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Universal Design of ICT

M2M: Universally Designed Multimedia Training and Learning Application for Maternal Health

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OSLOMET

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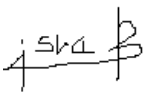

Abstract

The figure of Maternal Mortality Ratio in the global south is worrying and requires a serious attention from all stakeholders. Despite the progress made on maternity healthcare in the last two decades, a huge effort is still required to achieve the SDG3 target. The effort includes capacitating the health professionals and local doulas through training and learning application platforms. Universally designed multimedia training and learning applications plays such a significant role in facilitating this effort. To design an accessible maternity training and learning application, the accessibility barriers of the target diverse user groups must be identified, and the impact of the barriers need to be quantified.

In this research work, we have developed a prototype called M2M that comprises VR-based animation. We have used the prototype to identify the possible accessibility barriers of multimedia-based maternity training and learning application experienced by people with low vision through the combination of heuristic and barrier walkthrough methods.

We studied the severity of the identified accessibility barriers and their impact which will serve as a benchmark to develop a fully-fledged maternity health training and learning application for the global south. We have shown the strong correlation between the number of UI elements and the prevalence of accessibility barriers that must be considered in designing the UI/UX of the fully-fledged maternity training and learning application. We have also observed that multimedia contents must be evaluated independently for any accessibility issues before integrating the contents to training applications.

Keywords: Universal Design, Universal Design for Learning, Multimedia Training and Learning Application, Maternity Training and Learning Applications, Virtual Reality-based Learning

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Acronyms

DRC:	Democratic Republic of Congo
EU:	European Union
HCI:	Human Computer Interaction
ICM:	International Confederation of Midwives
ICT:	Information Communication Technology
INE:	National Institute of Statistics (Mozambique)
M2M:	Universally Designed Training and Learning Application for Maternity Health
MMR:	Maternal Mortality Ratio
MRI:	Magnetic Resonance Imaging
SDG:	Sustainable Development Goal
UAAG:	User Agent Accessibility Guideline
UI:	User Interface
UN:	United Nations
UX:	User Experience
VC:	Virtual Classroom
VR:	Virtual Reality
W3C.	World Wide Web Consortium
WCAG:	Web Content Accessibility Guideline
WHO:	World Health Organization

Chapter One: Introduction

1.1. Background

Pregnancy and childbirth are among the beautiful phenomena that happen to humans. Maternity Healthcare aims to keep the happening of this phenomenon without any maternal mortality. This makes maternity health one of the major priorities of the SDG3 (UN, 2019). By 2030, the SDG3 targeted that the global maternity mortality ratio shall be reduced to less than 70 per 100,000 live births (UN, 2019). The creation of improved services and products through innovation is key to achieve this target. Researches have shown that innovative ICT artifacts play a significant role in achieving the SDGs especially in "*fragile, low-resource, and remote settings*" (Asi & Williams, 2018).

The innovative artifacts help to improve the efficiency of maternity healthcare settings that encompasses the medical professionals, women, vulnerable communities, civil societies, and other relevant decision-makers and stakeholders. They have irreplaceable contributions in safeguarding "*sustainable and equitable access*" to necessary "*healthcare interventions*" (WHO, 2019). These contributions also increase the proportion of birth attended by skilled health workers which are significant to reduce maternal mortality.

Several figures have shown worrying facts about maternal mortality ratios in the global south. As per the world health statistics by WHO, "*In 2016, maternal mortality was the second leading cause of death for women of reproductive age, after HIV/AIDS, and was the leading cause among women aged 15–29 years*" (WHO, 2019). In 2016, about 95% of the maternal mortalities are recorded in low-income and lower-middle-income countries (WHO, 2019). Africa recorded about 65% of maternal mortality in 2016 (WHO, 2019). In the same year, "*1 woman in 41 who lives in low-income countries died from maternal causes*" (WHO, 2019). This is generally because of poor maternity healthcare setting that is also affecting the socio-economic perspective of the Sub-Saharan African countries.

The loss and grief due to maternal mortality are exposing peoples to different socio-economic problems. Researches have shown that mother mortality leads to increased child(ren) mortality (David et al., 2014; Zhou et al., 2016). This demonstrates the tragedy of maternal mortality can

expand to the next generation of a family and community which makes its socio-economic impact worsen. A shift is required from stakeholders to tackle major causes of maternal mortality which are quite preventive through awareness creation and training of local midwives called doulas.

Creating awareness among the community about maternity health and engaging communities in this process contributes massively to reduce maternal mortality. To do this, effective health communication platforms play a vital role. These platforms have an impact on how a community behaves regarding health issues and how positive is the outcome of their behavior (Dianne, 2007; Schiavo, 2013).

ICT innovations can serve as a capacity-building means to healthcare infrastructures in developing countries. They enable effective provision of accessible healthcare services to communities through innovative health information systems (Free et al., 2010; Kreps, 2017; Marin, Massad, Gutierrez, Rodrigues, & Sigulem, 2016; United Naitons, 2019). Capacitating developing countries' maternal healthcare systems using a multimedia training and learning platform is an example of these innovations. Several types of research have shown that multimedia e-learning platforms can facilitate the training of midwives and doulas in such an efficient and effective manner (Alamantariotou & Nicolopoulou, 2016; Asi & Williams, 2018; Clark & Mayer, 2016; Kreps, 2017; Mayer, 2017).

1.2. Statement of the Problem

Even though most of the maternal mortalities are avoidable, they are still the headache of developing countries including Sub-Saharan African countries. The major causes of maternal mortalities are postpartum hemorrhage, hypertensive disorders, unsafe abortion, and delivery-related complications (Black, Laxminarayan, Temmerman, & Walker, 2016). The extent of the mortality is depending on timely and adequate clinical intervention on the causes (Black et al., 2016; Stanton et al., 2013; Zhou et al., 2016). However, a lack of maternity health professionals including midwives is affecting the expected clinical interventions. The local doulas who often replace the role of professional midwives do not have the required knowledge and skill to tackle issues happen during pregnancy, at the time of delivery, and in the postpartum period (Black et al., 2016). Digital training facilities for doulas by remote midwives and other health professionals can improve the competencies of midwives and local doulas (Arbour, Nypaver, & Wika, 2015; Arcia, Stonbraker, & Warner, 2019).

For instance, 85% of Mozambican women who are in their reproductive age could not able to continue their education above primary school (Stanton et al., 2013). This creates a barrier in the maternal healthcare communication setting as pregnant women are the center of the communication (Ahmed, Creanga, Gillespie, & Tsui, 2010). This is also affecting Mozambican women to do not make early critical decisions which are significant for the prevention of maternal mortality (Arcia et al., 2019). This shows the need for a universally designed multimedia training and learning platform in consideration of user diversity that can be expressed in terms of educational background, ability, disability, gender, and digital skill.

Hence, the proposed research will identify accessibility barriers and study their severity which is significant to develop and implement universally-designed multimedia training and learning application.

- This research attempts to address the following questions:
- How critical and culturally-sensitive maternity issues are represented using accessible multimedia?

- What are the key accessibility barriers experienced by people with low vision when they interact with maternity training and learning applications?
- How can the impact of identified accessibility barriers be quantified?

1.3. Objective

1.3.1. General Objective

The main objective of the proposed research is to identify accessibility barriers and their severity level that needs to be considered in designing and implementing universally-designed multimedia training and learning application for midwives and doulas in Sub-Saharan countries.

1.3.2. Specific Objectives

To accomplish the general objective stated above, the following specific objectives are identified:

- Comprehensive literature review about health communication and key issues, maternal healthcare service in sub-Saharan Africa, multimedia training and learning platforms, and accessible healthcare systems;
- Identify user diversities and possible ICT barriers related to the proposed solution;
- Collect and analyze user and system requirements for a prototype;
- Create a sample accessible maternity healthcare multimedia content;
- Develop a prototype;
- Evaluate the prototype to identify barriers and measure their severity;

1.4. Method

To achieve the general and specific objectives mentioned above, the following methods will be used:

- Literature Review

The researchers will review different kinds of related books, articles, conference proceedings papers, global reports, and online resources to get a clear understanding of the research area.

- Prototyping

A prototype will be developed to show how the system can be developed and to identify and quantify the possible accessibility barriers. The prototype is also used to address the research questions stated in section 1.2.

- Data Collection and Analysis

The data that is to be used to develop the multimedia content shall be collected from Midwife2Midwives which is a network of midwives and other sources. Selected user requirements will be collected and analyzed to model the basic functionality of the prototype. Interviews, User Surveying, and System Archeology of a similar application shall also be used as data collection techniques.

- Design and Development Approach

Agile software development methodology shall be used to iteratively develop the prototype and the multimedia content.

1.5. Ethics

The proposed research will be conducted in accordance with the research ethics guidelines stated in "*Ethical Guidelines for Research at Oslo Metropolitan University*" and "*The Norwegian National Research Ethics Committees*". The data collection activity will also be conducted in consideration of Norwegian rules and regulations regarding interviewing and observing research participants.

All participants in the data collection and user testing of this research work will be informed about:

- The purpose of the research; that is to design and implement multimedia training and learning application for maternity health.
- A right to decline and to withdraw from participation in any situations and phases of the research work.
- The consequences (if any) of participating in the research work.

1.6. Project Management Plan

1.6.1 Work Packages

Work Package1

User Requirement and Analysis: This work package deals with the elicitation and analysis of selected user requirements for the proposed prototype. User surveys shall be used as a technique to collect requirements. The work package will start in the first week of September and the requirement analysis document will be delivered on December 14, 2020.

Work Package2

UI/UX Design: UX will be designed based on the understanding of user requirements in work package1. The process of UX design will be handled parallelly and iteratively with work package1 starting from October 1, 2020, and shall continue to February 2021.

Work Package3

Prototype Development: This work package shall start on November 1, 2020 and focuses on developing a prototype based on selected functional requirements. The proposed prototype will be delivered on December 14, 2020.

Work Package4

Sample Multimedia Content: A sample multimedia content shall be prepared starting from December 14, 2020 and integrated it to the prototype. A prototype shall be ready at the end of March 2021 for evaluation.

Work Package5

Prototype Evaluation and Analysis: Prototype evaluation shall be conducted starting from the first week of March and shall continue for three weeks.

1.6.2 Schedule

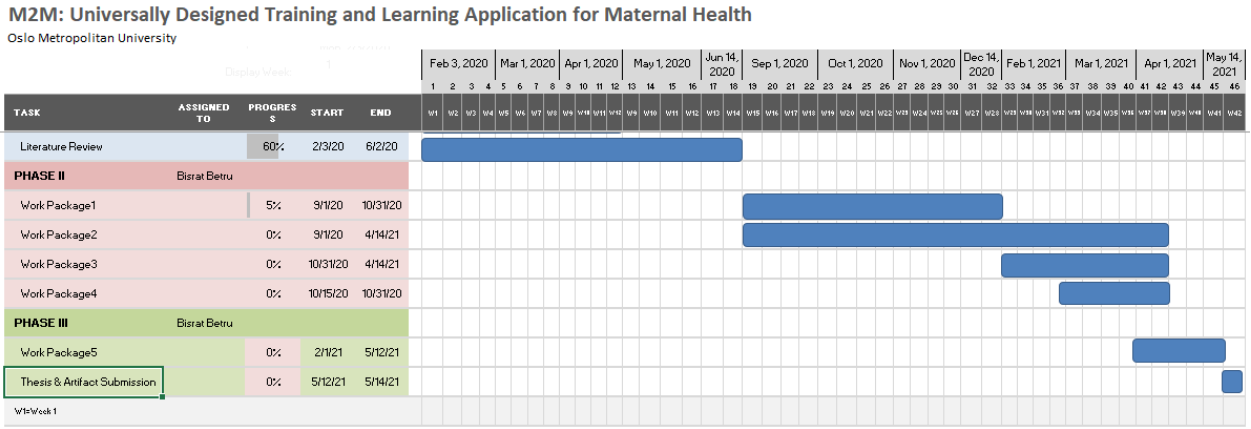


Figure 1.1 Gantt Chart

We prefer to manage the schedule based on the above work packages and the three project phases that are distributed in three corresponding semesters of OsloMet. As a result, we prepare the following Gantt chart to show the main tasks (work packages) in three project phases.

1.6.3 Risk Assessment

We are expected to analyze the possible risks that may affect the successful completion of this research project work. As a result, we have used the techniques suggested in (Selby, 2007) to identify and resolve the possible project risks.

1.6.3.1 Risk Identification

The proposed project may involve some sort of risks that have to be mitigated for the proper completion of the research project. We have used existed software risk checklists and assumption analysis (Selby, 2007) to identify the possible risks of the proposed project.

The identified risks are related to user requirements, project schedule, and quality of the research project. We choose user requirements since it decides the functionality and accessibility of the prototype. Whereas, we pick schedule from the software risks checklist due to the current global pandemic that potentially affects the researchers' travel to Mozambique.

We have summarized the risks in Table 1.1.

Risk Category	Risk ID	Identified Risk	Impact
M2M: Requirement	M2MRisk1	Poor definition of user requirements	Inaccessible and Impractical product
	M2MRisk2	Missing Stakeholders	Ineffectual product
	M2MRisk3	Conflicting requirements	Inaccessible product
M2M: Schedule	M2MRisk4	Compromised schedule due to the current situation of COVID-19. i.e. Late travel to Mozambique	Late Delivery
M2M: Quality	M2MRisk5	Compromised quality due to the current situation of COVID-19. i.e. Late travel to Mozambique	Minimized Scope

Table 1.1: Identified risks

1.6.3.2 Risk Resolution

We shall use risk reduction and risk avoidance (Selby, 2007) strategies to resolve the identified risks. The primary target of the risk resolution is to minimize the probability of occurrence of the identified risks and its potential impact on the project whereas the purpose of the risk avoidance

strategy is to prevent the risk from occurring. The resolution techniques are summarized in Table 1.2.

Risk ID	Identified Risk	Risk Resolution Strategy	Risk Resolution
M2MRisk1	Poor definition of user requirements	Risk avoidance	Requirement validation
M2MRisk2	Missing stakeholders	Risk avoidance	Stakeholder mapping
M2MRisk3	Conflicting requirements	Risk avoidance	Requirement validation
M2MRisk4	Compromised schedule due to COVID-19. i.e. Late travel to Mozambique	Risk reduction	Execution of parallel project tasks until fieldwork travel.
M2MRisk5	Compromised quality due to the current situation of COVID-19. i.e. Late travel to Mozambique	Risk avoidance	Minimizing the scope of the research project.

Table 1.2: Risk resolution

Chapter Two: Methodology

2.1. Overview

We will follow the design science research methodology since it fits well with the objective of the research project. This is because the prototype we will develop can be considered as an artifact that shall enable the design and development of accessible maternity training and learning application. We will use literature review to clearly understand both the problem and solution domain and justify the process we follow to develop the M2M Prototype. We will use interviews, user surveys, and observation of related applications (online training systems) as a data collection technique. We will also use prototyping to develop a sample M2M application with basic training and learning functionalities.

In this section, we present the methods we will use to achieve the objectives of the research project.

2.2. Literature Review

We conduct a comprehensive literature review to understand the problem domain and to map the solution. We review books to understand how we can rapidly develop the M2M prototype. We review articles and conference proceedings papers to get a clear understanding of the research area. We review relevant global reports and online resources to understand the global trend and figure of maternity health. We consider reliable resources like the WHO and UN when we refer to global statistical figures about maternity health and other issues. We also review related works to understand state-of-the-art applications related to health communication and how these applications are impacting the healthcare infrastructure in terms of achieving the SDG goals.

In general, our main literature review activities will be:

- ✓ Assessing health communication issues;
- ✓ Assessing maternity healthcare services and issues in Africa;
- ✓ Assessing issues in multimedia learning and training platforms;
- ✓ Assessing issues in universally designed interactive healthcare systems;

- ✓ Assessing issues related to prototyping;
- ✓ Assessing issues related to prototype evaluation;
- ✓ Assessing issues related to accessibility barriers identification and their quantification.

2.3. Data Collection and Analysis

In this research work, we will collect data related to user requirements and accessibility barriers encountered by selected users. The requirement data will be analyzed to develop the prototype with the basic functionalities of the M2M application. We use an interview based on the guideline attached in Appendix-A to identify system actors and basic functional requirements. We also use observation of related applications like coursera.com to understand the nature of training and learning applications and to develop a prototype. We do not conduct formal system archeology on related applications except understanding how these related applications works and interact with users.

We use cooperative accessibility evaluation technique to evaluate the prototype since it fits well for a "*simple testing session*" (Benyon, 2014). The cooperative accessibility method is engaging, economical, and allow the participants to co-evaluate a prototype. Besides, cooperative accessibility fits well with the global pandemic situation that makes hard to conduct user testing.

We will use a modification of the Barrier Walkthrough technique in evaluating the prototype which helps us to analyze accessibility barriers in terms of their severity on user satisfaction and productivity.

2.4. Accessibility Guidelines

We will use WCAG 2.0 and UAAG 2.0 accessibility guidelines from W3C to validate the accessibility of selected requirements of the prototype as well as to evaluate and analyze the accessibility of the prototype in consideration of selected common accessibility barriers.

2.5. Prototyping

This research work involves the development of a prototype called M2M. It is not a fully-fledged application rather it is a universally-designed and multimedia-based web application with basic functionalities of maternity training and learning platform. The main purpose of the prototype is

to address the research questions stated in section 1.2; mainly to possible accessibility barriers and to measure their severity. As a result, we will not iteratively develop a prototype (of different versions) rather we develop a single version prototype that will serve us to address the objectives of the research work.

2.6. Prototype Development Tools

Axure RP 9 Team Edition

We will use the Axure RP 9 Team Edition to develop a mid-fidelity interactive prototype. We choose Axure RP 9 Team Edition because of its suitability for rapid interactive prototype development.

Sample Multimedia Content

We will use the professional Autodesk® 3ds Max® 2017 to develop a VR-based multimedia content (animations not longer than three minutes) regarding the use of UBT (Uterine Balloon Tamponade). We will use Adobe Premier Pro 2019 to edit the animation and to integrate sound and transcript. We prefer to prepare a non-immersive 3-D desktop VR content since it is relatively easy to develop and to integrate to our prototype. Besides, non-immersive desktop VR contents are cheap since they do not require special expensive equipment like the VR headset.

Chapter Three: Literature Review

3.1 Health Communication and Key Issues

3.1.1 Health Communication

Human is a communicative and learning being. This makes communication decisive in every socio-economic activity of human life. The provision of equitable and accessible healthcare services requires effective communication. The effectiveness of health communication is measured by its positive outcome (Dianne, 2007; Marin et al., 2016) to community health. The primary purpose of health communication is to impact people to make timely decisions either for prevention or risk minimization (Northouse & Northouse, 1985). Health communication is a complex process(Dianne, 2007) that conveys a health-related message and usually takes place in an interpersonal setting between multiple parties (Dianne, 2007; Marin et al., 2016).

The complex nature of health communication has been represented in different models that are used to discuss the process and components of health communication. The health communication model by (Northouse & Northouse, 1985) is one of the widely used models that depicted health communication entities and their interaction. It showed two major interpersonal relationships (a health professional with another professional and a health professional with a client) found in health communication. Both types of relationships are different in terms of the message they convey and message complexity. However, both interpersonal relationships may be influenced by external factors called “the *significant others*” (Northouse & Northouse, 1985).

Nowadays, the components of health communication and of course the whole communication process are influenced by the advancement in technology. This trend will continue as ICT infrastructure improvement is growing fast globally including in developing and highly populated countries.

3.1.1.1 Critical Factors in Health Communication

In general, the success of health communication is measured by its outcome on the involving parties. Several studies suggested different factors that decide the success of a health communication platform. In the context of this research work, the following key factors (Dianne,

2007; Northouse & Northouse, 1985; Schiavo, 2013) are selected since they are decisive in maternity health communication systems.

- Audience-centered: The communication platform must consider individuals or groups who are communicating. Without a clear understanding of the users of the communication facility, it is difficult to deliver the intended outcome.
- Research-based: Health communication does not hit its primary purpose without a scientific articulation of the communication environment. This requires studying the "*policies*", "*social norms*", and "*key issues*" available in the environment for desired behavioral change.
- Cost-Effective: The communication facility has to be designed to effectively utilize "*budget and personnel*" without compromising the primary target.
- Strategic: The message, the channel, the communicating parties, and other relevant components must be identified and brought together in an action plan to achieve the target.
- Cultural Competency: The communication platform has to cope-up with the norms and values of the target audiences.
- Adaptable: The communication facility has to be adjustable to the context of the communication environment to deal with different limitations and constraints.

3.1.1.2 Communicating Culturally-sensitive Information

The message is the major component of any type of communication. Communicating maternity health issues has been a challenging task due to different socio-cultural factors. Cultural beliefs and lack of autonomous decisions by women (Ganle & Dery, 2015; Kambala, Morse, Masangwi, & Mitunda, 2011; Matsuoka, Aiga, Rasmey, Rathavy, & Okitsu, 2010; Munguambe et al., 2016) are the major socio-cultural barriers of maternity health communication in sub-Saharan Africa. This creates a huge problem to provide maternity healthcare services since such kind of socio-cultural barriers prohibit women to access the available maternity healthcare services. As per the communication model in section 2.1, the '*significant others*' are influencing maternal health communication in sub-Saharan Africa. This implies the role of the '*significant others*' in culturally-sensitive maternity health communication. For this reason, engaging family members along with

the client in the communication platform is vital for a better outcome (Black et al., 2016; Callejas & Hernandez, 2020).

The utilization of local doulas in such a situation is the best strategy for equitable maternal healthcare services in developing countries. This is because the local doulas are the only available personnel that deal with maternity issues either in awareness creation among the community or clinical intervention (Steel, Frawley, Adams, & Diezel, 2015). Maternal health training and learning platforms must consider the engagement of these doulas and their socio-cultural conditions when the applications are designed and implemented. To sum up, In the case of maternity health, not only communicating medically sound information is important but also the consideration of socio-cultural sensitivity of the message is also significant (Matsuoka et al., 2010; Schiavo, 2013).

3.1.1.3 Current Health Communication and Medical Technologies

ICT has been making a huge impact on medical and therapeutic disciplines. This impact is expected to continue in the face of current global public health challenges which are aggravated by poor healthcare infrastructures. According to a medical blog (Proclinical, 2019), In 2019, smart mobile technologies, wearable health applications, precision medicine, and telehealth systems are among the top technologies that were predicted to dominate the health sector by 2020 (Proclinical, 2019). In the context of this research project, we will discuss some of the predicted medical technologies as follows.

Smart M-Health Technologies

Owning a smartphone and using different mobile applications in day-to-day activities have been growing globally. This reinforces research and investment towards the innovation of M-Health technologies. Mobile applications have been used to "*improve diagnosis, investigation, treatment, monitoring, and management of diseases*" across the globe (Kreps & Neuhauser, 2010). In 2015, there were about 1,377 iOS M-Health applications available in the United States (Statista, 2019). M-Health applications have shared about 37 billion dollars of the global market in 2019 (Statista, 2019). In the same year, 84% of the applications were free to download and use.

M-Health technologies are currently used to facilitate healthcare services that include the provision of health information, electronic health record management, remote patient monitoring, and so on (Buntin, Burke, Hoaglin, & Blumenthal, 2011; Cerrato & Halamka, 2019). They are expected to grow in the new decade despite their privacy, security, and accuracy issues (Cerrato & Halamka, 2019; Kreps & Neuhauser, 2010).

Wireless Sensors and Wearable Applications

The integration of mobile and web applications along with wireless sensors and wearable gadgets have been showing promising results in different sectors including the health sector. Wearable applications are currently used for early detection and treatment of diabetes, hypertension, respiratory, cardiovascular diseases, and so on (Cerrato & Halamka, 2019; Phillips et al., 2019). Wireless sensor technologies are also used in healthcare systems to measure blood glucose, to monitor patient movements, and to collect vital signs (Cerrato & Halamka, 2019; Phillips et al., 2019).

Telehealth

The process of providing medical treatment using ICT infrastructure has been the dominant discussion in health informatics. The remote analysis of patient's images like MRI and remotely directing either the patient or the health professional to do some clinical intervention is already applied in different healthcare settings. This allows the patients to get instant medical advices and diagnosis from remotely located health professionals (Marin et al., 2016). Telehealth is increasingly used to manage chronic and non-communicable diseases since it's suitable for "*convenient and cost-effective remote care*" for such kind of cases (Phillips et al., 2019; Proclinical, 2019). Telehealth is expected to share 113.1 billion dollars of the global market by 2025 (Intelligence, 2020).

Precision Medicine

Personalized services are available online based on individual preferences and context. Currently, we can customize UIs for better human-computer interaction based on our preferences but personalized treatments were a bit far from being practical. Nowadays, due to the breakthrough

in medical technology and genetics science, treating individual patients based on their specific genes becomes possible through Precision Medicine (Jameson & Longo, 2015; Proclinical, 2019). Precision Medicine is enabling physicians to treat cancer patients through personalized medicines and therapies "*based on the individual genetic makeup*" (Proclinical, 2019; J. Zhang, Späth, Marjani, Zhang, & Pan, 2018).

In conclusion, different medical information systems and technologies are produced based on ICT to accelerate the progress in creating a healthy and well-being society. However, a huge scientific effort is still required to solve global medical challenges.

3.2 Maternal Healthcare Services

3.2.1 Maternal Healthcare in Africa

The sub-Saharan African region is struggling with different public health issues. Despite the effort of the region along with international humanitarian organizations including the UN and WHO, the region is still far away from achieving SDG3 targets. Maternity health problems and their consequences are among the major public health issues that the sub-Sahara African countries are struggling to reduce. In 2015, the MMR of sub-Saharan Africa is 546 per 100,000 live births which is extremely far from the average MMR of developed countries which is 12 maternal deaths per 100,000 live births (Jolivet et al., 2018; United Naitons, 2019). In the same year, the sub-Sahara African countries accounted for 66.3% of the global MMR which was the largest proportion in the world (Alkema et al., 2016).

Some African countries like South Africa are recording huge progress in reducing MMR. However, most of the sub-Saharan African countries are still struggling to make a significant progress in maternity healthcare. According to a study in 2013, Ethiopia MMR was 497 maternal deaths per 100,000 live births(Tessema et al., 2017). As per the study on 6299 Nigerian women who gave birth from 2007 to 2012, 34.9% of them did not attend maternal healthcare services (Fagbamigbe & Idemudia, 2015). In 2012, Mozambique MMR was also recorded high which was 500 maternal death per 100.000 live births (Stanton et al., 2013). In DRC, the MMR was very high in 2008 which was 670 per 100,000 (Rate, 2017). These all figures have shown promising signs of progress from

2008 to 2018. However, DRC has remained as the sixth-highest MMR in the world in 2018 (H. Lee, Park, Ndombi, & Nam, 2019).

Several pieces of research studied the critical factors behind these shocking figures. "*Affordability, availability and accessibility*"(Fagbamigbe & Idemudia, 2015) were the critical factors in Nigeria(Fagbamigbe & Idemudia, 2015) and shared by other sub-Saharan African countries (Stanton et al., 2013; Tessema et al., 2017). Different kinds of local and cross-national conflicts are among the critical factors for such high MMR in DRC (Wijeratne & Weeks, 2017). Cultural beliefs also a decisive factor in deciding to attend the available maternal healthcare services (Ganle & Dery, 2015; Munguambe et al., 2016). Almost all of the above studies which are investigated the reason behind high MMR in sub-Saharan African countries mentioned a lack of skilled midwives and other health professionals as one of the critical factors.

The traditional birth attendants and doulas play a significant role in the sub-Saharan African maternity healthcare services as they are the one who combats with poor healthcare settings. In DRC, in 2008, more than 40% of births were attended by these traditional attendants or doulas (Rate, 2017). In Malawi, doulas are the common options for most rural maternity health issues (Kambala et al., 2011). In 2011, more than half of births in the rural areas of Mozambique were attended by doulas in 2011 (Cole et al., 2018).

The process of "*professionalization*" of these doulas is helpful to reduce MMR in sub-Saharan African countries (Steel et al., 2015). Innovative ICTs are ideal solutions in accelerating this "*professionalization*" process by capacitating doula's knowledge and competencies through training and learning platforms (Arbour et al., 2015). The innovative artifacts are also essential to achieve the SDG3 target that aims to have less than 140 maternal deaths per 100,000 live births by 2030.

The following figure (Alkema et al., 2016) summarizes the MMR of sub-Saharan African countries in comparison to other regions and the SDG3 targets (Alkema et al., 2016). The figure (Alkema et al., 2016) also shows how much effort is required in terms of policy, research, innovation, and investment to achieve the SDG3 target aiming to reduce the MMR of the sub-Saharan region by

at least two-thirds. This target is almost impossible to achieve without innovative technological products that are capable to accelerate the progress and to reduce global disparities.

	Scenario 1			Scenario 2		
	MMR in 2030 (deaths per 100 000 livebirths)	Maternal deaths in 2030	Cumulative maternal deaths	MMR in 2030 (deaths per 100 000 livebirths)	Maternal deaths in 2030	Cumulative maternal deaths
Worldwide	161	223 000	3 878 000	64	89 000	2 508 000
Developed regions	8	990	19 000	4	500	14 000
Northern Africa	43	1700	34 000	21	850	25 000
Sub-Saharan Africa	357	161 000	2 692 000	128	58 000	1 646 000
Caucasus and central Asia	21	320	6500	11	160	4800
Eastern Asia	18	2400	50 000	9	1200	37 000
Southeastern Asia	72	7900	150 000	36	3900	109 000
Southern Asia	115	40 000	778 000	58	20 000	564 000
Western Asia	59	3200	58 000	30	1600	42 000
Caribbean	117	7400	14 000	58	370	11 000
Latin America	39	3600	70 000	20	1800	51 000
Oceania	123	360	6400	61	180	46 000

Regions and developmental status based on MDG classification. Scenario 1 is based on past experience in a typical country (annual rate of reduction of 2·9%) and scenario 2 is based on the Sustainable Development Goal of a global MMR of less than 70 deaths per 100 000 livebirths by 2030, and MMR of less than 140 deaths per 100 000 livebirths for each country. The number of maternal deaths has been rounded as follows: <100 rounded to the nearest 1; 100–999 rounded to nearest 10; 1000–9999 rounded to nearest 100; and >10 000 rounded to nearest 1000. MMR=maternal mortality rate. MDG=Millennium Development Goals.

Figure 3.1 Projections of MMR and Maternal deaths for 2030 taken from Alkema, L., Chou, D., Hogan, D., Zhang, S., Moller, A.-B., Gemmill, A., . . . Mathers, C. (2016). Global, regional, and national levels and trends in maternal mortality between 1990 and 2015, with scenario-based projections to 2030: a systematic analysis by the UN Maternal Mortality Estimation Inter-Agency Group. The Lancet, 387(10017), 462-474. Included based on the 2016© by UN Maternal Mortality Estimation Inter-Agency Group.

3.2.1.1 Current Maternal Healthcare Issues in Africa

It has been clear that maternal health communication correlates with socio-economic issues of the environment where the communication platform exists. In sub-Saharan Africa, the maternal health communication platform involves vulnerable communities who are suffering from poor

healthcare services, political instabilities, low economic conditions, and socio-demographic factors (Jolivet et al., 2018).

Maternal health communication in Africa also involves cultural competency issues as the continent is diversified in terms of ethnic, cultural, and religious backgrounds. The virtual training of midwives and doulas needs to consider this diversity since the doulas directly face with women from different backgrounds. The consideration will equip the doulas to effectively address maternity health complications by developing an understanding of each woman's experience and mind setting (Callejas & Hernandez, 2020). This is why the ICM recommends consideration of cultural competencies to provide "*respectful maternity care*" for a diversified population (Butler, Fullerton, & Aman, 2020).

3.3 Multimedia Training and Learning Platforms

Multiple media known as multimedia became the core components of e-learning platforms. This is because multimedia accelerates understanding (Clark & Mayer, 2016) to learners through active engagement in the learning-teaching process. This is called the "*multimedia effect*" (Clark & Mayer, 2016) that is resulted from embedded multimedia contents in learning platforms. The use of multimedia in learning platforms has several advantages including personalized education, flexibility, and comfortability for a variety of personality types (juang Wang, 2010). Multimedia provides learners "*more control*" on the schedule, content, learning styles, and pace of education or communication (Lau, Yen, Li, & Wah, 2014).

According to (Mayer & Mayer, 2005) two approaches are used for multimedia content design in learning platforms.

- Technology-centered Approach: This is an approach deals with the incorporation of ICTs to design multimedia-based learning. Eg. Multimedia in virtual reality (Mayer & Mayer, 2005).
- Learner-based Approach: It focuses on how to enhance learning using multimedia. In this approach, the multimedia serves as an "*aid to human cognition*". The human factor is also the key to the learning-teaching process (Mayer & Mayer, 2005).

The following table based on (Mayer & Mayer, 2005) summarizes both approaches in terms of their concept, target, and critical factors that decide the outcome of multimedia-based learning.

Design Approach	Driving Concept	Target	Critical Factors
Technology-centered approach	The capability of multimedia technology.	To provide access to the content based on the multimedia	The use of cutting-edge technologies in the production and organization of the multimedia
Learner-centered approach	How does the human mind work? i.e How humans process and retain information?	To aid human cognition	The adaptation of multimedia technology to support human cognition

Table 3.1: Multimedia-based Learning Approaches

Both approaches deal with the notion of learning outcome which is resulted from the integration of multimedia content either as "*response strengthening*" or "*knowledge construction*" (Mayer & Mayer, 2005). The use of multimedia as "*response strengthening*" mainly focuses on increasing "*the connection between a stimulus and a response*" whereas the use of multimedia as "*Knowledge construction*" is to represent a learning concept in a way that can be simply understood and later applied by the learner (Mayer & Mayer, 2005).

3.3.1 VR-based Training and Learning Platforms

Virtual Reality is an interactive technology that is capable to simulate a physical environment to people using 3-D images, videos, and animations with the help of special devices like sensors and headsets. VR technologies mainly divided in two categories based on their simulation that are known as immersive VR environments and non-immersive VR environments (E. A. L. Lee, 2011). The immersive VR environments are expensive because of their special hardware requirements whereas non-immersive VRs are relatively cheap and easy to interact with traditional input devices including keyboard, joystick, and mouse (E. A. L. Lee, 2011). Desktop VRs are an example

of non-immersive VR environments that are widely applicable in educational landscapes (Abdelaziz, Alaa El Din, & Senousy, 2014).

Virtual Reality technologies has been applied in different sectors because of their advantage in simulating real-world scenarios. These technologies are widely adopted in online education platforms to improve content browsing and hands-on experience (E. A. L. Lee, 2011) as well as to increase learning outcome (Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014).

3.4 Multimedia Applications Development Technologies

The notion of multimedia technology deals with sounds, images, videos, and other related data. Any application that process, analyze, present, and interact with these type of data is considered as a multimedia application (Furht, 2012). The following are some types of multimedia applications.

- Hypermedia Applications: The multimedia along with hypertext used to provide interactive multimodal information (Chambers, 2020; Furht, 2012).
- Conferencing Systems: Multimedia application used for remote meetings (Furht, 2012).
- Multimedia Agent Applications: These types of multimedia applications used agents or modules that "*apply intelligence heuristics*"(Furht, 2012) to the multimedia data for the intended purpose (Deldjoo, 2020). Eg. Video processing multimedia applications.
- Virtual Reality Applications: Applications used multimedia for virtual user experience in different sectors like health, tourism, computer games, and so on (Lv, Chirivella, & Gagliardo, 2016).

The followings are some of the computer software which are used to create interactive multimedia content.

- Adobe Animate (formerly Adobe Flash Professional): An Adobe multimedia authoring product used to design interactive multimedia animations for different technologies including the web.
- Autodesk 3ds Max: is a professional software package by Autodesk Media and Entertainment that is mainly used for authoring 3D animations, models, games, and images.

- Wick Editor: A free and opensource tool used to create interactive multimedia content.
- Verge3D: A toolkit used to develop interactive multimedia for websites. It is often used to create e-learning content.
- Adobe Captivate: Another Adobe product used to create interactive multimedia content for a learning-teaching purpose.
- iSpring Suite: It is an E-learning development software using interactive multimedia course contents.

3.5 Universally Designed Interactive Healthcare Systems

The concept of universal design has been a dominant discussion in HCI and other disciplines. Several types of research have been conducted to address issues including user diversity and gaps in user knowledge (Meiselwitz, Wentz, & Lazar, 2010). These issues are significant in the discussion of accessible interactive healthcare systems as they may create disparities among users. The notion of usability is also significant for maternity learning applications as they involve doulas and women who are diversified in gender, disability, digital skill, ability, the context of use, and so on.

In most low-income countries, pregnant women are not in a situation that they can identify which maternity information they require and how to process it (Arcia et al., 2019). The midwives and doulas in sub-Saharan African countries have also problems in upgrading their skills and competencies from training often available online that require digital skills to access the content (Black et al., 2016). This creates different kinds of barriers that may result in a digital divide. In Mozambique, most of the maternal mortality is recorded in rural areas where there exists "*poor and vulnerable communities*" and most of the live births were attended by traditional doulas (Munguambe et al., 2016). The proposed solution to train these traditional doulas using an e-learning platform is fundamental in upgrading both professional midwives and traditional doulas' skills and competencies (Arbour et al., 2015). Besides, considering universal design principles in the design of this learning and training application is the only available option to make it accessible, understandable, and usable (Asi & Williams, 2018; P. Zhang & Galletta, 2015).

The multimedia maternity learning content (Freire et al., 2013) of the proposed system must be accessible and the user interface of the system has to be designed in a way that improves usability (Tzeng & Zhou, 2013). Otherwise, the expected positive outcomes of the proposed training and learning application will not be achieved.

3.5.1 Current Trends in Interactive Healthcare Systems

The production of interactive healthcare systems has been growing massively in the last two decades. This is because of the advancement in technology and the increase in owning computing devices like smartphones, tablets, and laptops. The need for health-related information has also shown an increase in the same period. In the first six months of 2016, about 75% of google users searched mostly about health issues primarily focusing on common-cold, flu, and maternity topics (Google, 2016). In 2016, there were more than 400 million unique mobile subscribers in sub-Saharan Africa (Avle, Quartey, & Hutchful, 2018). About 38% of these subscribers have a cellular Internet connection (Avle et al., 2018). These figures have been attracting the attention of different academic and research institutions, governmental and non-governmental organizations, and private companies to develop interactive healthcare systems.

In the first quarter of 2020, there were more than forty-five thousand iOS healthcare mobile applications (Statista, 2020b). In the same period, there were more than forty-three thousand android mobile applications in Google Play (Statista, 2020a). Currently, healthcare applications are mainly used to "*monitor and treat chronic conditions*" (Martínez-Pérez, De La Torre-Díez, & López-Coronado, 2013), to facilitate patient recording (Paul, Ezz, & Kuljis, 2012), and to remind and alert about critical medical information (Suarez-Coloma, Verdier, & Roncancio, 2013).

Chapter Four: Prototyping

4.1 Overview

The primary purpose of this chapter is to design and develop a prototype. Prototype is an artefact that is mainly used to manifest an idea or solution in a testable manner (McElroy, 2016) . We have designed an interactive mid-fidelity prototype called M2M using Axure RP 9 Team Edition. The M2M prototype will be used to test how users will interact with the system and to observe the accessibility barriers occurred in the interaction. We design the prototype based on the PACT (People, Activities, Context, Technologies) principle (Benyon, 2014) that enables the participation of users from the early stage of prototype development.

We have collected high level user requirement which has to be reflected in the M2M prototype. In collecting the user requirements, we have considered the environmental context where the application is going to be deployed, the basic functionalities of the system that should be included in the prototype, the primary actors who shall interact with the prototype, and the quality attributes that the M2M application must be adhered to.

We have used interviews and brainstorming among the potential users to collect user requirements. The interview guideline is attached in Appendix-A. System Archaeology technique is also used to "*understand and analyze functionalities and qualities of existing related systems*" (Pérez-Castillo, de Guzmán, & Piattini, 2011; Sommerville, 2011). For this purpose, we have used Coursera as a point of reference since both Coursera and M2M focuses on online training. The requirement specification is prepared in the consideration of the prototype, not the final product. As a result, there might be missing requirements that make the specification less comprehensive for the design and development of a fully-fledged maternity training and learning application. However, this requirement specification is complete and focused in the sense that "*the manufacturing process of the prototype may differ from the process of the final product*" (Schork & Kirchner, 2018).

4.2 Prototype Design

4.2.1 Identifying Actors

Firstly, we have identified the primary actors (users) who shall interact with the M2M application. We have consulted the WHO website to retrieve formal definitions of Midwife, Health-Professional, and Doula and summarized it in Table 4.1.

Code	Actor name	Role
M2M-A1	Midwife	A person who is "*skilled, knowledgeable, and compassionate care for childbearing women, newborn infants and families across the continuum throughout pre-pregnancy, pregnancy, birth, postpartum and the early weeks of life*" and access M2M system as a trainer and/or/ a trainee.
M2M-A2	Local Doula	A "*person chosen by the woman to provide her with continuous support during labor and childbirth*" and access M2M to deliver training for women and to get training from midwives.
M2M-A3	Pregnant Women	A woman who is in her gestation period and access M2M to get training from health professionals and local doulas regarding maternity issues.

Table 4.1: M2M Actors

4.2.2 Selected Functional Requirements

We have identified functional requirements that are directly related to the basic functionalities of the M2M application that need to be included in the prototype. We are developing a universally designed training and learning application that must consider diversity among people, situations, and devices. As a result, we considered WCAG 2.0 and UAAG 2.0 guidelines from W3C to address the accessibility and usability of each functionality (in the requirements) by people with diverse abilities. We have also considered the seven principles of universal design that must be considered in the design, implementation, and testing of the identified functional requirements. The functional requirements are summarized in Table 4.2.

Code	Requirement Description	Requirement Elaboration	Included UD Principle	Guideline Reference
M2M-FR1	The system shall manage user account registration and login services regardless of user diversity.	All users shall able to register regardless of their input device used and inputting mechanism used.	Equitable in use, Flexibility in use, Simple and intuitive use, and Perceptible information	WCAG 1.1,
M2M-FR2	The system shall provide accessible and usable maternity health content regardless of user diversity and content presentation techniques.	Any course content (presentation, document, audio, video) shall be accessible and usable regardless of the user's preference for content presentation and presentation time.	Equitable in use, Flexibility in use, Simple and intuitive use, Perceptible Information, Space and Size for approach and use	WCAG 1.1.1, UAAG 1.9
M2M-FR3	The system shall manage the virtual classroom regardless of the diversity of attendees.	The system shall have a virtual classroom that supports auditory, textual, and visual communications.	Equity in use, Flexibility in use, Perceptible information	WCAG 1.1, WCAG 1.4, UAAG 1.5

Table 4.2: M2M Functional Requirements

4.2.3 Prototype User Interface Specification

In this section, we present sample UI wireframes to demonstrate how we will design the basic "*interface objects and their actions*" (Sommerville, 2011) and the overall user experience (Hartson & Pyla, 2012) of the M2M prototype. We choose 'User Registration' and 'M2M Virtual Classroom' pages to demonstrate our approach of defining the interface objects and user experience control mechanisms.

4.2.3.1 The ‘User Registration’ Page

This is the page responsible for user registration to the M2M application prototype. The main component of the page is the registration form where unregistered users provide their basic information required to use the application. The registration page will have a disclaimer showed under the registration form to notify the user regarding the terms of use, cookies, and privacy policy as per the European Union data protection regulation. It will also contain the M2M logo and other decoration images. The specification of this page is summarized in Table 4.3.

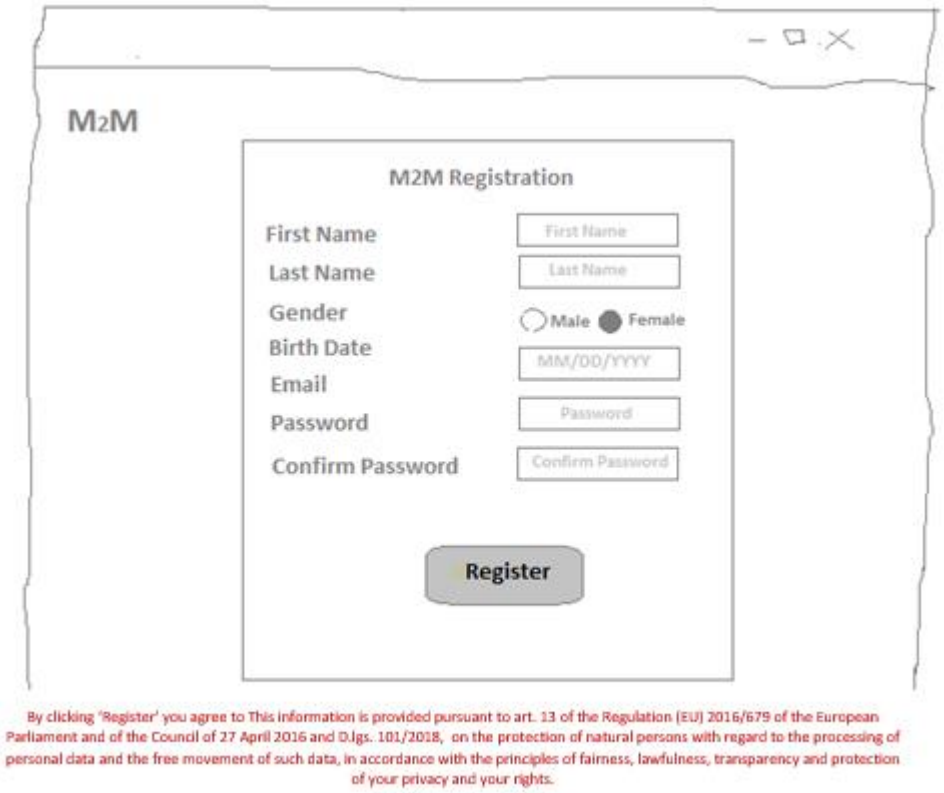
Name	M2M: User Registration Page
Purpose	It aims to register new users of M2M.
Elements	1. Confirmation and welcome to the M2M application message. 2. An error notification whenever a user makes an error in input fields like Birth Date and Email. 3. An error message regarding minimum length for a password.
Wireframe	
Navigation and User Interaction	To register the user is required to enter First Name, Last Name, Gender, Birthdate, Email, Password, and a confirmation for the password and clicks the 'Register' button. A successful registration action shall lead the user to the homepage of M2M.
Control Mechanisms	Input validation, Error Notifcation

Table 4.3: UI Specification, User Registration page

4.2.3.2 The 'Virtual Classroom' Page

This page is responsible for providing a virtual classroom environment for users who are successfully registered and signed in. The main components of the page are M2M Navigation Bars

(Account, Course, Schedule), Active Courses form, and Course Content area. The M2M Navigation component is used to navigate on the virtual classroom. The Active Courses form is where users view the courses they are registered and selects the course they want to access. The specification of this page is summarized in Table 4.4.

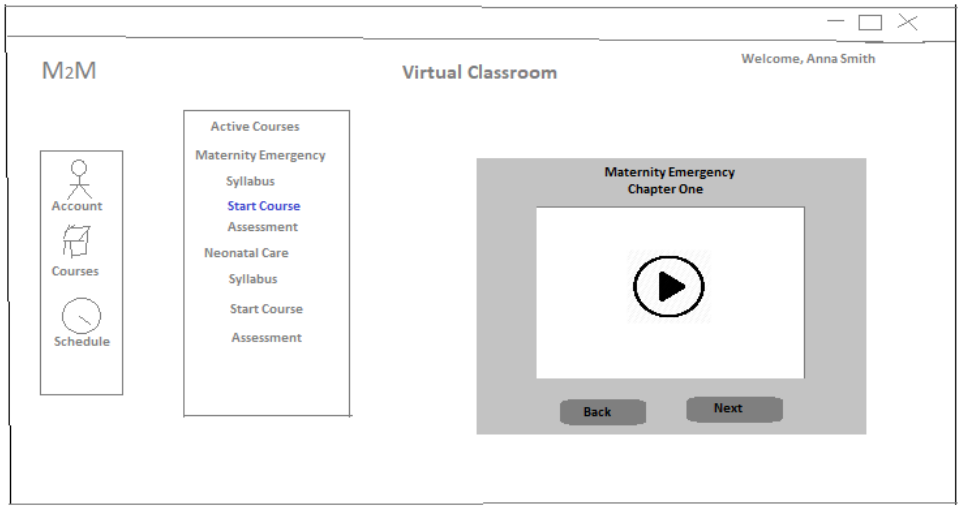
Name	**M2M: Virutal Classroom Page**
Purpose	It aims to provide a virtual classroom environment for M2M trainees.
Elements	1. The Course Content area is where users access the course content in the form of multimedia. 2. Start, Back, Next, and End buttons to navigate the multimedia course content. 3. A control to on/off/ a subtitle of audio/video/ course contents.
Wireframe	
Navigation and User Interaction	To access course content, the user is required to click the Courses navigation bar, select the desired course from the Active Course form, and click the Start Course link. A successful course start action shall lead the user to access multimedia-based course content in the Course Content area.
Control Mechanisms	Subtitles, Pause/Play/ Content, Course Completion Notification

Table 4.4: UI Specification, Virtual Classroom page

4.2.4 Sample Multimedia Content for the Prototype

We have prepared a sample VR-based multimedia content for the prototype. The VR-based multimedia content is about handling a postpartum hemorrhage which is one of the leading obstetric causes (Merdad & Ali, 2018) for maternal mortality in Sub-Saharan African countries. We have followed the Learner-centered approach (Furht, 2012) when we develop the multimedia content to ensure that the content is easy to process and to retain.

In developing the VR-based multimedia content, we have considered the critical factors that decides successful health communication mentioned in section 3.1.1.1. Firstly, we have prepared a screenplay and storyboard based on recorded video content about maternity health issues by Norwegian maternity health professionals. Then, we model the characters and the environment and later make the animation. Finally, we applied lighting and render it before editing the animation and integrate a sound to the animation.

We have presented some of the snapshots of the VR-based multimedia content in Figure 4.1 and Figure 4.2.

Figure 4.1 Midwife opening UBT Kit and inserting the catheter

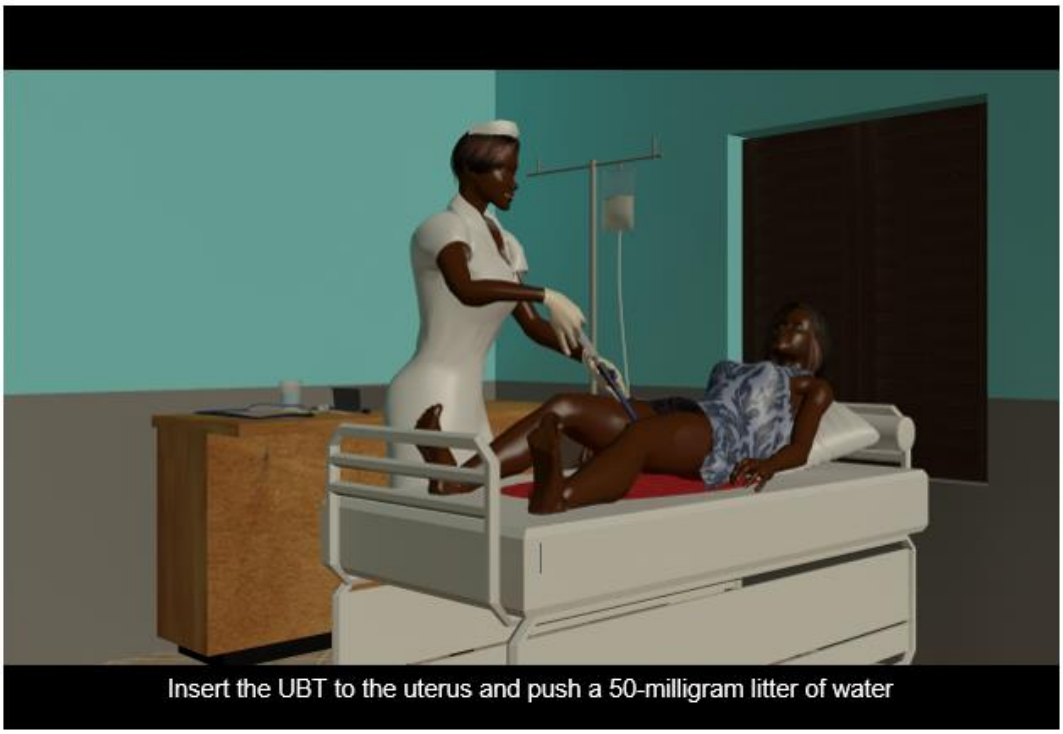


Figure 4.2 Midwife inserting the UBT Kit to the Uterus

4.3 Prototype Development

4.3.1 User Flows

We have prepared the following user flows based on the selected functional requirements. User flows are crucial to "*determine the scope of the prototype*" (McElroy, 2016) and later to test accessibility and usability of the product (P. Zhang & Galletta, 2015). User Flows are also critical to identify how the interactive parts are organized and presented to the user (McElroy, 2016). In this section, we present sample user flows used to achieve a definite goal by using the M2M prototype. Figure 4.3 shows user flow for registration and Figure 4.3 depicts user flow for accessing recently enrolled courses.

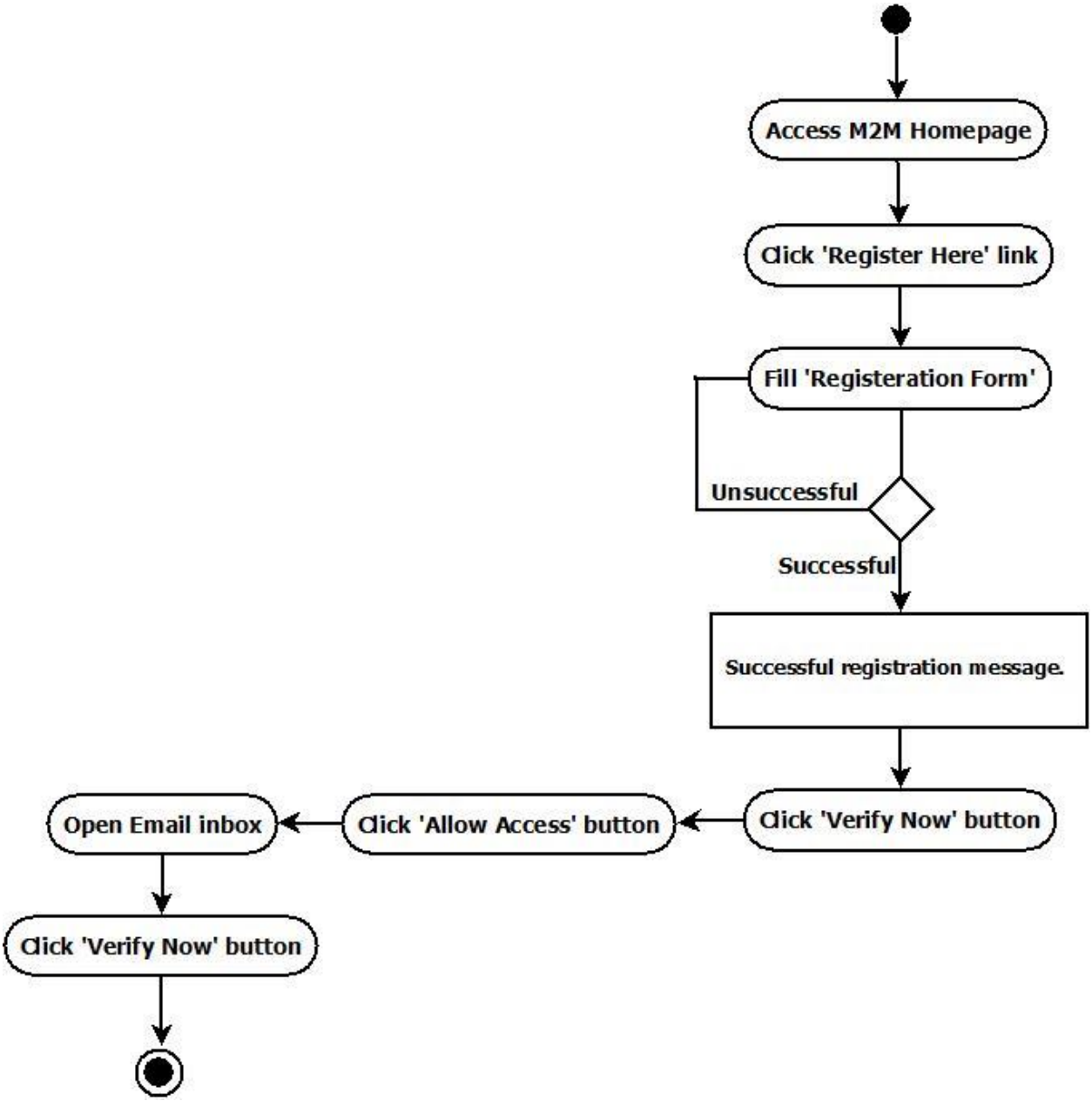


Figure 4.3 User Flow for registration

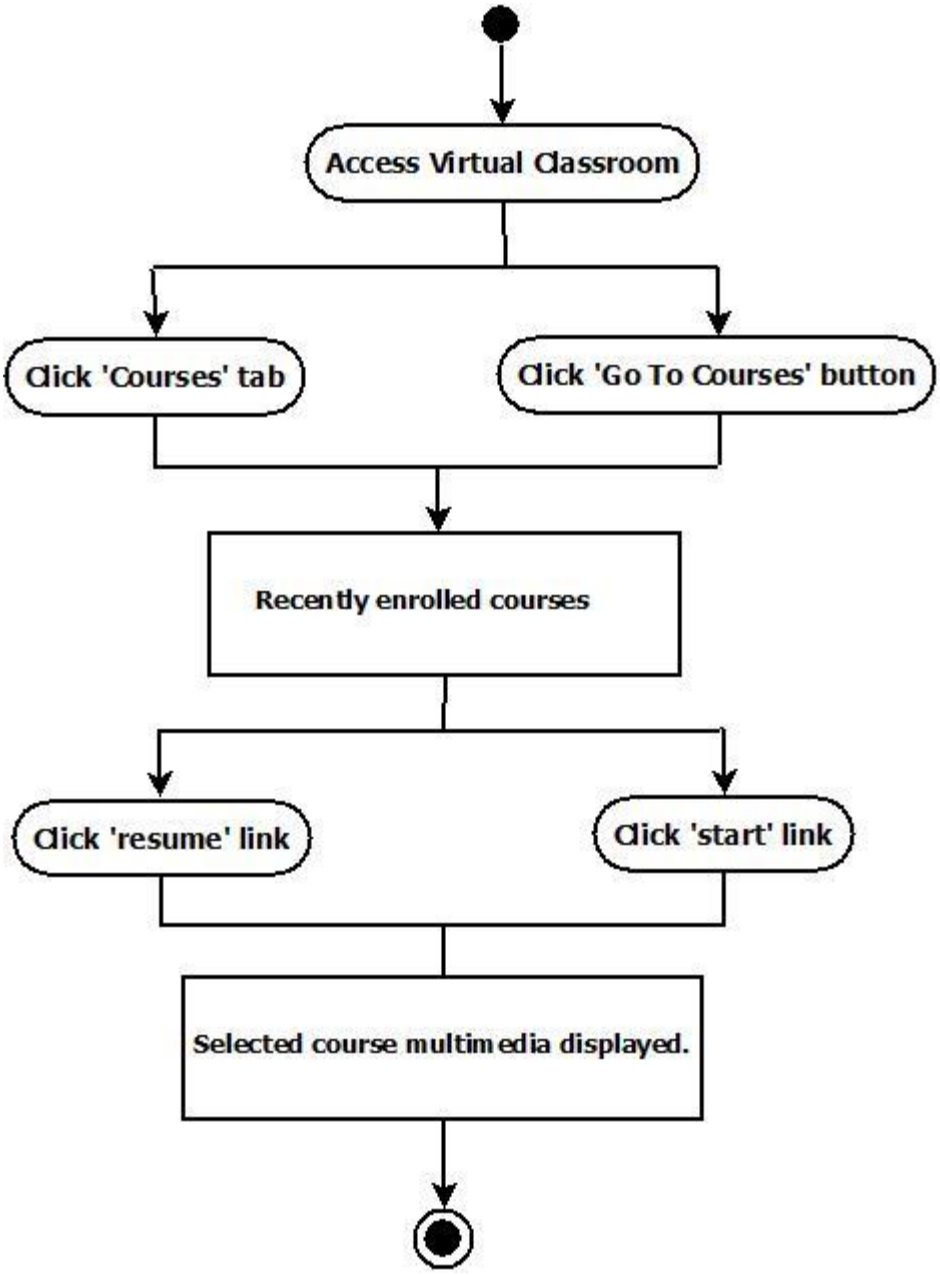


Figure 4.4 User flow for accessing recently enrolled courses.

4.3.2 Building the Prototype

After all the user flows are defined, the prototype is built using Axure RP 9 Team Edition as a web application. In this section, we present sample scenarios in the prototype. Some of the scenarios are attached in Appendix-B. Figure 4.5 shows user registration scenario and Figure 4.6 shows accessing course content scenario.

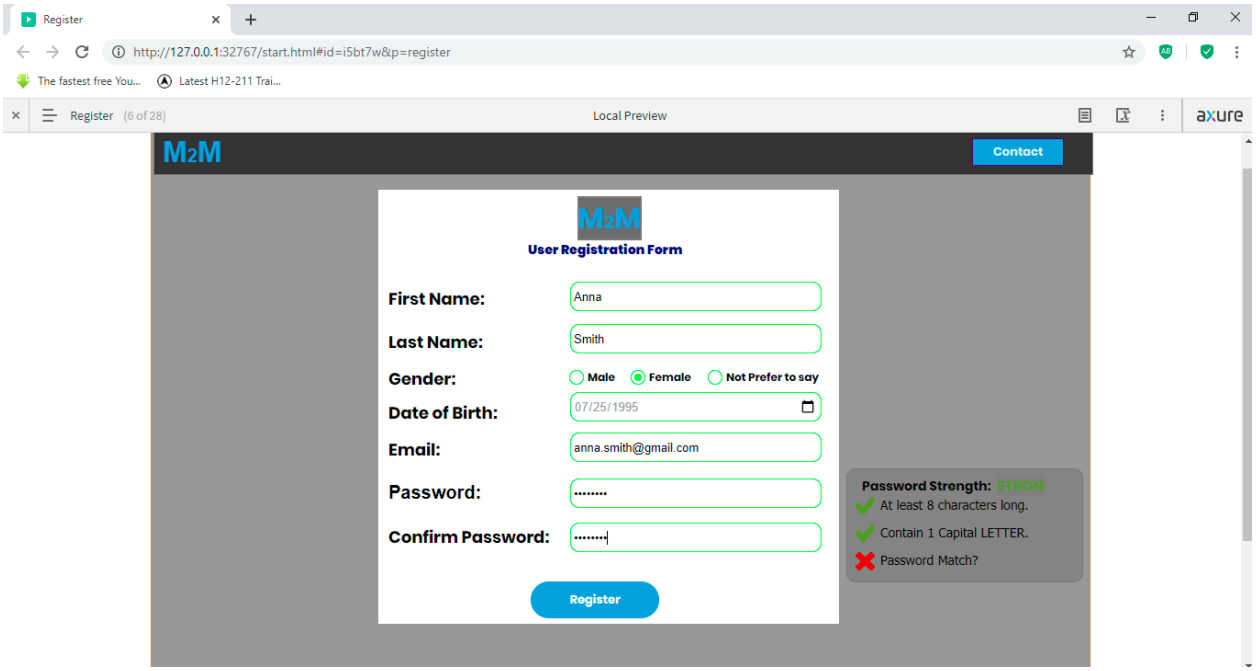


Figure 4.5 User is registering and the password doesn't match

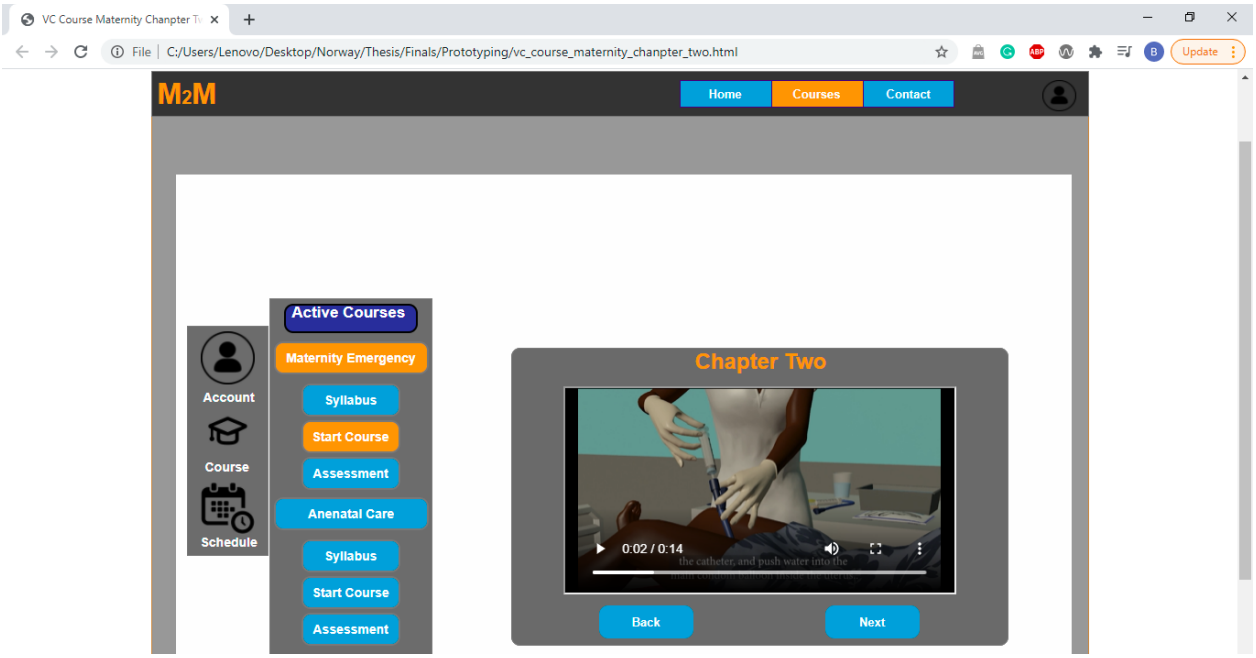


Figure 4.6 User is accessing Maternity Emergency course comprises VR-based animation

Chapter Five: Prototype Evaluation

5.1 Overview

In this chapter, we evaluate the prototype and analyze the results in consideration of accessibility barriers. We have used the heuristic web accessibility method suggested in (Acosta-Vargas, Salvador-Ullauri, & Luján-Mora, 2019) with the combination of the Barrier Walkthrough method proposed by (Yesilada, Brajnik, & Harper, 2009) and the cooperative evaluation (Benyon, 2014) technique. We have used the combination of these methods because they will help us to identify accessibility barriers and their severity occurred in interacting with M2M with minimum resources.

Firstly, we have selected three use cases of the M2M and we have prepared three task scenarios based on the selected use cases. The selected task scenarios are 'User Registration', 'Access a Virtual Classroom', and 'Access a Maternity Emergency Course' that contains VR-based animation about Post-partum Hemorrhage. Secondly, we have defined user personas, difference in ability, and selected assistive technologies. As a result, we have identified midwives as user groups and screen magnifier as an assistive technology. We selected people with visual impairment as group of people with different abilities. Finally, we have selected interaction with mouse, touchpad, and Keyboard as interaction devices with M2M after we defined the following common accessibility barriers (Harper & Yesilada, 2008) in consideration of the selected diverse user groups, task scenarios and selected interaction devices.

- Inconsistent navigation
- Low contrast
- Insufficient time to complete a task
- Functional elements that cannot be control by keyboard
- Unexpected actions
- Multimedia without audio description
- Images of text that degrade or pixelate when magnified

5.2 Selected Diverse User Group and Task Scenario

It is very hard to get a recent figure about the prevalence of visual impairment in Sub-Saharan Africa. In 2010, 21.4 million people were visually impaired from which more than 16 million had low vision (Naidoo et al., 2014). We have selected five participating users with low vision whose age is between 30-41 from the Sub-Saharan African region. The profile of the participating users is attached in Appendix-C. The selected users often access web using magnifying glasses and Windows Screen Magnifier.

The participated users are trained and instructed to perform the tasks stated in Table 5.1.

Task ID	Task Description
Task1	register to M2M system by accessing the homepage.
Task2	login to M2M
Task3	access the virtual classroom
Task4	access 'Maternity Emergency' course comprises VR-based animation content from the virtual classroom.
Task5	logout from M2M.

Table 5.1 List of Task Scenarios

5.3 Evaluation Setup

The evaluation takes place using the same laptop for all participants with Google Chrome Version 90.0.4430.72 in silent room where there is only one participant and one author (expert observer). Firstly, the author has explained the purpose of the system and later showed how to perform the selected tasks. Later, the author provided a task sheet for the participants in hard copy for reference in the middle of the tasks. The tasks take 30 minutes which is 50% longer than the total task time as per the cooperative evaluation (Benyon, 2014) guideline. The author communicated and observed the participants in the evaluation period regarding any difficulty they encounter. After the participants completed the tasks, they have responded for post-evaluation questionnaire. The questionnaire is attached in Appendix-D.

5.4 Evaluation Metrics

We have used the accessibility barriers metrics (Yesilada et al., 2009) defined based on the heuristic walkthrough (Sears, 1997) method. As per the accessibility walkthrough method (Sears, 1997), the severity of a barrier is determined by the impact of the barrier on performance parameters called productivity and user satisfaction. We have modified (contextualized to the M2M prototype) the suggested metrics and presented the definition of the metrics below.

- Persistence: The frequency of the barriers appeared. A total persistence is calculated as persistence multiplied by the number of users who reported that barrier.
- Severity: The degree of the effect of the barrier on the execution of a task. This value is given by the author and if it is 1-2 that means it is a minor severity and does not affect the execution of the task. If severity is between 3-5, the barrier affects task execution, but the user overcomes it using different alternatives. This severity level affects user satisfaction but not productivity. If the severity is greater than 5, it critically affects the task execution and user often exit the application or unable to reach task's goal that affects both productivity and user satisfaction.

We have to relate persistence and severity to measure the impact of barriers on performance parameters. As a result, we have prepared data showed in Table 5.2 based on the method and classification suggested in (Acosta-Vargas et al., 2019) to determine the impact level of the barriers.

Persistence	Severity
1-2	Minor
3-5	Significant
>5	Critical

Table 5.2. Persistence severity

5.5 Evaluation of the Multimedia Content

The content of the sample course is represented using VR-based animation. We didn't evaluate the mutlimeida content indepndently for any accessibility issue before integrating it to the

prototype. Instead, we have included open subtitle as an access service after we complete the rendering of the anmiation. After we complete the multimedia content development, we have integrated it to the prototype for evaluation.

Chapter Six: Result and Analysis

6.1 Evaluation Result

We have summarized the evaluation results for each task stated in section 5.2 in the following tables. Table 6.1 summarizes the evaluation result of registering to M2M prototype task whereas Table 6.2 summarizes the evaluation result of logging to M2M task. Table 6.3 summarizes the evaluation of accessing the virtual classroom and Table 6.4 summarizes the evaluation of accessing a course content about post-partum hemorrhage that comprises the VR-based animation.

Accessibility Barrier	**Total Persistence**	**Severity**	**Pages Involved**	**No of Users Reported**
Low contrast	6	Critical	homepage, user registration page	3
Insufficient time to complete a task	1	Significant	user registration page	1
UI elements that cannot be controlled by keyboard	7	Critical	homepage, user registration page	1
No keyboard shortcut	5	Critical	homepage, user registration page	1

Table 6.1 Task1 Evaluation Result

The only participant user who experiences 'Insufficient time to complete a task' accessibility barrier exits the evaluation after the first task. The participant took more than ten minutes to register to M2M and could not be successful and later decided to exit the evaluation.

Accessibility Barrier	Total Persistence	Severity	Pages Involved	No of Users Reported
Low contrast	3	Critical	Login	3
UI elements that cannot be controlled by keyboard	1	Minor	Login	1

Table 6.2 Task2 Evaluation Result

Accessibility Barrier	Total Persistence	Severity	Pages Involved	No of Users Reported
Low contrast	6	Critical	VC Home, VC Course List	3
Too many UI elements	9	Critical	VC Home, VC Course List	3
Missing tooltips	3	Minor	VC Home	1
Inaccessible graphical link images (without description)	4	Significant	VC Home, VC Course List	2
less intuitive UI components	9	Critical	VC Home	3

Table 6.3 Task3 Evaluation Result

Accessibility Barrier	Total Persistence	Severity	Pages Involved	No of Users Reported
Low contrast	3	Critical	VC Course Maternity Chapter One	3
Missing tooltips	2	Minor	VC Course Maternity Chapter One	1
Inaccessible graphical link images (without description)	2	Minor	VC Course Maternity Chapter One	2
Non-synchronized caption	2	Minor	VC Course Maternity Chapter One	1
Non-descriptive transcript	1	Minor	VC Course Maternity Chapter One	1
No-Audio Control	4	Significant	VC Course Maternity Chapter One	4
No Audio Alert	4	Significant	VC Course Maternity Chapter One	4

Table 6.4 Task4 Evaluation Result

There is no barrier registered for Task5 since it only requires a single-click operation to logout from the prototype.

6.2 Analysis of Result

6.2.1 Severity of Tasks

The main purpose of the evaluation is to identify the accessibility barriers based on the predefined common barriers mentioned in section 5.1. As a result, we have triangulated our expertise with participants feedbacks to get an in-depth understanding of accessibility barriers related to multimedia training and learning application for maternity health. The evaluation and analysis is done based on the sequence of goal-oriented tasks which are organized to identify the persistence and severity of accessibility barriers in each task. The severities of the tasks are analyzed and presented in Figure 6.1.

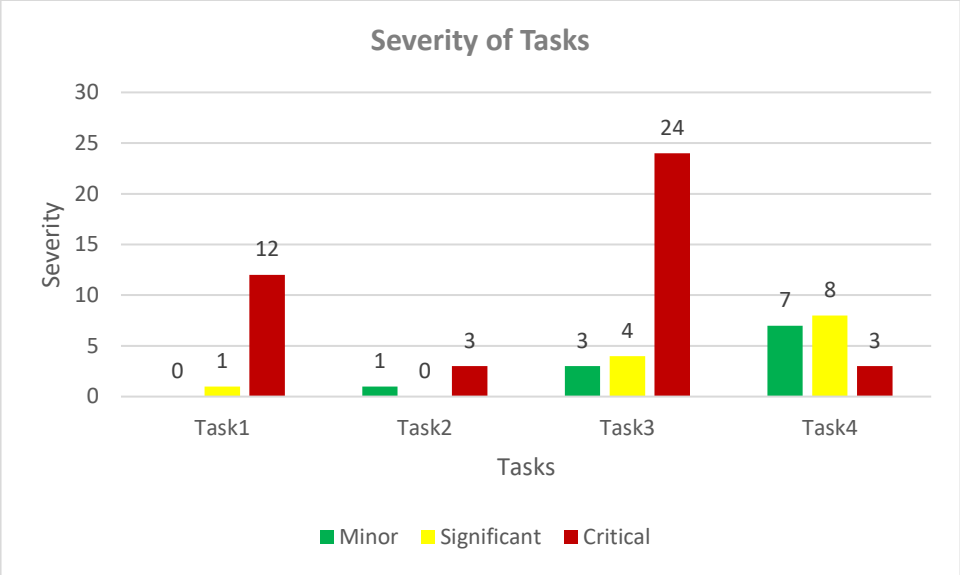


Figure 6.1 Severity of tasks

When the result is analyzed, 25% of the barriers are related to low contrast which is categorized as critical severity based on the barrier walkthrough method. Minor severity barriers represent 25% whereas the rest 50% corresponds to significant severity. The overall distribution of each barrier in all tasks is presented in Figure 6.2.

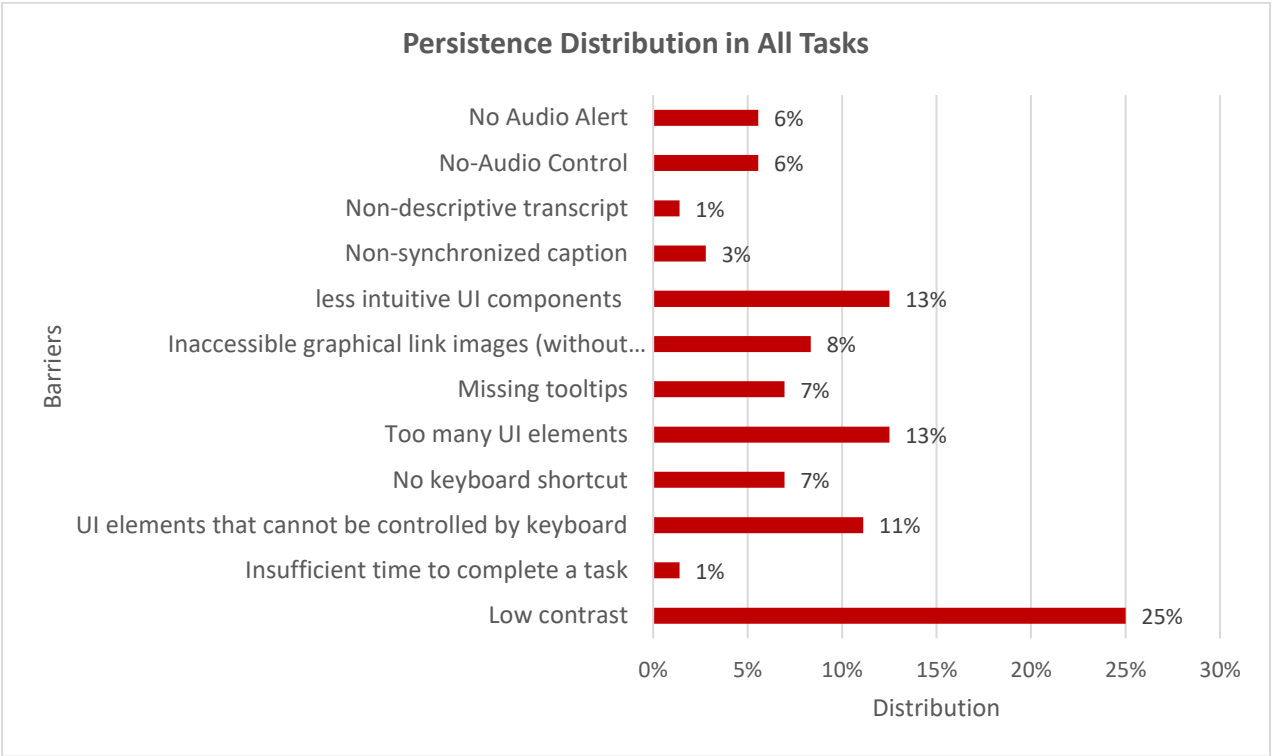


Figure 6.2 Persistence distribution in all tasks

6.2.2 Persistence Vs. Accessibility Principles

When we analyze the accessibility barriers based on accessibility principles, 61% of the total issues are related to perceivable, 32% belongs to operable, and the rest 7% belongs to understandable. The distribution of persistence across accessibility principles for all tasks is summarized in Table 6.5.

Perceivable	Operable	Understandable
61%	32%	7%
44	23	5

Table 6.5 Persistence distribution in accessibility principles

Most of the accessibility barriers belongs to the accessibility principle of perceptibility. This is because 41% of less perceptible content results from low contrast and 20% of less perceptibility comes from less intuitive UI components. The contrast issue can be resolved in referring the minimum contrast ratio of the WCAG 2.0 standard. The use of automatic accessibility testing tools for contrast issues can also solve the problem when a fully-fledged maternity learning and training application will be developed.

We have used only color codes as the only means to distinguish between UI elements and their functionalities which causes the 20% of accessibility issues related to perceptibility that is because of less intuitive UI components. This implies that, the notion of distinguishing UI elements must consider other techniques in addition to color codes to develop an accessible multimedia training and learning application.

When we analyze the frequency of accessibility barriers (persistence) across the accessibility principles and a task, we get the figure depicted in Table 6.6. The first percentile represents the appearance of accessibility barriers in a $Task_n$ that violates a given accessibility principle relative to all other accessibility barriers in a $Task_n$ whereas the second percentile represents the persistence of accessibility barriers relative to all other accessibility barriers that violates a given accessibility principle in all tasks.

Task	Perceivable			Operable			Understandable		
	Persistence	relative to		Persistence	relative to		Persistence	relative to	
		$Task_n$	$Task_{ALL}$		$Task_n$	$Task_{ALL}$		$Task_n$	$Task_{ALL}$
Task1	6	32%	14%	13	68%	57%	0	0	0
Task2	3	75%	7%	1	25%	4%	0	0	0
Task3	19	61%	43%	9	29%	39%	3	10%	60%
Task4	16	89%	36%	0	0	0	2	11%	40%

Table 6.6 Analysis of persistence across accessibility principles

6.2.3 Persistence Vs. Number of UI Elements

Table 6.6 shows most of the accessibility barriers in each task are belongs to perceivable. This implies that people with low vision who have interacted with M2M had difficulties to percept UI components and their corresponding semantics despite they have used Windows Magnifier and Windows contrast settings as assistive technologies. In Task3, 43% of the barriers are belongs to perceivable compared to all other tasks. This is because the pages involved in Task3 (VC Home, VC Course List) have more number of UI elements compared to other pages in other tasks.

To study more, we compute the correlation between the persistence value and the number of UI elements in tasks. The data is summarized and presented in Table 6.7.

Tasks	Persistence	No of UI elements
Task1	19	22
Task2	4	8
Task3	31	23
Task4	18	21

Table 6.7 Number of UI elements Vs. Persistence

$$Correl\ (X,Y) = \frac{\sum(x-\bar{x})\,(y-\bar{y})}{\sum(x-\bar{x})^2 \sum(y-y)^2} \quad \text{.....(1)}$$

As it is depicted in Figure 6.3, By applying (1), we get a correlation coefficient of 0.89 which shows a strong correlation between number of UI elements in a page and the frequency of accessibility barriers. This implies that the number of UI elements in a page should be relevantly small to make the UI/UX simple, intuitive, and more accessible.

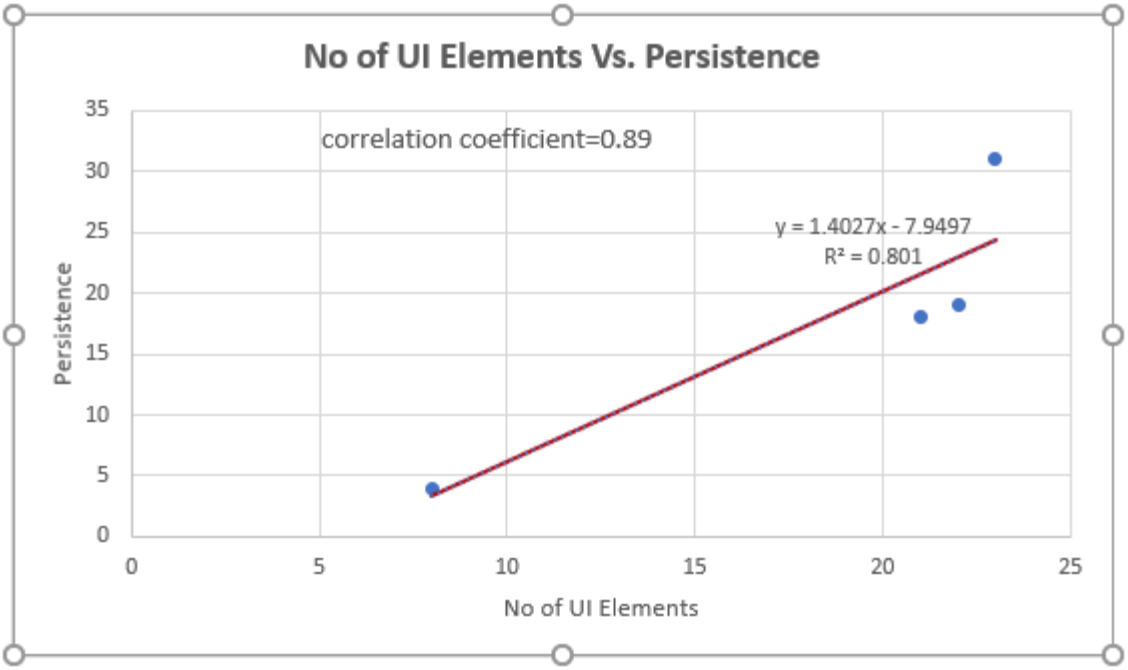


Figure 6.3 No of UI Elements Vs. Persistence

It is also observed that all the participants are familiar with the traditional user registration and login interfaces where they did report less accessibility barriers. However, they encountered more barriers in pages related to virtual classroom. The comparison between the traditional login and registration pages and non-familiar virtual classroom pages summarized in Figure 6.4. This implies that more emphasis needs to give to pages or interfaces that involves domain-specific and non-familiar functionalities in designing the UI/UX of the fully-fledged maternity training and learning application.

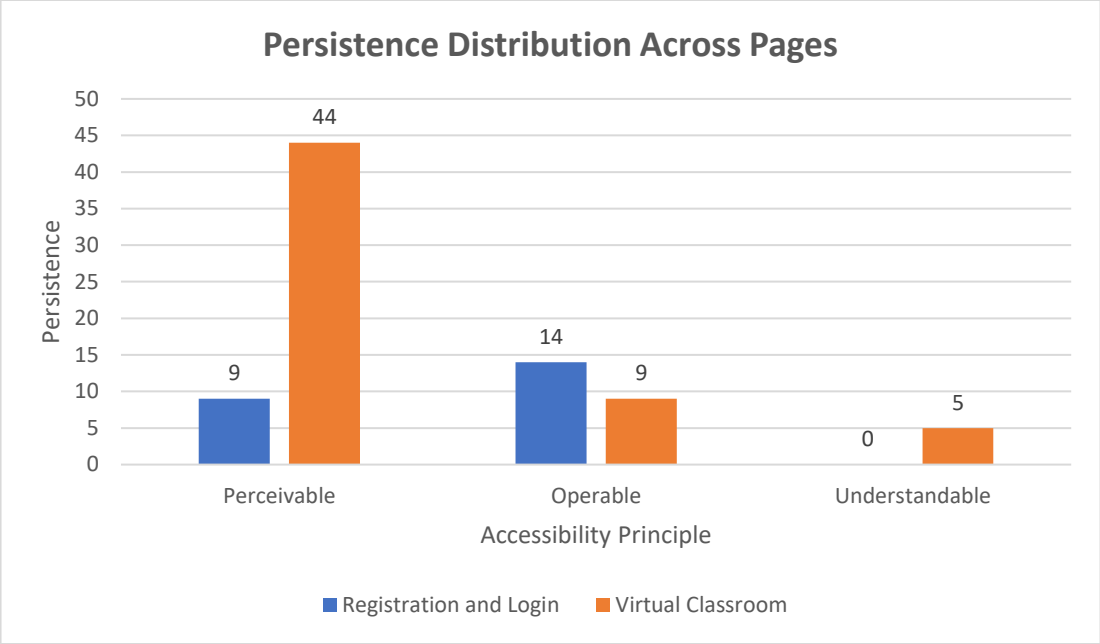


Figure 6.4 Persistence distribution across pages

We did not record any kind of accessibility barriers related to the robustness accessibility principle. This is because, we did not evaluate the prototype against different version of user agents.

6.2.4 Accessibility of The Multimedia Content

It is observed that the number of persistence increases when a task involves a multimedia content. As it is indicated in Figure 6.5, 83% of the accessibility barriers are related to the multimedia content itself in Task4. It can be referred from Figure 6.6 that the multimedia content's transcript is hard to perceive due to low contrast of the text. This infers that the contrast of the transcript and caption of a multimedia content must consider the contrast ratio to the page and the contrast ratio to the multimedia itself (the VR-based animation). For this reason, the accessibility of maternity multimedia needs to be evaluated independently before integrating it to the application.

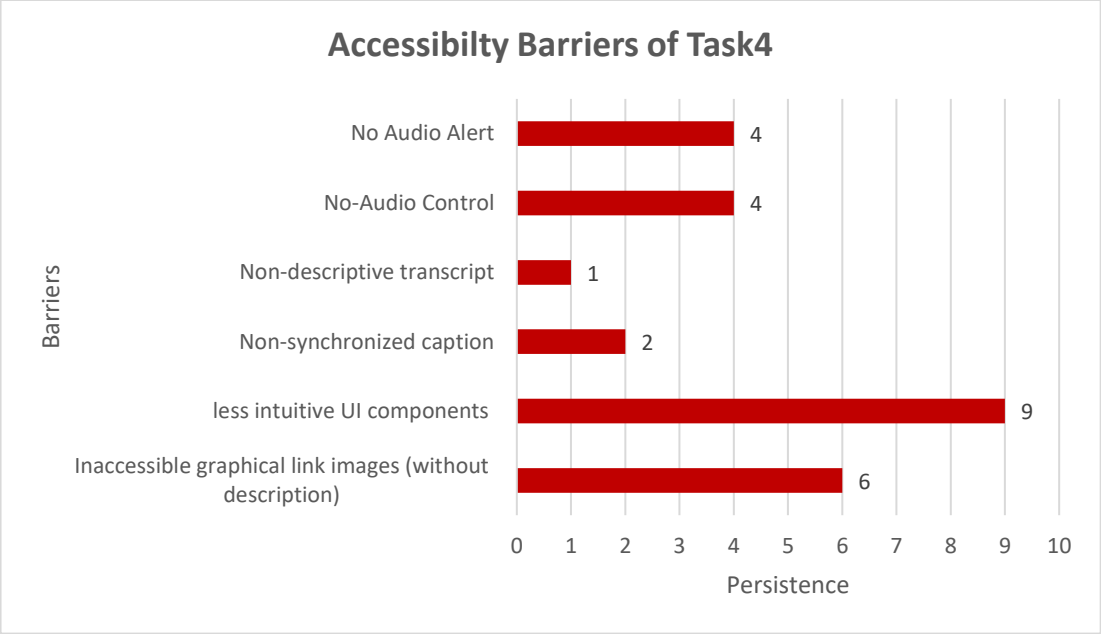


Figure 6.5 Persistence distribution across pages

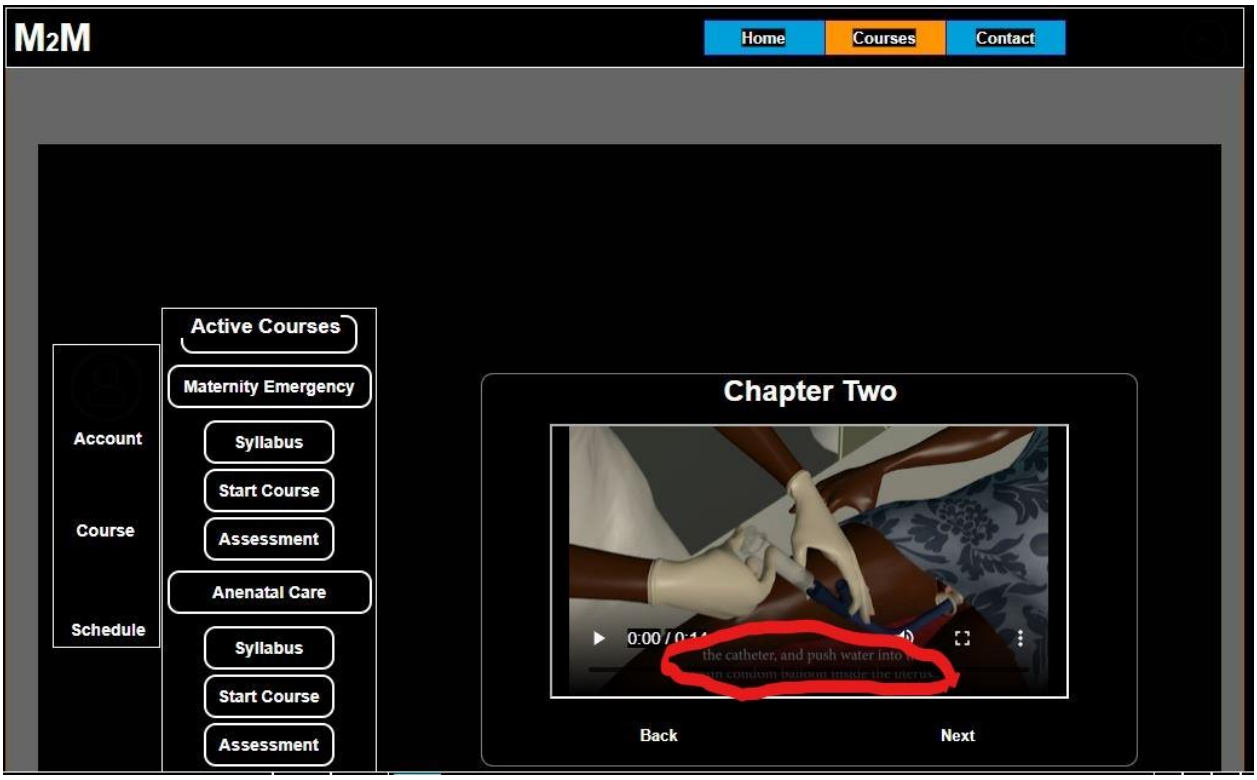


Figure 6.6 Low contrast of transcript that makes hard to perceive in Task4

6.3 Limitation of the Study

This study has several limitations related to number and type of participants. We managed to participate only five users who all are midwives. Four out of five participants are Ethiopians, and

the only other participant from Sub-Saharan Africa is Nigerian. In addition, we could not manage to participate local doulas in the evaluation of the prototype because of travel restrictions caused by the COVID-19 global pandemic. These all factors narrow our sample that may limit the significance of our study.

Chapter Seven: Conclusion and Future Work

7.1 Conclusion

The figure of MMR in the global south is worrying and requires a serious attention from all of the stakeholders. Despite the progress made on maternity healthcare in the last two decades, a huge effort is still required to achieve the SDG3 maternity health target. The effort includes capacitating the health professionals and local doulas through training and learning application platforms. Universally designed multimedia training and learning applications plays such a significant role in facilitating this effort. To design an accessible maternity training and learning application, the accessibility barriers of the target diverse user groups must be identified, and the impact of the barriers need to be quantified.

In this research work, we have developed a prototype to identify the possible accessibility barriers of maternity health training and learning application experienced by people with low vision. We studied the severity of the identified accessibility barriers which serve as a benchmark to develop a fully-fledged learning and training application for maternity health.

This research work contributes in two directions. Our first contribution is the identification of accessibility barriers related to maternity health training and learning application and their severity that impacts performance parameters. This contribution will significantly maximize the accessibility and usability of maternity training and learning application and enhances user satisfaction and productivity. Secondly, we have shown the strong correlation between the number of UI elements and the occurrence of accessibility barriers. This correlation must be taken in account in designing the UI/UX of the fully-fledged maternity training and learning application.

7.2 Future works

The design and development of a fully-fledged accessible maternity training and learning application for the Sub-Saharan Africa requires to consider the wide diversity of users, diversity of devices, diversity of user agents, and diversity of usage contexts. Despite our effort to develop a prototype that used to identify the accessibility barriers and their severity, there are still some important issues that must be addressed to develop a fully-fledged training and learning

application for maternity health. We have summarized some of the future directions in this topic as follows:

- The evaluation of the prototype is done using the combination of barrier walkthrough, cooperative evaluation, and heuristics method by only considering people with low vision. Further study must be conducted in consideration of other diverse users and their situations.
- The prototype we have developed is a web application. The prevalence of mobile devices and the expansion of Internet infrastructure in the Sub-Saharan Africa results people to access online training contents through their mobile devices. The identification and severity measurement of accessibility barriers related to maternity training and learning mobile applications requires further study.
- We have developed a VR-based multimedia content as part of the prototype. The pedagogical effect of integrating VR-based maternity multimedia content in online learning and training applications require further study.

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Appendices

Appendix-A: Interview Guideline

Requirement Elicitation Interview Guideline

✓ **Overview**

Research Project: M2M: Universally Designed Training and Learning Application for Maternal Health

Institution: Oslo Metropolitan University

Approval Status: Assessed and approved by NSD (Norsk Senter For Forskningsdata) with reference number 235391.

Purpose: The purpose of this interview is to collect the user requirements of the proposed application--Universally Designed Training and Learning Application for Maternal Health.

Interview Mode: Online

Alternative Mode: The questions may be sent via email for participants with consent and textual information about the interview.

Duration: 25 minutes

✓ **Consent**

I have received and understood information about the project *M2M Universally Designed Training and Learning Application for Maternal Health* and have been given the opportunity to ask questions. I give consent:

- ☐ to participate in *an interview*
- ☐ *for my personal data to be processed outside the EU – if applicable*
- ☐ *for information about me/myself to be published in a way that I can be recognized*

I give consent for my personal data to be processed until the temporary end date of the project, June 2021.

(Signed by participant, date)

✓ **Questions**

Duration	Purpose	Question	Clarification	Remark
2 minutes	Introduction and request for permission to record.	Personal Introduction by the interviewer and asks the interview whether it is ok to record the meeting.	Explain why the interview is recorded, if it's required.	
4 minutes	Introduction about the objective of the research work.	An overview introduction about the general objective of the research work by the interviewer (researcher).	Explanation of the purpose and scope of the research work.	
3 minutes	To identify M2M actors	Who do you think that the primary users of the proposed application?		
4 minutes	To identify M2M non-functional requirements	What kind of qualities do you expect from the proposed application?	Is it performance/security/ safety?	
5 minutes	To identify functional requirements	What are the key issues that pregnant women should learn regarding maternal health?	Issues that can be communicated with the M2M application.	If the interviewee is a midwife or gynaecologist.
5 minutes	To identify functional requirements	What are the key issues that local doulas should learn via the proposed learning and training application?	Issues that can be communicated with the M2M application.	If the interviewee is a midwife or gynaecologist.
2 minutes	To wrap-up the online interview	Thank you for participating and anything you want to add/ask?		

Table A.1: Interview Questions

Appendix-B: Sample Scenarios in the Prototype

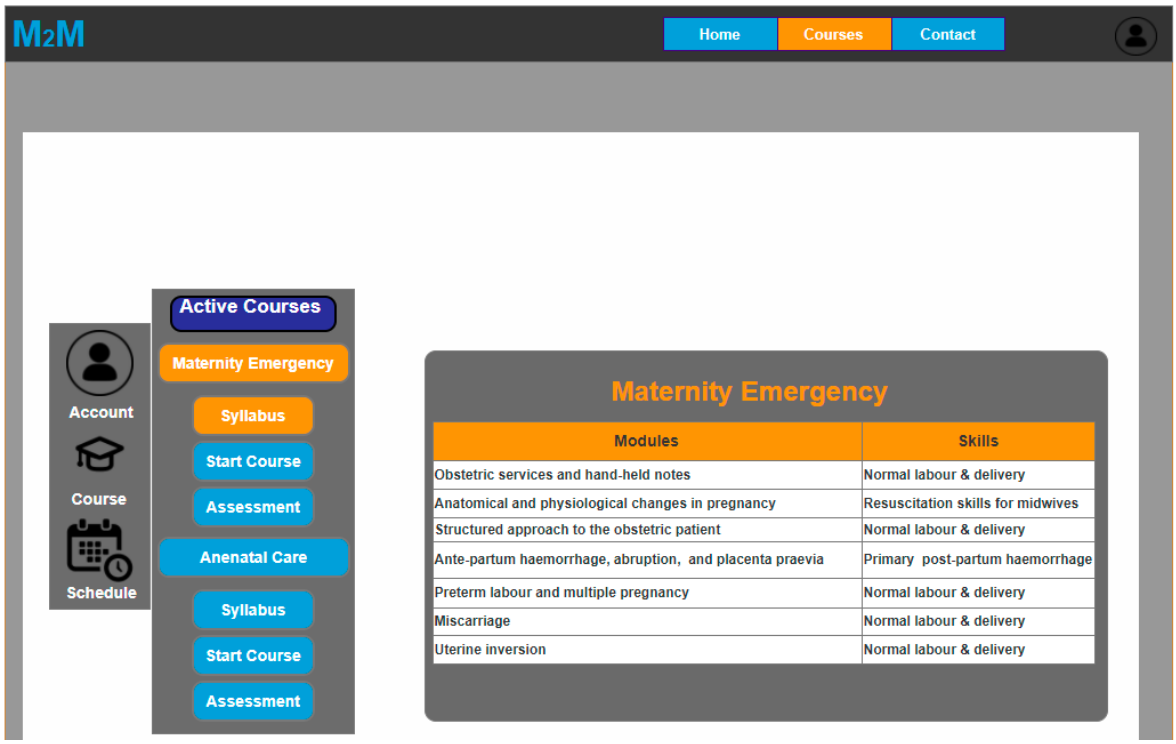

Figure B.1 User accessing Maternity Emergency Course Syllabus

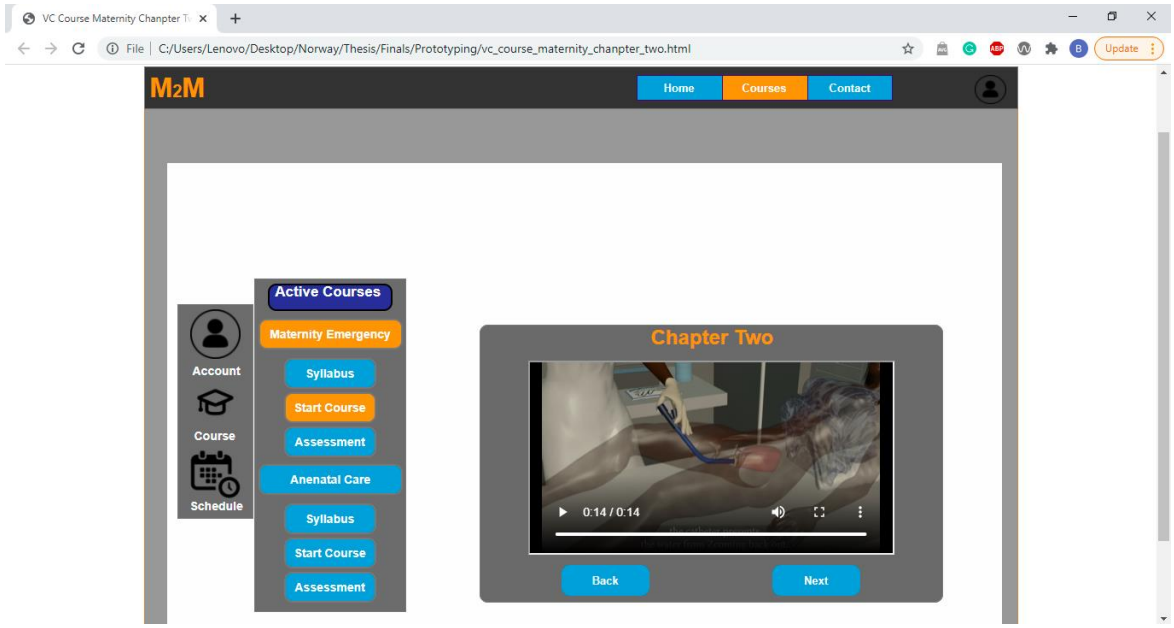

Figure B.2 User is accessing Maternity Emergency course

Appendix-C: Profile of the Participants

Participant ID	Participant Organization	Participant Position	Years of Experience
P1	Addis Ababa University, Black Lion Specialized Hospital, Addis Ababa, Ethiopia	Midwife Nurse	4 years
P2	Addis Ababa University, Black Lion Specialized Hospital, Addis Ababa, Ethiopia	Senior Midwife Nurse	10+ Years
P3	Ghandi Memorial Hospital, Addis Ababa, Ethiopia	Midwife Nurse	6+ Years
P4	Ghandi Memorial Hospital, Addis Ababa, Ethiopia	Midwife Nurse	2 years
P5	Bethel Teaching Medical Hospital, Addis Ababa, Ethiopia	Midwife Nurse	10+ Years

Table C.1 Profile of Participants

Appendix-D: Post Evaluation Interview Guideline

Post Evaluation Interview Guideline

✓ **Overview**

Research Project: M2M: Universally Designed Training and Learning Application for Maternal Health

Institution: Oslo Metropolitan University

Approval Status: Assessed and approved by NSD (Norsk Senter For Forskningsdata) with reference number 235391.

Purpose: The purpose of this interview is to collect participated user's feedback about their experience of completing task scenario using M2M-Universally Designed Training and Learning Application for Maternal Health.

Interview Mode: Physical

Alternative Mode: The questions may be sent via email for participants with consent and textual information about the interview.

Duration: 25 minutes

✓ **Consent**

I have received and understood information about the project *M2M Universally Designed Training and Learning Application for Maternal Health* and have been given the opportunity to ask questions. I give consent:

- ☐ to participate in *an interview*
- ☐ *for my personal data to be processed outside the EU – if applicable*
- ☐ *for information about me/myself to be published in a way that I can be recognized*

I give consent for my personal data to be processed until the temporary end date of the project, June 2021.

(Signed by participant, date)

✓ **Questions**

Duration	Purpose	Question	Clarification
3 minutes	Introduction and request for permission to record.	Personal Introduction by the interviewer and asks the interview whether it is ok to record the meeting.	Explain why the interview is recorded, if it's required.
3 minutes	To identify barriers related to low contrast	Do you able to see and access content after you use screen magnification?	This question is for all task scenarios.
2 minutes	To identify barriers related to insufficient time to complete a task.	Do you manage to complete task with the given time?	Observed by the interviewer since it is a cooperative evaluation.
4 minutes	To identify barriers related to UI elements that can't be controlled by keyboard.	Does M2M provides keyboard equivalent for all mouse operations?	Do you manage to complete the task using keyboard?
4 minutes	To identify barriers related to the number of UI elements in VC Home and VC Course page	Do you feel that there are too many UI elements in VC Home and VC course page?	Do you have difficulties in navigating on VC Home and VC Course page due to many UI elements?
4 minutes	To identify barriers related to non-descriptive transcript.	Does the transcript descriptive?	Is the transcript of the VR animation understandable?

4 minutes	To identify barriers related to no-audio control.	Do you able to adjust audio?	Do you able to increase/decrease/ audio of the VR animation?

Table D.1 Post-evaluation Interview Questions