stuffs and other necessary requirements such as transport to pregnant women, breastfeeding mothers, and their children.

*If I am given a chance to solve our problems, I would buy some food which I know that it is necessary for the health of a mother and her child and keep supplying, for example in the same way they give us free iron tablets because they know that they are necessary for the increase of blood in our bodies. So, I know that there are many mothers who can't afford to buy the recommended food so I would buy and give them. MT007, breastfeeding mother, 28 years*

*If I was in charge and I had the potential, I would make sure that I send every woman transport monthly because they come once monthly and most of them have no transport fare, they walk long distances. MT003, breastfeeding mother, 31 years*

Participants recommended scaling out the application to more pregnant women and mothers, and if possible, even to those who are not yet pregnant but are planning to do so.

*This application is very nice for that case I wish it could be promoted much more such that even our sisters who are heading into marriages would get a chance to use it in order to*

*promote safe delivery. I wish many mothers could experience the advantages of this application just as I did.* MT007, breastfeeding mother, 28 years

There was another recommendation of providing lighting for breastfeeding mothers to enable them to comfortably breastfeed during the night.

*It would be better if the solar you gave to us could be having a bulb for light because I have already told you that light is a problem and remember a baby needs to breastfeed whether it is night or day. So, I think if the solar had one bulb for the purposes of breastfeeding at night, then it would be better.* MT007, breastfeeding mother, 28 years

Other participants recommended use of more local languages and use of more local foods, explaining their nutritional value for women to easily substitute the ones that are not readily available to them.

*I would use all the languages to explain using local foods for all participants to understand. It is better to use the local available cheap foods to explain which food contained iron, vitamin, proteins among others.* MT013, breastfeeding mother, 29 years

There was another recommendation about redesigning the application in such a way that when the user is watching a video or listening to the audio, they can pause and call to seek clarification about content that is not clear without navigating away from the current screen.

*I would wish to have it in a way that when I am watching a video, I can also pause it and say something to a doctor or ask something and then they respond. For example, on breastfeeding I liked that video so much that I wanted to ask how best I can breastfeed during the night. I didn't know if I am supposed to wake up and sit during the night to breastfeed, but I couldn't ask.* MT007, breastfeeding mother, 28 years

Participants further recommended provision of more powerful solar chargers that could charge the phones in a shorter time, even on cloudy days.

*I would think of getting the solar that is powerful. This phone is more powerful than the solar chargers given, when I try to charge smaller phones they charge so faster yet smaller phones can't cover the function intended to be covered by the phones that you provided. Therefore, getting a solar that can fill up a phone battery in limited time is better.* MT007, breastfeeding mother, 28 years

Other participants recommended inclusion of a message sharing functionality into the applications so that the women can share the multimedia messages with others who have no access to the application. They further recommended a chat functionality where the women can share their experiences.

*I would love to record a video and share it with someone else, may be someone who has the same challenges as mine. I mean making it possible for me to share videos with others for example if I can forward a certain video from the application to someone else. MT054, breastfeeding mother, 22 years*

## **CHAPTER 10: DISCUSSION AND LIMITATIONS**

This chapter highlights the research findings and presents a comparison and contrast of the findings with relevant literature. The findings are based on the main research goal which was to develop a tool that supports maternal healthcare and is usable by illiterate and semi-illiterate pregnant women and is based on an access control security model for mobile health care systems that addresses the privacy and usability issues of mobile health systems in developing countries. The goal was achieved using the User Centered Design approach which follows four steps: 1) Understanding the context of the user, 2) Specifying the user requirements, 3) designing solutions and 4) Evaluation. This chapter is organised into three subsections corresponding to the research objectives in chapter 1 and are presented as follows:

- a. User requirements
- b. Design perspectives
- c. Impact of the intervention

### **10.1 User requirements**

Following the first two phases of the user centered design approach (understanding the context of the user and specifying user requirements) that were discussed in chapter 3, user requirements and challenges that were likely to influence the success of the intervention were got.

In chapter 4, results of the first field study indicated that for the application to be usable by the illiterate and semi-illiterate participants, it needed to be multimedia based, be implemented via mobile technology, and provide some form of security to the health data captured in the applications.

The developed application is mobile based and utilises multimedia based messages in form of videos and audios. The women receive monthly multimedia-based messages which they can retrieve at their own convenience. Studies show that fulfilling the users' requirements is the feasible way of ensuring acceptability of applications[156], [262]. Studies by Parker et al.[263], Holeman et al.[264], West[265], Mitchell et al.[266], Patil et al.[267], Tegegne and Weide[268], and Tolly et al.[269] show positive outcomes for mHealth applications in the areas of health education/awareness, communication/patient follow-up and decision making which were core attributes of our intervention.



### **10.1.1 Security/ privacy requirement**

International health systems standards such as HIPAA[270] and HL7[271] dictate that patients' health information must be protected and patients should consent and provide authorization for their records to be accessed. Patients' consent should also have an expiry period and there should be accountability for all the access[272], [273]. The participants' requirements reported in chapter 4 resonate with these standards.

The security of the information was ensured by developing and integrating the T2RoL access control security model into the applications. The T2RoL access control model achieves our second objective and is a hybrid of RBAC, TBAC and TMAC access control models integrated with a location component. The illiterate women authenticate themselves using a pictorial password which is a combination of pre-set pictures. On the other hand, health practitioners use the conventional username and password but at registration of their user accounts, they must specify their respective roles, tasks, and teams in the hospital. When the health practitioners are in mobile clinics, away from the hospital premises, they get access to patient records by scanning a QR code generated by the women on the mobile application with the interface app or inputting a username and password or a pictorial password on the interface application. Implementation of biometric security mechanisms such as face, and voice recognition were not feasible because we found that this category of users mostly has low processing power phones which may not process biometric data.

Participants who were HIV positive or had other sensitive conditions, and shared mobile phones were more concerned about their privacy, security of their health information and their communication with the health practitioners compared to those without. Security of information and privacy are core requirements for systems such as e-health applications that capture sensitive health information. Literature reports that access control models such as RBAC, TBAC and TMAC have been successfully implemented in health care system[274]–[276]. However, they may not be usable for the context of developing countries where illiteracy is high and users share mobile devices, which makes developing the T2RoL access control security model feasible.

## **10.2 Design perspectives**

Chapters 5, 6 and 8 present the T2RoL access control model, and the developed applications (web application, mobile application and the interface application) which are the results for requirements

ii and iii. These artefacts were designed and developed following the user centered design approach. Literature shows that the user centered design approach is a comprehensive approach to invent new usable solutions[277], [278].

### **10.2.1 User involvement**

It was found that designing for illiterate people follows the same design guidelines but presents a unique set of design requirements such constant involvement of users. Previous studies by Ives and Olson[279], Kujala[280], [281], Kushniruk and Nohr[282], Franz and Robey[283], and Santosa et al.[284], indicate that designing usable and acceptable applications requires involvement of users in all the design phases of the Software Development Life Cycle (SDLC). According to UNESCO guidelines for digital inclusion[285] and other studies[286]–[288], user involvement is even more critical when designing digital artefacts for the illiterate. The requirements were got following the first phase and second phases of the user centered design process which are hinged towards understanding the context and needs of the users by actively involving them in the design process as described in chapter 3. Literature further shows that artefacts developed with active involvement of users were likely to be usable and acceptable by the users[289], [290]. Results in chapter 9 show that participants in the design process of the application felt they owned the application and readily accepted it. Participants further recommended extending the scope of users to include other stakeholders such as spouses.

### **10.2.2 Design trade-offs**

There was a trade-off between usability and security. Addressing the conflict between making the app easy to use versus keeping it secure was a difficult task. The more usable the application got, the less secure it became. Literature shows that there is a need to create a balance between the design trade-offs when designing for all kinds of users[291].

Another trade-off was between user control versus user training. The conflict between allowing the illiterate users to be in control of the application and the need for prescriptive guidance/ training on how to use the application was also a challenge. Provision of constant guidance and training deprives the user the possibility of discovery and being in control.

There was also a trade-off between learnability and memorability versus complexity in terms of functionality detailing. The less complex the application was (fewer navigation steps), the easier it

was for the users to learn/ accomplish basic tasks and memorise the functionalities of the application when they returned to the application. A literature survey by Harrison et al.[292] recommends consideration of characteristics of the user and the tasks to be accomplished when dealing with this trade-off.

### **10.2.3 Design challenges**

Chapter 4 presents the design and social technical challenges of designing for users in developing countries. The study revealed that designing applications for users in low resource settings faces social and technical challenges that anyone hoping to design applications for this category of users has to consider before embarking on the design process. Design and social economic challenges such as illiteracy, sharing of mobile devices, and limited access to technological infrastructure such as internet and telephone network make designing and implementing the applications difficult. Studies confirm that it is paramount to address design and social economic challenges when designing for low resource settings in order to increase the chances of success of interventions[293]–[296].

## **10.3 App evaluation**

### **10.3.1 App acceptability and facilitating conditions**

Acceptability of the multimedia application was evaluated using the unified theory of acceptance and use of technology (UTAUT)[156] and the Technology acceptance model[297]. The models aim at explaining intentions of users to use information systems and their subsequent usage behaviour. The theories consider variables such as 1) perceived ease of use, 2) perceived usefulness, 3) social influence/norms, and 4) facilitating conditions as determinants of acceptance of information systems/ technologies.

Facilitating conditions are defined as the degree to which an individual believes that an organizational and technical infrastructure exists to support use of the system. Participants who had challenges with facilitating conditions such as lack of reliable electricity for charging the mobile phones reported that they could not use the reminder functionality of the application and rather opted for their paper based antenatal cards. Studies by Taylor and Todd[298], Lund et al.[299], [300], Oyeyemi and Wynn[301], Jennings et al.[302] and Luxton et al.[303] further confirm that facilitating conditions are a core component for technology usage and acceptance.

### **10.3.2 Perceived usefulness**

Results in chapter 9 indicate that the multimedia application was useful in acquiring knowledge about maternal health, reminding participants to attend antenatal appointments, and communicating with health practitioners. Participants' interest in acquiring knowledge about their health shows the desire to play an active role in making informed decisions regarding their health. This is evidenced by the results in chapter 9 where all the participants reported that the application enabled them to make decisions regarding their pregnancies.

Although different studies have examined different evaluation aspects, literature confirms that perceived usefulness is a key determinant of adopting of technological innovations. For instance, studies by Hauser and Simmie[304] researched about communication technologies, Hill, et al.[305] examined learning of a computer language, Swanson[306], and Larcker and Lessig[307] evaluated information reports, and all these studies point out usefulness as a factor of technology acceptance.

### **10.3.3 Social norms**

Based on results in chapter 9, participants' decision to use the application was based on the perception that other people who are influential or important to them considered it appropriate to use it. This resonates with the theory of reasoned action (TRA) which states that a person's intention to perform a behaviour is the main predictor of whether or not they actually perform that behaviour if he/she could perform a behaviour[308]. A study by Yousafzai[309] in adoption of internet banking and studies by Albarracín et al.[310], Doswell et al.[311], Roberto et al.[312] and Bentler & Speckart[313] in healthcare show that social norms contribute to people's decision to perform the behaviours such as use of technological artefacts. According to the theory, intention to perform a certain behaviour (behavioural intention) precedes the actual behaviour and it is subjective to social norms[314]–[316].

The unified theory of acceptance and use of Technology (UAUT) further confirms that a person's behaviour is influenced by how they believe other people will view them as a result of using the technology[156]. This is reflected in the results in chapter 9 whereby participants reported factors like increased social status, and affirmation from caretakers and behavioural influencers as motivating factors for using the multimedia application.

#### **10.3.4 App usability**

Contrary to interventions reviewed in literature in chapter 2 which are mainly text-based and unusable by the illiterate, our intervention enables illiterate and semi-illiterate users to access maternal health information via video and audio formats making it usable by them. Participants report in chapter 9 that the standalone design of the mobile application made it convenient for future reference to the multimedia messages without the need for incurring costs for internet or phone airtime which may not be affordable. Literature shows that interventions for low resource settings need to have low implementation costs on the side of the user[295], [317]–[319]. The literature further indicates that illiteracy is common in low resource settings[320] making our intervention feasible for the illiterate in low resource settings.

In chapter 9, results of application evaluation indicate that the users found the application easy to use. This was attributed to simple and straight forward navigation steps that required minimal memorability, and the simplicity of the content in the multimedia content. Studies show that users prefer technologies that do not require them to remember a lot of functionality details and are therefore are less accepting of applications that require memorability[224], [292], [321].

### **10.4 Impacts of the intervention**

An impact evaluation of the intervention was done focusing on 1) its impact on maternal health related knowledge 2) impact on Attitudes, and 3) impact on practices.

#### **10.4.1 Impact on maternal health related knowledge**

The results in chapter 9 show that the intervention group acquired knowledge in maternal health regarding identification of danger signs during pregnancy, nutrition and identifying labour signs.

##### *Identifying danger signs during pregnancy*

More participants in the intervention group (81.3%) considered persistent bleeding as a danger sign at endline compared to those at baseline (42.5%) and this was reflected by  $P = 0.000$ . Furthermore, there was a statistically significant decrease from 65% at baseline to 43.8% at endline in the number of participants that believed in the myth that nausea in pregnancy was a danger sign.

### *Identifying labour signs*

The intervention group experienced an increase in knowledge about labour signs. There was an increase from 37.5% at baseline to 62.5% at endline for participants who considered regular increasing pains in the uterus as a sign of labour, increase from 77.5% to 93.8% for those who considered slimy vaginal discharge as a sign of labour and from 17.5% to 37.5% for those who considered rupture of membranes as a sign of labour.

### *Nutrition*

Despite few statistically significant differences between the knowledge of participants about nutrition at baseline and endline, there is a decrease in the number of participants who believed in the myth that water is a source of calcium from 75% at baseline to 68.8% at endline, and from 25% to 15.6% for those who believed that doing exercise prevents anemia. Furthermore, qualitative results in chapter 9 indicate that some participants reported that they acquired knowledge about nutrition which influenced their decision-making regarding nutrition.

Studies by Datta et al.[322], Entsieh et al.[67], Patel et al.[323], Ngabo et al.[324] Ghose et al.[325] and Jennings et al.[326] that evaluated impacts of the mHealth applications on women's knowledge in maternal healthcare indicate that knowledge acquisition significantly influence women's decision making regarding their maternal health . This is also reflected in the results on impacts of the intervention as shown in chapter 9.

### **10.4.2 Impact on Attitudes**

Much as there are no statistically significant differences in the quantitative data, results from the qualitative study in chapter 9 indicate that some participants' attitudes were influenced by the intervention.

Studies show that acquiring authentic information is a motivating factor in health related decision making, and changing attitudes and behaviour[296], [327]–[329]. This is reflected in the qualitative results in chapter 9 where some participants reported a positive change in attitudes by 1) opting to consult health professionals instead of traditional health personnel, 2) getting pregnancy related health information from health professionals instead of peers, 3) delivering from the hospital instead of traditional birth attendants, 4) sleeping under a treated mosquito net, and 5) attending

antenatal appointments. Studies by Jiang et al.[330] and Tahir and Alsadat[331] report having more women opting for exclusive breastfeeding after receiving information about its benefits.

Literature further indicates that much as acquiring knowledge is a motivating factor, it may not necessarily dictate change in attitude but may be a motivating factor[327], [332]. Studies by Yudin et al.[332], Lau et al.[318], Moniz et al.[333] further show no significant change in attitudes and behaviour after receiving health information.

#### **10.4.3 Impact on practices**

Results in chapter 9 indicate that the intervention group made better decisions regarding breastfeeding and preparing for delivery. 96.9% of the intervention group opted to exclusively breastfeed for six months compared to 83.8% for the control group. 90.6% saved transport funds compared to 70.3% for the control group. Furthermore, 96.9% of participants in the intervention group had someone to escort them to the health facility to give birth compared to 86.5% of participants in the control group. The intervention group had less complications during pregnancy (12.5%) than the control group (32.4%).

Studies show a positive change in practices among intervention groups that received health information. For instance, a study by Bush et al.[334] reports an increase in attendance of antenatal visits, Dalrymple et al.[335] report improved nutrition among pregnant women, Krishnamurti et al.[336] and Evans et al.[337] report increased tendency to exclusively breastfeed and take recommended vitamins during pregnancy.

However, the control group had a higher number of participants who delivered in the hospital (97.3%), attended more than four antenatal visits (59.5%) compared to 84.4% and 56.3% respectively for the control group. This can be attributed to social economic factors such as lack of transport funds to go for antenatal appointments, distance from health facilities and/or health complications that may require visiting the hospital multiple times. Studies by Watkins et al.[338] and Hanson et al.[339] report that the distance from the health facilities influenced the women's ability to deliver there. More studies by Salihu and Zamani[340], Lund et al.[341], and Rotheram et al.[342] show that social economic factors influence maternal health practices such as attendance of antenatal appointments and nutrition.

## 10.5 Limitations

The pregnant women who tested and evaluated the mobile application lived within twenty kilometers from MRRH and this may not have been representative of all illiterate women because the living conditions of these participants may be different from those of women in further remote villages.

Furthermore, the study was based on a small sample of participants (80 illiterate pregnant women, 10 Health practitioners and 10 designers/ developers). It is not clear whether a larger sample may present new user requirements, new design insights or influence impact outcomes of the intervention.

In addition, in the evaluation study (second field study), participants were followed up for only nine months. It is not clear whether a longer period of follow-up would increase or decrease user satisfaction and affect application acceptance, and/or alter other findings such as attitudes and practices.

Some participants reported social economic factors such as lack of transportation to the hospital to attend their antenatal appointments, lack of funds for purchasing food to balance their diet or carry out antenatal scans. This may have affected the impact outcomes, but it is not clear whether provision of social economic support would significantly influence the outcomes and to what extent.

While access to health information at the user end was granted through use of authentication mechanisms, the health information captured by the web application had to be stored on the cloud server due to lack of ICT infrastructure. For instance, the hospital did not have an in-house server, and this made some participants to question the security of their health information. It is yet to be determined whether the presence of an in-house server and other localised infrastructure could influence acceptability of the web application.

Running the chat functionality of the applications required an internet connection. Poor internet connection in the rural areas made real time communication between the women and health practitioners unachievable sometimes. Downloading multimedia attachments in the chat was also



slowed down whenever the internet connectivity fluctuated. It is yet to be determined whether use of the applications in settings with stable internet connectivity would influence acceptability and usability of the applications.

Due to time constraints, the web application was tested on Windows operating system only and this makes it unclear whether it would provide a different user experience on other operating systems and thus alter outcomes. The mobile application was also developed for android phones making it unclear whether using it on mobile phones with other operating systems would affect usability and acceptability outcomes.

The applications were designed and implemented with and for the immediate users (illiterate and semi-illiterate pregnant women, and health practitioners). However, they later recommended involvement of other stakeholders such as spouses and immediate care givers in the design and implementation phases. It is not clear whether involvement of other stakeholders would provide new insights in the design and user requirements, and/or significantly influence the outcomes of the intervention.

## **CHAPTER 11: CONCLUSIONS AND OUTLOOK**

### **11. Introduction**

The mobile multimedia application to support maternal health care for illiterate and semi-illiterate women in low resource settings was considered usable and acceptable by the women. The application enabled the women to receive and retrieve maternal health messages in form of video and audio, set appointment reminders and call health practitioners.

In conclusion, we found that implementation of the multimedia-based application is a feasible way of ensuring maternal health education for illiterate and semi-illiterate pregnant women in a low resource setting. Illiterate and semi-illiterate pregnant women can utilize mHealth systems, but they need to be involved in all the design phases and their user requirements fulfilled if secure and usable systems are to be developed for them. This is partly because they have unique requirements, unlike their literate counterparts who are able to use conventional designs such as authentication mechanisms of username and password, SMS and text/ calendar-based reminders, the illiterate are unable to use them. Involvement of other stakeholders such as spouses, caretakers and policy makers is also paramount. This study revealed that women who showed the multimedia messages to their partners got financial and emotional support from them, and the partner involvement in issues like escorting them for antenatal visits and testing for HIV increased.

The application enabled the women to communicate with health practitioners, adhere to antenatal appointments and deliver in hospitals. It further enabled them to improve their maternal health related knowledge such as identifying danger signs during pregnancy and preventing malaria through sleeping under treated mosquito nets. The study showed a positive change in attitudes such as consulting health practitioners instead of traditional birth attendants, and adoption of good maternal and child health practices such as exclusive breastfeeding and eating a balanced diet.

#### **11.1 Privacy and usability**

Integration of the T2RoL access control model in the applications provided security and privacy of the health information taking into consideration of factors that are unique to developing countries such as illiteracy and sharing of mobile devices. We therefore demonstrated that designing usable

access control security models requires consideration of the context of users. T2ROL considers attributes such as role, task, team, and location of the user.

### **11.2 Challenges to implementation**

This study confirms that technological challenges such as unstable telecom and internet connections and unreliable power, and social economic challenges such as poverty and illiteracy influence the successful implementation of health interventions in low resource settings. For instance, lack of finances directly impacted on the ability for some participants to attend all the recommended antenatal appointments or to have the recommended nutrition. Also, limited access to reliable power hindered the participants from using the intervention at will due to the inability to charge their mobile phones. However, the mobile multimedia application was a standalone which enabled access to the multimedia messages whenever the women had access to their phones.

### **11.3 Strengths of the intervention**

The strength of this intervention is that it is based on participants' contributions and needs, who are the end users, which makes it acceptable to a similar category of users. Also, the requirements, design perspectives and procedures from this study are transferrable to other similar cases of designing for illiterate users.

The study is based on the user centered design approach, a well-tested and proved approach for designing technological interventions. Previous studies indicate that involving users throughout the entire development process ensures that the final technological artefact is usable and acceptable by the users.

### **11.4 Outlook**

Studies have shown that the ability to share experiences and information may be a key factor to user satisfaction, which explains the popularity of social media applications such as WhatsApp and Facebook. This fact, coupled with the recommendation by participants to add a sharing functionality in the application, makes it interesting to carry out further studies to explore the impact of the sharing functionality among illiterate pregnant women on maternal health.

As previously discussed, the small size of the study sample and the short follow-up duration are limitations of this study. Moreover, this sample was drawn within a radius of 20km from the study/

recruitment location which may limit generalisation. Therefore, studies involving larger numbers of participants from diverse contexts, and followed up for a long period of time will be necessary to further evaluate the impact of the application.

Much as the chat functionality between the illiterate women and health practitioners was prototyped, the health records were not incorporated in the multimedia mobile application. Considering the increasing need for collaborative decision making between health practitioners and patients, future studies may focus on linking the application to hospital digital healthcare systems and provide the illiterate women access to their records.

Engaging other stakeholders such as spouses and care takers was one of the recommendations given by the participants. Provision of economic support such as transport fare to health facilities for antenatal appointments was also recommended. Therefore, future efforts should focus on involving relevant stakeholders and providing economic support to determine if there are improvements in the previous outcomes.

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## Appendices

### Survey guides

#### Demographics, Health, and Technology readiness (formative)

Participant ID _____	Date ____/____/____
Staff initials _____	

#### **Demographics, Health, and Technology readiness: Mothers (formative)**

*Instructions: To be completed at enrollment. Please make reference to the participant's Antenatal medical chart where necessary.*

##### Demographics

1. Age: ☐ 18-28 ☐ 29-39 ☐ 40-50
2. Gender: ☐ Female
3. Where do you stay?.....
4. Your telephone number.....
5. Marital status: ☐ Married ☐ Cohabiting ☐ Single
6. Education: Highest level of education achieved:
7. ☐ None ☐ Primary level
8. Literacy

	English	Runyankole
Able to speak	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No
Able to read	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No

##### Health

9. Which trimester of pregnancy are you:  
☐ First trimester  
☐ Second trimester  
☐ Third trimester
10. HIV Status ☐ Negative ☐ Positive  
<if positive>  
a. Are you on Medication?  
☐ Yes ☐ No



11. Where do you currently get information about your pregnancy?
- ☐ Friends and relatives
  - ☐ Healthcare providers
  - ☐ Internet
  - ☐ Mass media e.g. Radio/TV
  - ☐ Other sources (please specify).....

12. How often do you get information about your pregnancy?
- ☐ Per day
  - ☐ Per week
  - ☐ Per month
  - ☐ More than a month

13. What form do you usually receive information about your pregnancy?
- ☐ Word of mouth
  - ☐ Written text
  - ☐ Video/audio
  - ☐ Others (please specify).....

14. Which pregnancy-related information do you often get?
- ☐ Nutrition
  - ☐ Antenatal check-up reminders
  - ☐ HIV testing
  - ☐ Birth preparedness
  - ☐ Danger signs
  - ☐ Exercises
  - ☐ Others: Please specify.....

**Technology Readiness**

15. Do you own a personal mobile phone? ☐ Yes ☐ No
- If yes, what type of mobile phone? ☐ Smart Phone ☐ Feature phone

16. Do you share a mobile phone? ☐ Yes ☐ No

17. Have you ever received any pregnancy-related information on your mobile phone? ☐ Yes ☐ No

If yes which kind of information was it about?

☐ Nutrition

☐ Antenatal check-up reminders

☐ HIV testing

☐ Birth preparedness

☐ Danger signs

☐ Exercises

☐ Others: Please specify.....

18. Would you like to receive pregnancy-related information on a mobile phone? ☐ Yes ☐ No

19. Would you prefer general pregnancy-related information or you prefer information tailored to your stages of pregnancy?  
☐ Prefers general information ☐ Prefers information tailored to my stages of pregnancy

20. How often would you like to receive pregnancy-related information on your mobile phone?  
☐ Daily

☐ Weekly

☐ Monthly

☐ Other: Please specify.....

Please give reasons for your preference.....

21. Do you think that being in a study that sends information on a mobile phone would improve maternal health? ☐ Yes ☐ No

Please give reasons for your answer

.....



22. Which kinds of information would you prefer for to be sent?

- ☐ Antenatal check-up reminders
- ☐ Nutrition
- ☐ Birth preparedness
- ☐ Danger signs
- ☐ Breast feeding
- ☐ Immunization
- ☐ Other (please specify).....

23. In what form, would you prefer to receive this information?

- ☐ Videos
- ☐ Audio
- ☐ Images
- ☐ Text (please specify the language.....)
- ☐ Other forms, please specify .....

Please give reasons for your  
preference.....  
.....

24. How long would you want each message to be?

- ☐ 2 to 4 minutes
- ☐ 5 minutes
- ☐ Above 5 minutes

Please give reasons for your preference.....  
.....  
.....



*You have finished!*  
*Thank you very much for your time*



## Survey for Technology readiness and satisfaction at baseline

### Survey for Technology readiness and satisfaction (Base-line)

**Study Title:** Using a mobile phone-based multimedia technology to support maternal health in rural southwestern Uganda.

Dear Participant, you have accepted to take part in a study by using the MatHealth application that supports maternal health care by utilizing multimedia messages, receiving reminders and communicating with the healthcare practitioners. The following questions are meant to help us understand your readiness in using the intervention.

#### Facilitating Conditions:

1. I possess a personal mobile telephone with the application installed on it.  
☐Yes ☐No
2. My personal mobile phone successfully receives reminders.  
☐Yes ☐No
3. I have electricity/solar for charging my mobile phone whenever the need arises.  
☐Yes ☐No.
4. I have reliable mobile telephone network at my home that could enable me to communicate with the health practitioner when the need arises.  
☐Yes ☐No ☐Not sure

#### Expected usefulness of the application

1. Using the application would be useful in acquiring knowledge about maternal health.  
☐Strongly Agree ☐Agree ☐Not sure ☐Disagree ☐Strongly Disagree
2. Using the application would be useful in reminding me to attend the antenatal appointments  
☐Strongly Agree ☐Agree ☐Not sure ☐Disagree ☐Strongly Disagree
3. Using the application would be useful in making decisions regarding my pregnancy  
☐Strongly Agree ☐Agree ☐Not sure ☐Disagree ☐Strongly Disagree
4. Using the application would be useful in communicating with the health practitioners while away from the clinic



☐Strongly Agree ☐Agree ☐Not sure ☐Disagree ☐Strongly Disagree

5. Using the application will positively affect the way I feel about pregnancy.

☐Strongly Agree ☐Agree ☐Not sure ☐Disagree ☐Strongly Disagree

6. Using reminders will help me to go for the antenatal visits

☐Strongly Agree ☐Agree ☐Not sure ☐Disagree ☐Strongly Disagree

7. Using the application will help me to reduce on the communication costs

☐Strongly Agree ☐Agree ☐Not sure ☐Disagree ☐Strongly Disagree

8. Using the application will improve my patient- health practitioner relationship

☐Strongly Agree ☐Agree ☐Not sure ☐Disagree ☐Strongly Disagree

#### **Perceived Ease of Use of the application**

1. It will be easy for me to access the multimedia messages in the application.

☐Strongly Agree ☐Agree ☐Not sure ☐Disagree ☐Strongly Disagree

2. It will be easy for me to learn how to access the reminders for my antenatal appointments.

☐Strongly Agree ☐Agree ☐Not sure ☐Disagree ☐Strongly Disagree

3. It will be easy for me to initiate communication with the health practitioner

☐Strongly Agree ☐Agree ☐Not sure ☐Disagree ☐Strongly Disagree

It will be easy for me to understand the information in the multimedia messages.

☐Strongly Agree ☐Agree ☐Not sure ☐Disagree ☐Strongly Disagree

4. It will be easy for me to remember to go for antenatal appointments.

☐Strongly Agree ☐Agree ☐Not sure ☐Disagree ☐Strongly Disagree

5. Overall, I will find the application easy to use.

☐Strongly Agree ☐Agree ☐Not sure ☐Disagree ☐Strongly Disagree

#### **Social Norms about using the application**

1. People who take care of my health think I should use the application.

☐Strongly Agree ☐Agree ☐Not sure ☐Disagree ☐Strongly Disagree



2. People who influence my behaviour think I should use the application.

☐Strongly Agree ☐Agree ☐Not sure ☐Disagree ☐Strongly Disagree

3. People who are important to me think I should use the application.

☐Strongly Agree ☐Agree ☐Not sure ☐Disagree ☐Strongly Disagree

4. People who will use the application will have high social status than those who will not use the application.

☐Strongly Agree ☐Agree ☐Not sure ☐Disagree ☐Strongly Disagree

#### **Foreseen application acceptancy**

1. I will use the application consistently.

☐Strongly Agree ☐Agree ☐Not sure ☐Disagree ☐Strongly Disagree

2. I will use the reminders consistently.

☐Strongly Agree ☐Agree ☐Not sure ☐Disagree ☐Strongly Disagree

3. I will use the communication function to contact the health practitioner whenever the need arises.

☐Strongly Agree ☐Agree ☐Not sure ☐Disagree ☐Strongly Disagree

4. I would like to use the application in my next pregnancy and I would recommend it to a friend/ relative

☐Strongly Agree ☐Agree ☐Not sure ☐Disagree ☐Strongly Disagree

#### **Ethical issues**

What possible concerns do you anticipate to have as a result of using the application?

.....

.....

.....

.....

.....

*Thank you very much for your help!*



# Survey for demographics and health, knowledge, attitudes and practices at baseline

Participant ID _____	Date ____/____/____
Staff initials: _____	

## Demographics and Health, and, Knowledge, Attitudes, and Practices (pregnant Women at Baseline)

### a). Demographics, and Health

*Instructions: To be completed at enrolment/baseline. Please make reference to the participant's Antenatal medical chart where necessary.*

#### Demographics

1. Age: ☐ 18-28 ☐ 29-39 ☐ 40-50

3. Primary residence			
County	Sub-County	Parish	Village/LC1
4. Would you call your residence a town or a rural area?			
Town <input type="checkbox"/>	Rural <input type="checkbox"/>		

2. Your telephone number.....

3. Marital status: ☐ Married ☐ Cohabiting ☐ Single ☐ Separated ☐ Widowed

4. Education: Highest level of education achieved:

5. ☐ None ☐ Lower primary: up to P3 level ☐ Upper primary: up to P7



6. Literacy

	English	Runyankole
Able to speak	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No
Able to read	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No
Able to write	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No

**Health**

7. What was the first day of your last normal menstrual period?.....

8. Which trimester of pregnancy are you:

☐ First trimester (up to 12 weeks)

☐ Second trimester (12-24 weeks)

☐ Third trimester (after 24 weeks)

9. Latest HIV Status ☐ Negative ☐ Positive ☐ Don't know

<if positive>

a. Are you on Medication?

☐ Yes ☐ No

10. Where do you currently get information about your pregnancy?

☐ Friends and relatives

☐ Healthcare providers

☐ Internet

☐ Mass media e.g. Radio/TV

☐ Other sources (please specify).....

11. How often do you get information about your pregnancy?

☐ Per day

☐ Per week

☐ Per month

☐ More than a month

12. What form do you usually receive information about your pregnancy?

☐ Word of mouth

☐ Written text

- ☐ Lack of exercises
- ☐ Lack of foods containing iron
- ☐ Poor sleep
- ☐ Worms
- ☐ I don't know
- ☐ Others: Please specify.....

4. How can anaemia be prevented during pregnancy?

- ☐ Eating more iron-contained food
- ☐ Having enough sleep
- ☐ Doing exercises
- ☐ Deworming
- ☐ I don't know
- ☐ Others: Please specify.....

5. Which of the following is the main source of calcium for pregnant women

- ☐ Soda
- ☐ Water
- ☐ Milk
- ☐ I don't know
- ☐ Others: Please specify.....

6. Which of the following is the main reason why pregnant women need calcium?

- ☐ Prevents heart burn
- ☐ Source a good skin
- ☐ Harding bones
- ☐ I don't know

7. Which of the following are danger signs during the first trimester of a pregnancy?

Please tick all that apply

- ☐ Persistent cramps
- ☐ Nausea
- ☐ Persistent bleeding
- ☐ Poor appetite
- ☐ Others: Please specify.....

8. Which of the following are labour signs? Please tick all that apply.

- ☐ Slimy Vaginal discharge
- ☐ Regular increasing pains in the uterus
- ☐ Rupture of membranes
- ☐ Don't know
- ☐ Others: Please specify.....

9. Which of the following methods is better for feeding new-born babies?

- ☐ Exclusive breast feeding
- ☐ Milk powder feeding
- ☐ Cows' milk
- ☐ Millet porridge
- ☐ Maize porridge

#### Attitudes

No	Please tell us the extent you agree or disagree with the following statements. Don't worry about getting the right answer, just say what you think. Please put a tick ✓ in the appropriate square.	Answer				
		Strongly agree	Agree	Disagree	Strongly disagree	No answer
1	It is not necessary for pregnant women to go for antenatal visits throughout their pregnancies as long as they are feeling ok.					
2	It is ok for a pregnant women to substitute consulting a traditional health personnel to consulting a modern health professional					
3	Delivering from a traditional birth attendant is now days more safe than delivering from the hospital					
4	Sleeping under a treated mosquito net when I am pregnant might cause miscarriage due to the insect side used in treating the net					
5	It is more reliable to get pregnancy-related information from my peers than the information I get from health professionals					
6	Spouse should not escort their wives for antenatal visits or during delivery since pregnancy only concerns wives					
7	Immunizing my baby is not necessary since immunisation contains substances that may be harmful to my baby.					

#### Practices

1. When did you attend your first antenatal examination? (Check ANO)

- ☐ Before 3 months



- ☐ After 3 months
- ☐ After 4 months
- ☐ After 5 months

2. How many antenatal visits have you done in your pregnancy so far (Check ANC card)?

- ☐ One visit
- ☐ Two visits
- ☐ At least four visits
- ☐ Eight visits
- ☐ I don't know

3. How often have you been taking iron tablets during your pregnancy

- ☐ Daily consistently
- ☐ Daily but would sometimes miss taking them
- ☐ Never took
- ☐ Others: Please specify.....

4. Which of the following is true about you?

- ☐ You intend to exclusively breastfeed your baby until s/he is six months.
- ☐ You intend to exclusively breastfeed your baby for less than six months.
- ☐ You don't intend to exclusively breastfeed your baby during the first six months

What are the components of a balanced diet?

- ☐ Proteins
- ☐ Carbohydrates
- ☐ Fats
- ☐ Do not know
- ☐ Others: Please specify.....

5. Have you tested for HIV

- ☐ Yes
- ☐ No

6. Which of the following is true about you?

- ☐ You intend to deliver your baby from clinic/hospital with the help of a qualified birth attendant



☐ You intend to deliver your baby from your home with the help of your relative/friend

☐ You intend to deliver your baby from a traditional birth attendant

7. Do you intend to attend Antenatal clinic?

☐ Yes

☐ No

8. If yes, how many visits do you intend to attend?

☐ 1

☐ 2-3

☐ 4

☐ 8

9. Do you think you will attend all visits as prescribed by the health worker?

Yes

No



## Survey for technology readiness and satisfaction at midline

### Survey for Technology readiness and satisfaction (Mid-line)

**Study Title:** Using a mobile phone-based multimedia technology to support maternal health in rural southwestern Uganda.

Dear Participant, you accepted to take part in a study by using the MatHealth application that supports maternal health care by utilizing multimedia messages, receiving reminders and communicating with the healthcare practitioners. The following questions are meant to help us understand why you missed your previous appointment/ stopped using the application.

#### Facilitating Conditions:

1. I possess a personal mobile telephone with the application installed on it.  
☐ Yes ☐ No
2. My personal mobile phone successfully receives reminders.  
☐ Yes ☐ No
3. I have electricity/solar for charging my mobile phone whenever the need arises.  
☐ Yes ☐ No
4. I have reliable mobile telephone network at my home that could enable me to communicate with the health practitioner when the need arises.  
☐ Yes ☐ No ☐ Not sure

#### Perceived Usefulness of the application

1. Using the application has been useful in acquiring knowledge about maternal health.  
☐ Strongly Agree ☐ Agree ☐ Disagree ☐ Strongly Disagree
2. Using the application has been useful in reminding me to attend the antenatal appointments ☐ Strongly Agree ☐ Agree ☐ Disagree ☐ Strongly Disagree.
3. Using the application has been useful in making decisions regarding my pregnancy.  
☐ Strongly Agree ☐ Agree ☐ Disagree ☐ Strongly Disagree.
4. Using the application has been useful in communicating with the health practitioners while away from the clinic





- ☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.
5. Using the application has positively affected the way I feel about pregnancy.  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.
  6. Using reminders have helped me to remember to go for the antenatal visits  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.
  7. Using the application has helped me to reduce on the communication costs  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree
  8. Using the application has improved my patient- health practitioner relationship  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree

#### **Perceived Ease of Use of the application**

1. It has been easy for me to access the multimedia messages in the application.  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.
2. It has been easy for me to learn how to access the reminders for my antenatal appointments.  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.
3. It has been easy for me to initiate communication with the health practitioner  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.
4. It has been easy for me to understand the information in the multimedia messages.  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.
5. It has been easy for me to remember to go for antenatal appointments.  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.
6. Overall, I have found the application easy to use.  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.

#### **Social Norms about using the application**

1. People who take care of my health thought I should use the application.  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.
2. People who influence my behaviour thought I should use the application.

☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.

3. People who are important to me thought I should use the application.

☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.

4. People who use the application have high social status than those who do not use the application. ☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.

#### Application acceptancy

1. I have been using the application consistently.

☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.

2. I have been using the reminders consistently.

☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.

3. I have been using the communication function to contact the health practitioner whenever the need arose. ☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.

4. I would like to continue using the application even in my next pregnancy and I would recommend it to a friend/ relative

☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.

#### Ethical issues

What possible concerns do you anticipate to have as a result of using the application?

.....

.....

.....

.....

.....

*Thank you very much for your help!*



Survey used for demographics and health, knowledge, attitudes and practices at endline

Participant ID _____	Date ____/____/____
Staff initials: _____	

**Demographics and Health, and, Knowledge, Attitudes, and Practices  
(Mothers: Endline)**

**a). Demographics, and Health**

*Instructions: To be completed at endline. Please make reference to the participant's Antenatal medical chart where necessary.*

**Demographics**

1. Age: ☐ 18-28    ☐ 29-39    ☐ 40-50

3. Primary residence			
County	Sub-County	Parish	Village/LC1
4. Would you call your residence a town or a rural area?			
Town <input type="checkbox"/>	Rural <input type="checkbox"/>		

5. Your telephone number.....

6. Marital status: ☐ Married    ☐ Cohabiting    ☐ Single    ☐ Separated    ☐ Windowed

7. Education: Highest level of education achieved:

8.    ☐ None    ☐ Lower primary: up to P3 level    ☐ Upper primary



9. Literacy

	English	Runyankole
Able to speak	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No
Able to read	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No
Able to write	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No

**Health**

10. When did you give birth (Date)?.....

11. Current HIV Status ☐ Negative ☐ Positive ☐ Don't know

<if positive>

a. Are you on Medication?

☐ Yes ☐ No

12. Where do you currently get postnatal information about your health and that of your baby?

☐ Friends and relatives

☐ Healthcare providers

☐ Internet

☐ Mass media e.g. Radio/TV

☐ Other sources (please specify).....

13. How often do you get information about your health and that of your baby?

☐ Per day

☐ Per week

☐ Per month

☐ More than a month

**b). Knowledge, Attitudes and Behaviours**

**Knowledge**

1. Under normal circumstances, when should the first antenatal examination be done?

☐ As soon as I miss my periods/suspect I am pregnant

- ☐ After 3 months
- ☐ After 4 months
- ☐ After 5 months
- ☐ Others: Please specify.....

2. How many antenatal visits should a pregnant woman make during the nine months of her pregnancy?

- ☐ Nine visits
- ☐ Two visits
- ☐ At least four visits
- ☐ At least eight visits
- ☐ I don't know
- ☐ Others: Please specify.....

3. What causes anaemia during pregnancy?

- ☐ Lack of exercises
- ☐ Lack of foods containing iron
- ☐ Poor sleep
- ☐ Worms
- ☐ I don't know
- ☐ Others: Please specify.....

4. How can anaemia be prevented during pregnancy?

- ☐ Eating more iron-contained food
- ☐ Having enough sleep
- ☐ Doing exercises
- ☐ Deworming
- ☐ I don't know
- ☐ Others: Please specify.....

5. Which of the following is the main source of calcium for pregnant women?

- ☐ Soda
- ☐ Water
- ☐ Milk





- ☐ I don't know
- ☐ Others: Please specify.....

6. Which of the following is the main reason why pregnant women need calcium?

- ☐ Prevents heart burn
- ☐ Source a good skin
- ☐ Harding bones
- ☐ I don't know

7. Which of the following are danger signs during the first trimester of a pregnancy?

Please tick all that apply

- ☐ Persistent cramps
- ☐ Nausea
- ☐ Persistent bleeding
- ☐ Poor appetite
- ☐ Others: Please specify.....

8. Which of the following are labour signs? Please tick all that apply.

- ☐ Slimy Vaginal discharge
- ☐ Regular increasing pains in the uterus
- ☐ Rupture of membranes
- ☐ Don't know
- ☐ Others: Please specify.....

9. Which of the following methods is better for feeding new-born babies?

- ☐ Exclusive breast feeding
- ☐ Milk powder feeding
- ☐ Cows' milk
- ☐ Millet porridge
- ☐ Maize porridge

#### Attitudes

No	Please tell us the extent you agree or disagree with the following statements. Don't worry about getting the right answer, just say what you think. Please put a tick ✓ in the appropriate square.	Answer				
		Strongly agree	Agree	Disagree	Strongly disagree	No answer

1	It is not necessary for pregnant women to go for antenatal visits throughout their pregnancies as long as they are feeling ok.					
2	It is ok for a pregnant women to substitute consulting a traditional health personnel to consulting a modern health professional					
3	Delivering from a traditional birth attendant is now days more safe than delivering from the hospital					
4	Sleeping under a treated mosquito net when I am pregnant might cause miscarriage due to the insect side used in treating the net					
5	It is more reliable to get pregnancy-related information from my peers than the information I get from health professionals					
6	Spouse should not escort their wives for antenatal visits or during delivery since pregnancy only concerns wives					
7	Immunizing my baby is not necessary since immunisation contains substances that may be harmful to my baby.					
8	It is not necessary to attend postnatal appointments as long the mother and the baby are well					

### Practices

- When did you attend your first antenatal examination? (Check ANC card)
  - ☐ Before 3 months
  - ☐ After 3 months
  - ☐ After 4 months
  - ☐ After 5 months
- How many antenatal visits have you done in your pregnancy so far (Check ANC card)?
  - ☐ One visit
  - ☐ Two visits
  - ☐ At least four visits
  - ☐ Eight visits
  - ☐ I don't know
- How often have you been taking iron tablets during your pregnancy
  - ☐ Daily consistently
  - ☐ Daily but would sometimes miss taking them
  - ☐ Never took
  - ☐ Others: Please specify.....
- Which of the following is true about you?



- ☐ You tested for HIV/AIDS when you were pregnant and got negative result
- ☐ You tested for HIV/AIDS when you were pregnant and got positive result
- ☐ You did not test for HIV/AIDS when you were pregnant

Do you think interventions to prevent HIV transmission from an infected pregnant mother to her baby are effective? ☐ Yes ☐ No

5. If you tested HIV negative, which PMTCT interventions did you adopt? (tick all that apply)

- ☐ ARVs
- ☐ Hospital Delivery
- ☐ Good ANC
- ☐ Good PNC

6. Which of the following is true about you?

- ☐ You delivered from clinic/hospital with the help of a qualified birth attendant
- ☐ You delivered from your home with the help of your relative/friend
- ☐ You delivered from a traditional birth attendant

7. Which of the following is true about you?

- ☐ You had a normal baby without complications
- ☐ You had complications during delivery but had a normal baby
- ☐ You had complications during pregnancy but delivered a normal baby
- ☐ You had a still birth (*in case of a still birth, please ignore the questions that follow*)

8. Which of the following is true about you?

- ☐ You are exclusively breastfeeding your baby, and you intend to continue until s/he is six months.
- ☐ You are exclusively breastfeeding your baby, but does not intend to continue with exclusive breastfeeding until the baby is six months.
- ☐ You are not exclusively breastfeeding your baby



9. Which of the following diets are you taking?

- ☐ Proteins
- ☐ Carbohydrates
- ☐ Fats
- ☐ Others: Please specify.....

10. When did you have your first PNC visit?

- ☐ After 6 hours
- ☐ After 6 days
- ☐ After 6 weeks
- ☐ After 6 Months
- ☐ Have not had any PNC
- ☐ Others (specify).....

11. Do you intend to attend all the PNC recommended by your healthcare provider?

- ☐ Yes   ☐ No   ☐ Not sure

12. How did you prepare for the birth of your baby

- ☐ Knew the facility for my delivery in advance
- ☐ Had saved transport funds
- ☐ Had Maama Kit
- ☐ Had someone to escort me to the facility
- ☐ Never prepared

13. Which of the following is a danger sign of pregnancy? (tick all that apply)



☐ Raised blood pressure

☐ Bleeding in pregnancy

☐ Breaking of baby waters

☐ Convulsions

☐ Post-partum bleeding

☐ Any other...

12. Did you develop any danger sign of complication in this pregnancy

☐ Yes ☐ No ☐ Not sure



## Survey for technology readiness and satisfaction at endline

### Survey for Technology readiness and satisfaction (End-line)

**Study Title:** Using a mobile phone-based multimedia technology to support maternal health in rural southwestern Uganda.

Dear Participant, you have been participating in a study by using the MatHealth application that supports maternal health care by utilizing multimedia messages, receiving reminders and communicating with the healthcare practitioners. The following questions are meant to help us understand your experience of using the intervention.

#### Facilitating Conditions:

1. I possess a personal mobile telephone with the application installed on it.

☐ Yes ☐ No

2. My personal mobile phone successfully receives reminders.

☐ Yes ☐ No

I have electricity/solar for charging my mobile phone whenever the need arises.

☐ Yes ☐ No

3. I have reliable mobile telephone network at my home that could enable me to communicate with the health practitioner when the need arises.

☐ Yes ☐ No ☐ Not sure

#### Perceived Usefulness of the application

1. Using the application was useful in acquiring knowledge about maternal health.

☐ Strongly Agree ☐ Agree ☐ Disagree ☐ Strongly Disagree

2. Using the application was useful in reminding me to attend the antenatal appointments

☐ Strongly Agree ☐ Agree ☐ Disagree ☐ Strongly Disagree.

3. Using the application was useful in making decisions regarding my pregnancy

☐ Strongly Agree ☐ Agree ☐ Disagree ☐ Strongly Disagree.

4. Using the application was useful in communicating with the health practitioner while away from the clinic

☐ Strongly Agree ☐ Agree ☐ Disagree ☐ Strongly Disagree.



5. Using the application positively affected the way I feel about pregnancy.  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.
6. Using reminders helped me to remember to go for the antenatal visits  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.
7. Using the application helped me to reduce on the communication costs  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree
8. Using the application improved my patient- health practitioner relationship  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree

#### **Perceived Ease of Use of the application**

1. It was easy for me to access the multimedia messages in the application.  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.
2. It was easy for me to learn how to access the reminders for my antenatal appointments.  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.
3. It was easy for me to initiate communication with the health practitioner  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.
4. It was easy for me to understand the information in the multimedia messages.  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.
5. It was easy for me to remember to go for antenatal appointments.  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.
6. Overall, I found the application easy to use.  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.

#### **Social Norms about using the application**

1. People who take care of my health thought I should use the application.  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.
2. People who influence my behaviour thought I should use the application.  
☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.

3. People who are important to me thought I should use the application.

☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.

4. People who use the application have high social status than those who do not use the application. ☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.

#### Application acceptability

1. I used the application consistently.

☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.

2. I used the reminders consistently.

☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.

3. I used the communication function to contact the health practitioner whenever the need arose. ☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.

4. I would like to use the application in my next pregnancy and I would recommend it to a friend/ relative. ☐Strongly Agree ☐Agree ☐Disagree ☐Strongly Disagree.

#### Ethical issues

What possible concerns do you anticipate to have as a result of using the application?

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*Thank you very much for your help!*



## Interview guides

### Qualitative interview guide for intervention group

#### Qualitative Interview Guide

##### Intervention group

1. How are you? How is your family?
2. Tell me about the mobile phone-based application for maternal health you are using for your pregnancy. What does it do?
3. In what ways was it easy/hard to learn using the mobile phone-based application? Why?
4. In what ways was it easy/hard to use this mobile phone-based? Why?
5. How has it helped you? How?
6. What do you like about it?
7. What do you dislike about it?
8. What concerns do you have about using the application? What are some of the challenges of using it? Can you give me some examples? In what ways is \_\_\_\_\_ a challenge? *Probe on each challenge mentioned (e.g., application failure, network connectivity, convenience).*
9. What improvements would you make to the mobile phone-based application? Why?
10. Do you have any concerns about people seeing you with the mobile phone-based application?
11. How do people react when they see you with the mobile phone-based application?
12. As part of this study, you also receive pregnant-related messages in form of videos/audios. What is the purpose of the messages?
13. When/how often did you receive the pregnant-related messages using the application? Why did you choose that time of day?
14. Tell me about the last time you received a pregnant-related message using the application. What did the message say? What did you do immediately after receiving it? *Probe about the individual's particular experience: What was she doing? Where was she?*
15. Are the messages what you were expecting when you joined this study? In what ways have they been different from your expectation? *(probe for errors in message sending e.g frequency and experience)*
16. What do you like about the messages? What do you dislike? Why? *Probe about content as well as the act of receiving the messages.*
17. Do you like the messages? Why





18. In what ways do the messages help you with your pregnancy? How so? *Probe for specific examples.*
19. What concerns do you have about using messages to support you in your pregnancy? What are the difficulties you face in receiving messages? *Possible probes: timing, privacy (esp in the case of sharing the phone), social acceptance of the messages, network connectivity, application failure (e.g., phone not working), inconsistent use (no battery charge, changes in phone number).*
20. Tell me about the last time, if any, that the SMS reminder resulted in you taking your pills. What happened, exactly?
21. What do others (family members, friends, people in your community) think about the messages you receive? Do they know what they are for? How do people react when they see you read the messages? Tell me about a time when someone noticed you reading the message.
22. Would you like to receive the messages in the future? Why or why not? Could anything be done differently to improve the messages?
23. Is there anything else you would like to tell me about receiving the messages that we haven't talked about?

Thank you very much for your time. We have finished the interview.



## Focus group discussions

### Focus group discussion guide for health practitioners

#### Focus Group Discussion guide for Healthcare workers

Thank you for coming to this group discussion today. As we mentioned earlier, we are planning to carry out a study whose main goal is to improve maternal health using a mobile phone-based application in rural southwestern Uganda. The application will use videos and audios to regularly send information to pregnant women at various stages of their pregnancies. Examples of information to be sent include; antenatal check-up reminders, nutrition, birth preparedness, and identifying danger signs. The study will involve 80 pregnant women receiving antenatal services at Mbarara Regional Referral Hospital.

Here is a demo of the application which we hope to improve and give to pregnant mothers *<practically show the current prototype including sample videos/audios to be sent>*. We hope to enhance this prototype, and then learn if the videos/audios will result in increased access to high quality, relevant local and culturally acceptable maternal health information that can enable mothers and families demonstrate improved health-seeking and preventative behaviors. These behaviours include early uptake and adherence to antenatal check-ups and care including HIV testing, good nutrition, birth preparedness, dealing with danger signs, among others; all of which should ultimately contribute to improved maternal and child survival.

We are now going to ask you about the maternal health challenges mothers experience, how the planned application will address the challenges, opinions and perceptions about the planned applications, predicted barriers in using the application, as well privacy and confidentiality considerations. There are no right or wrong answers, we just like to know what your thoughts are.

We will record your responses, so that we may write them down accurately at a later time. We will then delete the recording to protect your confidentiality.

Before we get started, do you have any questions for me?

1. Do you think it is important to send women reliable maternal health information about their pregnancy? Why? Or Why not?





2. What challenges do you think women normally experience in getting maternal health-related information about their pregnancies?
  - a. probe for:
    - i. *reliability, access, frequency, sufficiency, ability to understand it, privacy/confidentiality etc*
    - ii. *causes of each of the mentioned challenges*
    - iii. *probe more on level of literacy*
3. How can an intervention that send mobile phone-based video and sound to pregnant mothers' phones address some of the above mentioned challenges?
  - a. Probe for potential influence on:
    - i. maternal-health related knowledge e.g. importance of carrying out *antenatal check-ups, good nutrition, HIV testing, knowledge of danger signs (when to return), and birth preparedness or birth planning, baby nutrition including breast feeding, post-natal care*
    - ii. Attitudes about maternal health
      1. *do you think the health workers at the Ante natal visits provide you with adequate maternal health related information*
      2. *Do you think you need and alternate source of information*
    - iii. Adoption of preventive behaviours e.g. *early uptake and adherence to antenatal check-ups and care including HIV testing, good nutrition, birth preparedness, dealing with danger signs*
4. How do you feel about an intervention that utilizes mobile phone-based video and sound to send pregnant-related information to expectant mothers?
  - a. Probe:
    - i. Likes about the intervention
    - ii. Dislikes
  - a) What challenges do you anticipate in sending maternal health-related information (videos/audios) on pregnant mothers' phones?
5.
  - b) **Probes:**
    - i. How do you think women would feel if someone else accessed their pregnancy-related information (videos/audios) on their phone?
      1. What pregnant-related information do you think women would like to keep private? Please give reasons for your answer.

2. Please give us suggestions about how this information can be kept private.
- ii. Do you think there is something that could sometimes hinder women from receiving the planned videos/audios for maternal health? Please tell me more about it.
  - a. Probe for potential challenges *e.g.*
    - i. *Usability skills*
    - ii. *Shared phones*
6. Is there anything else you would like to tell me about the use of mobile phone-based videos/audios to support maternal health?

Do you have any questions for me? *We have finished this discussion. Thank you very much for offering to talk to us.*



## Focus group discussion guide for pregnant women

### Focus Group Discussion guide for Pregnant Mothers

Thank you for coming to this group discussion today. As we mentioned earlier, we are planning to carry out a study whose main goal is to improve maternal health using a mobile phone-based application in rural southwestern Uganda. The application will use videos and audios to send information to pregnant women at various stages of their pregnancies. Examples of information to be sent include; antenatal check-up reminders, nutrition, birth preparedness, and identifying danger signs. The study will involve 80 pregnant women receiving antenatal services at Mbarara Regional Referral Hospital.

Here is a demo of the application which we hope to improve and give to pregnant mothers *<practically show the current prototype including sample videos/audios to be sent>*. We hope to enhance this prototype, and then learn if the videos/audios will result in increased access to high quality, relevant local and culturally acceptable maternal health information that can enable mothers and families demonstrate improved health-seeking and preventative behaviors. These behaviours include early uptake and adherence to antenatal check-ups and care including HIV testing, good nutrition, birth preparedness, dealing with danger signs, among others; all of which should ultimately contribute to improved maternal and child survival.

We are now going to ask you about the maternal health challenges you experience, how the planned application will address the challenges, opinions and perceptions about the planned applications, predicted barriers in using the application, as well privacy and confidentiality considerations. There are no right or wrong answers, we just like to know what your thoughts are.

We will record your responses, so that we may write them down accurately at a later time. We will then delete the recording to protect your confidentiality.

Before we get started, do you have any questions for me?

1. Do you think it is important to receive reliable maternal health-related information about your pregnancy? Why? Or Why not?
2. What challenges do you normally experience in getting maternal health-related information about your pregnancy?
  - a. probe for:
    - i. *reliability, access, frequency, sufficiency, ability to understand it, privacy/confidentiality etc*
    - ii. *causes of each of the mentioned challenges*
    - iii. *probe more on level of literacy*



3. How can an intervention that uses mobile phone-based video and sound address some of the above mentioned challenges?

a. Probe for potential influence on:

- i. maternal-health related knowledge e.g. importance of carrying out *antenatal check-ups, good nutrition, HIV testing, knowledge of danger signs (e.g. when to return), and birth preparedness or birth planning, baby nutrition including breast feeding, post-natal care*
- ii. Attitudes about maternal health e.g.
  - *do you think the health workers at the Antenatal visits provide you with adequate maternal health related information?*
  - *Do you think you need and alternate source of information?*
- iii. Adoption of preventive behaviours e.g. *early uptake and adherence to antenatal check-ups and care including HIV testing, good nutrition, birth preparedness, dealing with danger signs*

4. How do you feel about an intervention that utilizes mobile phone-based video and sound to send you maternal health-related information?

a. Probe:

- i. Likes about the intervention
- ii. Dislikes

5. What challenges do you anticipate in receiving maternal health-related information (videos/audios) on a phone?

a) **Probes:**

- i. How would you feel if someone else accessed your pregnancy-related information (videos/audios) on your phone?
  1. What information would like to keep private? Please give reasons for your answer.
  2. Please give us suggestions about how this information can be kept private.
- ii. Do you think there is something that could sometimes hinder you from receiving the planned videos/audios for maternal health? Please tell me more about it.
  - a. Probe for potential challenges e.g.
    - i. *Usability skills*
    - ii. *Shared phones*

6. Is there anything else you would like to tell me about the use of use of mobile phone-based videos/audios to support maternal health?

Do you have any questions for me? *We have finished this discussion. Thank you very much for offering to talk to us.*