ENHANCED M-LEARNING ASSISTIVE TECHNOLOGY TO SUPPORT VISUALLY IMPAIRED LEARNERS IN TANZANIA THE CASE OF HIGHER LEARNING INSTITUTION

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ABSTRACT

The growing penetration of mobile and networked devices, for example, standard phones, smartphones and tablets have gradually transformed the mode of teaching and learning in Higher Learning Institutions (HLIs). The learning process is increasingly online, with students using electronic devices to access content and to self-learn at any time and from any place. This online ubiquitous learning is termed electronic-learning, or mobile learning (M-learning) when mobile devices are used. In Tanzania, 36% of people aged 24-29, which is the largest age group of students in HLIs, own a mobile device. As a result, m-learning has been increasingly adopted by HLIs. However, little is known on the level of engagement in M- learning by visually impaired learners (VILs) in Tanzania; for instance, the tools they use and the challenges encountered when accessing learning contents. With an estimated 250 VILs in Tanzanian HLIs, it is essential to ensure that the ever-increasing reliance on electronic and mobile learning does not leave them with knowledge and skills gaps, as these could contribute to poor performance, dropping out and lower chances of employment after graduation. In this regard, assistive technology is needed in HLIs because as the world shifts from traditional classroom settings to online settings, VILs needs it in order to move with the pace and improve academic achievement.

This study is intended to determine the usability of existing versatile assistive technologies among VILs in Tanzanian HLIs and the challenges that they face when accessing online learning platforms. User requirements for assistive features were gathered, and an assistive technology prototype was developed and validated. Data were collected via surveys and interviews involving 33 VILs in four HLIs. The study found that 67% of respondents did not know about mobile assistive technologies or integrated assistive technologies on online learning platforms. Also, 66% could not afford smartphones and were therefore unable to use assistive technologies. The prototype was developed for Android devices and consists of three parts: a user management component for user authentication; a learning resources component for a learning management system available in their HLIs; and a speech synthesizer. Whereby the platform can be able to synthesizer text and graphical contents into audio content, with the pitch analyzer. A usability test was conducted with 7 VILs using the System User Scale (SUS) questionnaire. The prototype achieved an average score of seventy-six-point eight percent (76.8%), which was higher than the 68% usability score given to existing Android accessibility tools. It is confirmed that accessibility,

knowledge and skills are the principal concern with respect to the adoption and usage of learning technology for visually impaired learners.

DECLARATION

I, Juliana Samuel Kamaghe do hereby state to the Senate of Nelson Mandela African Institution of Science and Technology that this dissertation is my original effort and that it has neither been submitted nor being concurrently submitted for a degree award in any other institution.

10/03/21

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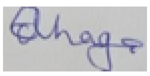

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CERTIFICATION

The undersigned certify that, they have read and hereby recommend for acceptance by the Nelson Mandela African Institution of Science and Technology a dissertation titled: *"Enhanced M-learning assistive technology for improving learning in Higher Learning Institutions in Tanzania: The case of visual-impaired students."* in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Information and Communication Science and Engineering of the Nelson Mandela African Institution of Science and Technology

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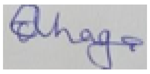

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Finally, my lovely husband, who was constantly there for me throughout my PhD studies. Dear Asifiwe Kyando, without your support and encouragement, I would not have made this far. I understand it was hard staying with our children, but I'm always thankful to God for you.

DEDICATION

To the memory of my late Parents, Eng. Samuel Kamaghe & Edina Ngalla and my late loved ones (mother-in-law Asisimwe Sanga and baby sister Bahati Kamaghe).

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LIST OF ABBREVIATION

API	Application Programming Interface
AT	Assistive Technology
DFD	Data Flow Diagram
HLI	Higher Learning Institutions
VIL	Visually Impaired Learners
i.e.	id Est
ICT	Information and Communication Technology
IT	Information Technology
LMS	Learning Management System
MOOC	Massive Open Online Course
NBS	National Bureau of Standards
PDA	Personal Digital Assistant
SUS	System Usability Score
TCRA	Tanzania Communication Regulatory Authority
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
CCBRT	Comprehensive Community Based Rehabilitation in Tanzania
WHO	World Health Organizations

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

The World Health Organization (WHO) approximates that fifteen percent (15%) of the global population, i.e. approximately 650 million individuals, are disabled (WHO, 2018). This number includes those with physical disabilities, visual impairment, i.e. a disability where a person has low vision or no sight at all, and those with albinism. It has been noted that the majority of people who are visually impaired face more difficulties in accessing social services than those suffering from other disabilities since there is no early intervention, little addressing of their needs in education and no functioning vision as an enabler (Gordon *et al*., 2017; Pacheco *et al*., 2018). Besides, the student's attitude (i.e. self-identity, positive aspects of being visually impaired, engagement with support) and institutional delivery (i.e. campus navigability, essential services support, university-level support) are often barriers (Gordon *et al*., 2017; Pacheco *et al*., 2018).

The WHO estimates that there are about 314 million visually impaired people globally, with 45 million being blind (Lin *et al*., 2017). In East African countries, it has been estimated that there are approximated 2.4 million visually impaired people; whereby, Tanzania has large prevalence followed by Rwanda. According to Tanzania's National Bureau of Statistics (NBS), there are approximately 1.1 million visually impaired people in the country. Although more than 500 000 are enrolled in primary education, only around 5000 make it to tertiary education, as shown in Fig. 1 (NBS, 2014). Figure 1 shows, the number of visually impaired students enrolled in tertiary education has steadily increased in the past few years. It is therefore increasingly important to ensure Higher Learning Institutions (HLIs) are well equipped with supportive services to ensure these students can fully engage in learning activities. Even though the registration rates for VILs such upsurge is not noteworthy, the number of VILs known to HLIs is inadequate.

The advancement of Information and Communication Technologies (ICTs) has paved the way for economic development around the world. There has been a growth of ICTs services in education, healthcare and other sectors. In education, the use of ICTs has led to an increase in vast teaching and learning facilities and has led to new learning paradigms including mobile learning (m-learning), 3D-based learning (games) and animation learning (Martínez *et* *al*., 2015). VILs will profit from these ICT tools that will be used as an alternative to instructors / other learners dependences, the ICT-based course is considered to help them to inspire their understanding on learning materials (Ghavifekr & Rosdy, 2015).

	Level of Education						
	Never attended, adult education or pre-school	Primary	Secondary	Vocational training	Tertiary non university	University	Total
Total	**927,206**	**1,119,694**	**107,759**	**36,269**	**22,090**	**12,652**	**2,225,671**
Albinism	1,751	9,772	1,786	737	213	597	14,856
Seeing	429,648	551,569	57,694	25,808	11,044	5,270	1,081,034
Hearing	246,160	248,776	15,706	5,685	5,082	2,143	523,553
Walking	471,283	399,227	21,234	10,725	6,878	3,889	913,237
Remembering	318,669	266,404	25,051	1,335	3,873	4,940	620,271
Selfcare	118,429	95,081	9,608	548	720	2,092	226,478
Communicating	113,696	65,879	5,404	638	-	1,086	186,704

Figure 1: Numbers of Students Enrolled in Different Education Levels Grouped by Disability (NBS, 2016)

M-learning is described as flexible learning by using various mobile tools such as mobile phones, tablets and notebooks, and providing learners with lithe time (Aparicio *et al*., 2016; Bhardwaj & Kumar, 2017). M-learning can lead to a shift from instructor-centered education to a learner-centered system, i.e. blended learning, which is used in open and distance education (Ahmed & Ghareb, 2017). The goal of m-learning is to provide learners with the capability to adapt to learning anywhere at any time (Patel, 2019).

M-learning enables user to access learning content directly via mobile devices or it can involve accessing learning material through cloud computing. Cloud computing is a model for permitting abundant, applicable on-demand system access to a shared pool of configurable computing parts which will be backed immediately and at liberty by nominal leadership or service supplier communication (Yeh *et al*., 2014). Cloud computing is the use of software, services and technologies that are hosted on the internet rather than on the user's device and online learning platforms now offer services in the cloud e.g. Moodle Cloud. The use of cloud computing in m-learning allows learners with limited device storage and computational power to still be able to access the large contents available online, with the aptitude of ultra-virtualization on e-contents (Arpaci, 2016).

According to TCRA, the number of mobile phone subscriptions (SIM cards) in Tanzania has grown from 25.4 million in 2011 to 43.5. Million in 2018, as shown in Fig. 3. Currently, more than 80% of the population has access to mobile phones (TCRA, 2020). The situation is similar to many other countries in Africa (Asongu *et al*., 2018). Also, according to statistical data reported in June 2020, there are approximately 27 100 146 internet users in Tanzania which allow user have accessibity in their devices as shown in Fig. 2. The growing availability and usage of mobile phones have made m-learning popular with higher education students on the continent (Abdul *et al*., 2016).

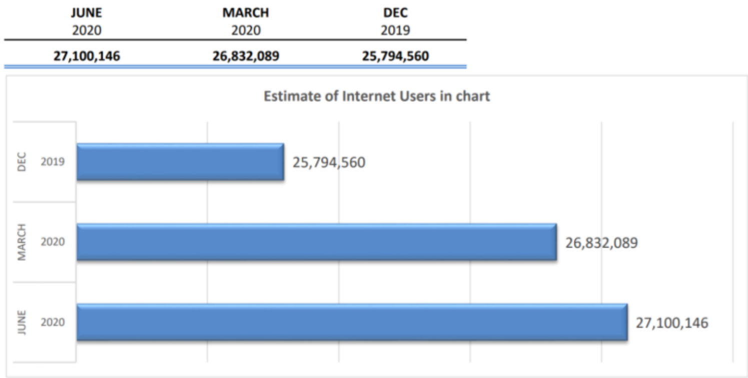

Figure 2: Internet Users in Tanzania (TCRA, 2020)

The adoption of ICT-enabled learning in HLIs can offer various benefits to VILs. First, it can improve their ability to acquire knowledge, for example, by allowing increased interaction between an instructor and VILs using online forums and classes or by VILs using online sessions, which overall can make students more involved in learning activities and encourage individual learning (Mnyanyi, 2014). Students can also gain the skills needed to improve academic performance and it encourages collaboration with other disabled learners. This is a massive advancement as it provides equal opportunities for disabled students (Liu *et al*., 2010). The most popular LMS around the world are the Moodle, Blackboard and TalentLMS (Binyamin *et al*., 2019; Ismaili *et al*., 2016)

The usage of ICT-based learning can marginalize visually impaired learners (VLIs). Many research projects report that the majority of web sites visited are not accessible for visually impaired learners (VILs) (Heiman *et al*., 2017; Pacheco *et al*., 2019; Walsh *et al*., 2015) and people with visual impairment are amongst the slightest considered in the educational setting of online learning in general (Frost *et al*., 2019; Sezer *et al*., 2019). In addition, the LMSs used by HLIs do not have a lot of in-built support for visual impairments. They provide discussion forums and note chats, which are most suitable for full-sighted students. Also, the contents hosted in LMS are text-based and many have graphical representations (Farley *et al*., 2015). This is especially true for science, technology, engineering, and mathematics subjects (Kumar-Basak *et al*., 2018). To access text material, VILs would have to use software such as text-to-speech tools that scan text and synthesize to voice or use magnifiers. Accessing graphical content is more difficult as the available software can read out the textual information but cannot describe what is shown. An additional challenge for VILs is that the software needed is often proprietary, and licenses can be expensive. For example, the talk button, which is a text-to-speech synthesizer costs about US$ 30 (+ VAT or sales tax, where applicable while BrailleMo, which is braille to speech software costs $100 for one user (Swietlinski & Kaszczuk, 2016). In addition, society's perceptions against people with visual impairment are known to affect their ability to cope with technological changes psychologically (Farley *et al*., 2015). Even though education is known to be vital for the development of a person's growth, some people in society still consider visual disabilities as a burden to them and therefore keep them from a good education (Mahali, 2019). Society's attitude may affect how VILs engage with m-learning and it is currently unknown how much and how well VLIs in Tanzanian HLIs engage with M-learning. In this regard, it is essential to take into account the requirements of VILs when developing learning platforms and content. Assessment of the current usage of Assistive Technologies by VILs and the challenges encountered can help ensure researchers, educators and HLIs develop and provide better tools to support the students.

Figure 3: Trends of the Mobile Subscriber in Tanzania (TCRA report 2016)

1.2 Statement of the Problem

Most online-learning environments assume that the learners have sight. Educational materials in sciences, technology, engineering and mathematics disciplines historically trust heavily on tables and graphics to give essential ideas, methods and architectures; therefore, the learning platforms often rely on vision-centric methods of presentation. Developing learning contents and interfaces for the visually impaired, i.e. Not dependent upon graphics, is complex (Yeh *et al*., 2014) and available accessibility software tools are expensive and focus on text-to-speech synthesis. As online learning through mobile devices gains popularity and as more VILs are admitted to HLIs, it is vital to address low accessibility of these platforms and contents. Hence the researcher would develop an Assistive technology that will be used by the VILs in their learning activities.

1.3 Rationale of the Study

In Tanzania Higher learning the use of Assistive technology for visually impaired learners is lower as the emerging of m-learning for teaching and learning purposes is becoming higher (Miller, 2014; Mtebe *et al*., 2018; Uddin *et al*., 2019; Wong *et al*., 2019). Assistive Technology allows VILs to have access on learning contents which are available on the learning platforms and the Internet (Pacheco *et al*., 2019). As advancements in usage of smart devices (smartphones, tablets, PDA, kindle readers, VILs are lacking knowledge and skills on how to use them for learning purposes which led them to take long time to study while other visual learners are moving forward. In order for VILs impaired learners to move with the technology they need Assistive technology which will help them in self-learning process for better academic achievement.

1.4 Objectives

1.4.1 General Objective

The general objective of the study is to develop an assistive technology that will enhance the accessibility of m-learning amongst visually impaired learners.

1.4.2 Specific Objectives

(i) To determine the knowledge and usage and challenges of existing mobile assistive technologies amongst VILs in Tanzanian HLIs.

(ii) To review m-learning and cloud computing technologies in assuring the restrictions facing mobile devices on M-learning.

(iii) To identify accessibility, reliability, functionality and running costs requirements of new assistive technology for VILs in Tanzanian HLIs.

(iv) To develop a prototype of the assistive technology for M-learning, which will be integrated with cloud computing for VILs people.

(v) To validate the developed prototype based on its design specifications.

1.5 Research Questions

(i) What is the level of knowledge and usage of assistive technologies available for VILs on mobile devices?

(ii) What does the literature say on m-learning and cloud computing technologies in assuaging the constraints facing mobile devices on m-learning for VILs?

(iii) What are the design features of assistive technology for M-learning, which will ensure affordability, accessibility and reliability support VILs?

(iv) How can a low-cost assistive technology prototype be developed to be integrated with cloud computing to suit VILs needs?

(v) How good is the proposed assistive technology design?

1.6 Significance of the Study

The findings of this study will increase awareness and usage of assistive technologies and improve understanding of enhancing accessibility and usability of m-learning to enhance learning by VILs. Moreover, skills and knowledge acquired will be used to strengthen the use of compatible m-learning platforms available in their HLIs to visually impaired learners resulting in the inclusion of teaching in higher learning. Higher Learning Institutions will use the findings and assistive Technology prototype to develop a usable system to help VILs to tackle challenges associated with the accessibility of m-learning teaching resources hence improve academic performance. This research may inspire other researchers to look into enhancing the learning of disabled people using ICTs.

1.7 Delineation of the Study

The study aimed to decrease problems facing visually impaired in Higher Learning Institutions and improve academic performance. The study focused on HLI that enrolled VILs and enabled them to undertake program of their choice. The study focused on m-learning in HLIs because learning contents usually require a high number of self-learning hours and most of the content is provided online on e-learning platforms. This study focused on three major Higher Learning Institutions namely the University of Dar es Salaam (UDSM), the Open University of Tanzania (OUT) and the University of Dodoma (UDOM) because most of the visually impaired learners are enrolled in large number in these HLIs. In these Higher Learning Institutions, the researcher was able to compare challenges of access to M- learning assistive technologies in educational services, in both learning methods (blended and conventional). The study focused on the problems visually impaired learners face while on campus and outside the university and the way they affect their studies. The concentration was on socio-cultural and technological factors like the locality factors and awareness knowledge, availability of assistive technologies, evaluation of government policies, and HLI policies regarding these technologies. Lack of interest among learners with visual impairment, household economic factors (wealth), group isolation, physical distances to and from universities and non- adaptive environment are among other elements of concern.

Given the financial and time constraints, the prototype designed was linked with only four Higher Learning Institutions, who were major in admission of visually impaired learners and are engaging on the use of m-learning in teaching and learning. The current study had the following limitations:

(i) Limited sample size due to the reluctance of participants and nature of sensitivity of VIL.

(ii) Attitude and behavior of leaners towards the usage of smart devices.

(iii) HLI denied access and integration of m-learning Assistive Technology.

(iv) Hesitant of HLI in adopting m-learning platforms.

(v) The study was carried on Dar es salaam and Dodoma region only as the major HLI are situated.

1.7.1 Conceptual Framework

The conceptual framework of the designed prototype is shown in Fig. 4. The framework was designed to enable researcher to have a glimpse of what needed to design smart device's assistive technology m-learning for VILs who are in Higher Learning Institutions. Also, it can be used as a benchmark of other designed assistive technologies which will be used by other disables learners in education sectors in Tanzania.

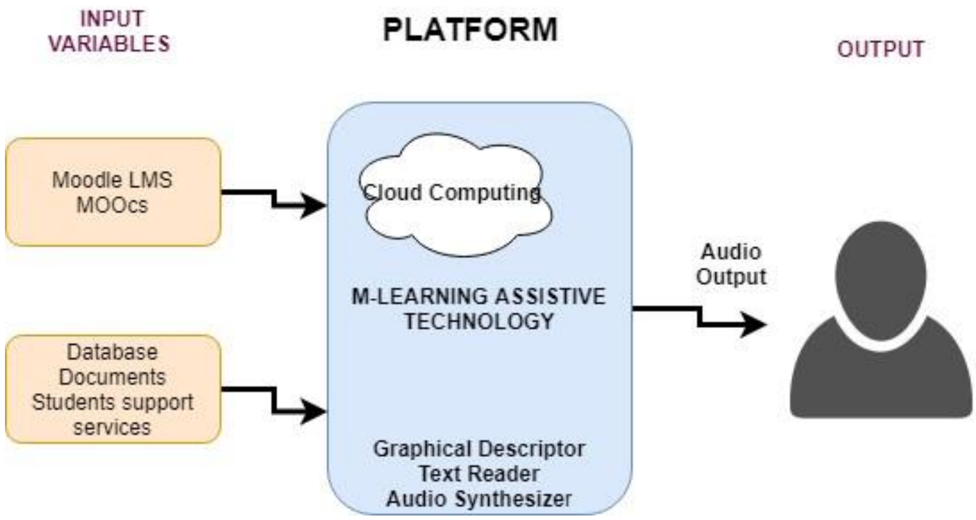

Figure 4: Conceptual Framework of the M-learning System

CHAPTER TWO

LITERATURE REVIEW

2.1 Disability Status in Tanzania

There has been an emergence of disability issues on the international development agenda. A profound change has taken place globally in the thinking on disability issues, whereby there has been an acknowledgment of disabled people being full and active members of society with equal rights and opportunities. Tanzania has followed with the national and sectoral levels, especially education, pushing for disabled rights and inclusion. For example, the national policy of 2003 states that "*Give special attention to providing new learning and ICT access opportunities for women and youth, the disabled and disadvantaged, particularly disenfranchised and illiterate people, in order to address social inequities*. (MOL, 2004)". Moreover, the Education Act No 25 (56) I of 1978 states that "*every citizen of Tanzania has the right to receive education as his/her ability permits*." Despite this, there are some barriers to disabled people receiving the right education at the right time(MD Main Uddin *et al*., 2019; NBS, 2015) and this may be due to the view of disability and disabled people in society.

Disability is a complex, multidimensional and contested term (Arrigo, 2005; Mloyi, 2013; Wattenberg, 2004; WHO, 2011). From a medical perspective, disability means a mental/physical impairment while from a socio-cultural perspective, disability is an incapacity to perform social activities. However, incapacity ought to be viewed neither as strictly medical nor as purely social because people with disabilities usually experience issues arising from their health condition (Perfect *et al*., 2018). One of these issues is the difficulty for disabled people to take part in normal daily life activities as disability can affect the senses that people need to conduct necessary tasks (Solodow *et al*., 2006). It is difficult for people with disabilities to take part in normal daily activities. It can limit what people do every day, or they can affect the way that people need to conduct essential responsibilities to continue with their lives.

People with visual impairment need specialized devices to help them use technologies, including ICT. These devices may be referred to as assistive technology (AT), access systems, software-based, adaptive technology or adaptive computing in ICT (Grönlund *et al*., 2010; Kouroupetroglou, 2014; Mnyanyi, 2014). The main category of disability that is being discussed in this research will be visually impaired persons and because this group of people in Tanzania who are most affected by the right to get education. .

2.2 Visual Impairment Status in Tanzania

Impairment is a feature and condition of an individual's body or mind which, unsupported, has limited, does bound, or will limit that individual's personal or social functions in comparison with someone who has not got that feature or condition. Impairment relates to physical, intellectual, mental, or sensory health; as such it is a personality issue (CCBRT, 2018). Visual impairment (VI) is an essential type of eye impairment (Guardia *et al*., 2011; UNESCO, 2009). Different authors define visual impairment differently. Some include blindness while others exclude it in the literature. Visual impairment is the name used for people who are lacking or have low sight, who require unique lights to see, who have blurred vision or who have tunnel vision (Hakobyan *et al*., 2013; Jain *et al*., 2014; Jeppeson, 2006). According to UNESCO (2009), the article describes "*visual impairment as a visual insight of less than 6/18 (vision problems can only see at six meters what a 'normal' sighted should see at 18 meters) to 3/60 (person with vision problems can only see at three meters what a 'normal' sighted person should see at 60 meters*. Visual impairments are categorized as low vision, functional blindness, and total blindness. Visually impaired persons require vivid resources in their educational process (Mnyanyi, 2014). Also, WHO (2010) on their report of persons with vision impairments included terms such as *moderately sighted, low vision, legally blind, and completely blind used in persons with visual impairments.* Partially sighted indicates some visual, which modified glasses have caused no need for excellent guidance (Engel *et al*., 2017; Hyder, 2016; Koester *et al*., 2017). Lower vision is the sight loss that cannot be fixed by ordinary glasses, contact lenses, medication, or surgery (Szpiro *et al*., 2016). A completely blind person has no sight at all, does not see any word and depends on other non-visual media (Freitas & Kouroupetroglou, 2008; Scott, 2017). Visually impaired entities, like individuals with disabilities, typically need some assistive equipment and services that take the level of requirements into consideration. Some VILs involve specialized spectacles, braille, or large printing equipment to help them offset their low vision (Bhardwaj & Kumar, 2017).

Due to poor structure and inadequate resources, statistics about blindness in Tanzania are very inexact. The statistics based on the World Health Organization use the prevalence-of-blindness evaluation formula of 1% of the world population. In Tanzania, the approximate number of blind people in the Tanzanian society would be approximately 1.1 million divided as follows: 56% due to cataract (around 616 000 people), 20% due to corneal scars (about 220 000 people), 10% due to glaucoma (about 110 000 people) and 14% due to other causes (around 154 000 people) (NBS, 2015).

2.3 M-learning Adoption Amongst Visually Impaired Learners in Higher Learning

Prior studies have examined challenges and issues of assistive technologies in the adoption of m-learning. Ludi *et al*. (2012) examined assistive technologies for low vision and low sight users. The authors presented a useful approach for designing learning tools that enable learners to zoom captured content in live lectures through iPad. Mtebe and Raphael (2018) narrated the importance of using mobile learning in Higher Learning Institutions in Tanzania when shifting to blended learning and allow learners to access learning resources anywhere. Armano *et al*. (2010) reviewed the visibility of the Learning Management System (LMS) Moodle for visual impairment by accessing all usable smart device support technologies. Hakobyan *et al*. (2013), surveyed users with visual or hearing impairments about their mobile phone accessibility needs. Jancenelle *et al*. (2017) and Frey *et al*. (2011), examined the encounters facing visual disabilities to identify accessibility problems with the current mobile phone hardware. Ferati *et al*. (2016) plotted blind mobile phone users about accessibility problems with current mobile phones by using existing touch screen.

Douce (2015) depicted on making e-learning contents accessible to the disabled will give better experience and usability to students: Heidi and Leslie (2016) explained the experience of visually impaired in higher learning and the problems they are facing in higher learning environments, including familiarity and locality of classes. Also, Maćkowski *et al*. (2018) present the existing cooperating tutoring platform for math education and knowledge in exploring mobile learning. The results of said research prove a good understanding of the mathematical equations described to comply with elaborate rules.

Depending on the level of math equations difficulty, the level of math, formulae knowledge is higher for the different structural explanations. For learners who are visually impaired, math and pictorial thoughts have a unique challenge due to the visual nature of data embedded in graphs, charts, tables and plots. Bateman *et al*. (2018) developed an electrostatic touch screen for visually impaired that provides information on mathematical concepts by adapting the user-centered design. Usage of a smart device can compensate for the challenge of lack of good infrastructures, locality and user dependency on others while studying (Joyce-Gibbons *et al*., 2018). Hence, Wong and Tan (2019) explained the benefit of mobile learning platforms using iPhones whereby it provides consistency and efficiency of Visually impaired learners. Despite encouraging efforts in some areas but there remains a lack of evaluated m-learning platforms for visually impaired learners in Tanzania, and they are lagging behind the technology itself, and HLI had these platforms used for learning but VILs are unable to use these platforms and creates a digital divide in Tanzania. Mwaijande (2014) stipulated on the accessibility of assistive devices for children with physical disabilities in Tanzania.

Also, Mnyanyi (2014) narrates using assistive technologies for visually impaired in Higher Learning Institutions where learners were using multimedia devices. eM Elsawy and Ahmed (2019) designed a framework for m-learning to be used in higher institutions that motivate learners to use it and learn to increase mobility and efficiency. Shohel and Power (2010) designed an m-learning for the professional development of the people, especially those who are in offices.

2.4 Present Educational Issues on Disabled Tanzanians

At present, in the Tanzanian educational sector, there are constant changes in the direction of learners with a visual impairment. Mloyi (2013) narrates that learners with disabilities should be educated in a general education setting because, in some future time, they will have to face the world with people who do not have any disabilities. The inquiry that rises is how to prepare instructors to be able to teach all learners equally towards constructing a world that accepts equality (Mnyanyi, 2014; Yeh *et al*., 2014). Currently, instructors are ill-prepared to assist disabled students because the educational needs of disabled students have not been given much attention (Wong *et al.,* 2019). Some of the problems that have held back these students include a lack of reliable educational resources, knowledge, skills and awareness of the learning management system (Fenrich, 2005; Hamidi *et al*., 2017; Karlan, 2011). These problems still exist even though some efforts have been taken to lessen the extent. With increasing recognition of the needs of these learners, a few HLIs have started using assistive technologies. The Open University of Tanzania (OUT) has an Assistive Technology Unit (ASTU) which provides computer-based support technology teaching for visually impaired learners. The Institute of Adult Education at the University of Dar es Salaam School of education also offers training on the usage of assistive technology available on personal computers i.e. screen readers and text recognition.

2.4.1 Tanzania Policy on Disability

The Convention Rights of People with Disabilities has taken effect from December 2006, making it the most significant negotiated human rights treaty. There were 82 participants to the Convention, 44 signatories to the Optional Protocol and one ratification of the Convention. It is the uppermost number of signatories in the record to a UN Convention on its aperture. Tanzania is one of the guarantors to the Declaration on the Rights of Persons with Disabilities (1975), Convention on the Rights of children (1989) and therefore the Standard Rules on the leveling of Prospects for Persons with Disabilities (1993). Tanzania has signed but not sanctioned the Convention on the Rights of Individuals with Disabilities or the Protocol. The execution of the National Policy on Disability (NPD) in 2004 was a different era the Government allowed disabled people to participate in social, economic development. Moreover, this was appreciated by the Committee on the Rights of the Child in its 2006 report and it was formed so that there will be groups for disabled people i.e. Tanzania League of Blinds (TLB), which help them to enact on this policy. Also, the system talked on the legislation of these organizations, i.e., the Tanzania League of the Blind, the Albino Association and the Tanzania Society for Palsy and Mental Retardation. It shows the different obstacles facing education to people with disabilities, difficulties like inaccessibility to HLI facilities, low enrollment in universities, the presence of education curriculum that does not integrate the requirements of persons with disabilities i.e. visual impaired.

The policy recognized the importance of assistive devices in improving practical skills for people with physical disabilities in the case of assistive devices. The tools include prosthetics, orthodontists, wheelchairs, canes, hearing aids, braille, etc. Also, the policy agreed that regardless of their value, they are not readily available plus people with disabilities have no information on where to get them and how expensive they are. The study reported on ICT accessibility to visually impaired learners by designing an m-learning Assistive technology. The study aims to support the national policy enacted by providing accessibility tools for visually impaired learners.

2.4.2 Visually Impaired Learners' Access to M-learning

Different studies have verified that ICT is not only reducing barriers of access to information for visually impaired learners also learners with visual impaired face unique barriers in using learning platforms available (Singhal *et al.*, 2019). Comparing both the visually impaired learners and non-visually impaired. It is four times simpler to use the m-learning platform services for non-visual impaired learners than learners who have either a low vision or are entirely blind (Tom *et al*., 2018). Due to this fact, most of the learning platforms were developed for non-visual learners who do not require any assistive technology and skills to use smart devices. Therefore, the interface of the smart devices touch screen must balance for this irregularity. The design for the accessibility interface will be of importance if the person using smart devices is visually impaired (Palalas, 2013). Different policies have been proposed, and technologies created so that learners can get access and use m-learning services. Some of the tools/applications for supporting VILs, includes Braille input, Screen Readers, Touch Screens, Eye Tracking and speech synthesizer.

2.5 Assistive Technology

Different authors have described Assistive technology as whichever technology that allows one to enhance, preserve, or advance the functional capabilities of a human being with particular learning requirements (Goldrick *et al*., 2014; Hakobyan *et al*., 2013; Isaila, 2014; Mwaipopo, 2011; Yeh *et al*., 2014). Its usability and adaptations can help unlock doors to formerly unapproachable learning opportunities for many learners with a particular need (Mwaijande, 2014; Mwakisole *et al*., 2018). The advantages of assistive technology are to empower learners with disabilities to have access to literacy in the school and university at large and help them to increase access to learning resources hence improve academic performance. It differs significantly from other types of technologies that assist students. It permits learners to grow in skills, be involved in the educational setting, and function individualistically. Assistive technology, for example, uses inventive gear such as videotapes (for audio and video), computer-assisted instruction, mobile accessibility, multimedia effects, sound enhancement and the Internet to increase the instructional modalities in their studies, exclusive of observing to precise students' needs (Joyce-Gibbons *et al*., 2018).

Therefore, m-learning assistive technology will be beneficial to visually impair by providing reliability (Dürrenberger *et al*., 2014), improved and accomplished higher rates of education and improved achievement in their studies. Completing academic tasks independently in time, which includes doing examinations without anyone reading the questions for them, including doing tasks they might not or else be able to handle without help, most relevant to a better sense of self-efficacy (Hayhoe, 2014; Matimbwa & Anney, 2016; Mcknight & Davies, 2012; Spiegel & Rodríguez, 2016).

2.5.1 Types of Assistive Technologies Used for Visually Impaired Learners

An extensive choice of software tools supports visually impaired in coming across different learning abilities and styles. Three specific examples of thriving technological supports are Optical Character Recognition (OCR) (for scanning text speech mixture of writing and the vocabulary originates in the majority word-processing programs. These technologies increase text or change the info into noticeable or tactile media.

Synthesis of speech (screen readers or read-back software) is an essential software for screen readers. Synthesis of speech (screen readers or read-back software) is a necessary software for screen readers. Instructors or learners do, on the other hand, need to pre-scan content before they can use it. A screen reading program translates the written text displayed on the computer screen for the voice synthesizer, which afterward reproduces the text as speech. A screen reader reads text as well read back other information that might be there on the screen such as menu options, files, folder name, for example:

(i) Non-Visual Desktop Access which is free software,

(ii) Window Eye and Voice over which is used in Mac computers,

(iii) The HAL screen reader which developed selected for blinds but is not free,

(iv) The CAST EReader can read Internet content, word processing files, text scanned, or text typed in, and enhance that text by adding voice spoke, visual highlighting, document navigation, page navigation, type and speech capabilities.

Optical Character Recognition (OCR) software allows learners to scan reading material into a computer and after that see only the text from the scanned article on the computer screen. It fundamentally separates the text from whichever pictures in the text and converts text information into a text layout.

2.5.2 Smart Device Assistive Technology

Lately, smart devices (smartphones, tablets, PDA, etc.,) provide a prospect for assistive technologies to be delivered to visually impaired (Khaddage *et al*., 2016) to aids mobility (Al-Harrasi & Taha, 2019; Patel, 2019). Smart devices provide a new opportunity for the learner to engage themselves in self-learning (Ashraf *et al*., 2016) at any time anywhere in the field of information technologies and provide portability (Deng *et al*., 2017) universal accessibility to the users. The usage of smart devices has paved the way for a higher learning institution to engage in using m-learning for teaching and learning, and offers portability (Billi *et al*., 2010) and enhance user mobility (Joyce-Gibbons *et al*., 2018). The rise and growth of screen reading software, e.g., TalkBack, VoiceOver, has paved the way for visually impaired to get accessibility to them (Awad *et al*., 2018; Leporini & Palmucci, 2018; Thompson, 2018).

Visually impaired uses mostly normal (standard) mobile devices for communication purposes (Hakobyan *et al*., 2013). With the increase of touchscreen-based devices, it has been difficult for the visually impaired learner to use when it involves graphical content (Heidi & Leslie, 2016; Wong & Tan, 2019). With the limitations of small keypads and connectivity to the internet has led to the usage of touch screen whereby it has discovered the utilization of sensory modalities other than vision like speech recognition (Paeck & Chickering, 2007), haptic (touch-based) feedback (Brewster *et al*., 2007) and non-speech auditory feedback. Also, multimodal input combines different sensory modalities (Hume, 2011) to decrease the need for visual interaction of smart devices (Bateman *et al*., 2018) whereby visual impaired are facing difficulties on the usage without proper knowledge of an application. With the advancement of vibrotactile, text-to-speech (TTS), and gestural recognition systems (Nishihara *et al*., 2017; Rafii *et al*., 2019; Rautaray *et al*., 2015) there is now an opportunity for improved accessibility to smart devices for visually impaired learners. Brewster *et al*. (2007) designed a *sonically-enhanced 2D gesture recognition system* in which a user might draw different shapes in a touchscreen to make commands to such a device but does not fit the requirement for visually impaired learners. Also, these systems were not designed specifically for visually impaired, so they rather avoid using them. Through the increase of mobile technologies (Bhowmick & Hazarika, 2017; Ismaili *et al*., 2019; Spagnol *et al*., 2018), which are integrating touch sensitive screens (Chang & Liu, 2016), there has been increasing research on the accessibility factor for visually impaired. Still, the obstacles with touchscreen devices are the absence of tactile feedback that was used by the physical keys of standard dumbphones.

Nowadays mobile devices provide a way to deliver assistive technologies, i.e., screen readers to touch screen to be used by visually impaired learners and provide mobility help to them but most of VIL lack knowledge on how to use them while learning (Butler *et al*., 2017). The assistive technologies include screen-reading software as shown in Table 1.

Table 1: Smart Devices Assistive Technologies

S/N	Assistive technology	Description	Pros	Limitations
1	Screen reading software	Reads items on theuser's screens and the user's interactions	Easier to use	Focuses on text based entities.
2	Voice Over on iOS and Talkback on Android	Reads icons, text, menus, features, emails and web pages. Also reads auto-corrected and auto-capitalized words before implementation while typing (Yeh & Yang, 2014).	• Free application • Able to read a wide range of items	• Available on iOS devices only, i.e., iPhone, iPad (~23%) worldwide market share in February 2019).
3	Talkback for Android	Screen reader for Android devices. Use speech, vibrations, and other audible feedback to help users know what they are on the screen, what they are touching on the screen and what they can do with it. (Kouroupetroglou, 2014).	• Free application • Tactile feedback	• Focuses on clickable elements • Cannot read books, emails or web pages
4	Braille Input applications E.g. BrailleTouch	Applications that allow users to enter text using the Braille alphabet:	• It is easier to use since it contains Braille	• Used for only Braille alphabet

S/N	Assistive technology	Description	Pros	Limitations
		• Smartphone app for eyes-free text entry using the standard 6- key Braille keyboard to navigate through • It is by 2 binary matrix, which is encoded by 63 characters (Frey *et al.*, 2011).	• Less expensive compared to other Braille keyboard apps • It incorporated with existing mobile touch screen • Allows faster and more efficit entry for visually impaired earners than standard keyboards.	• Costs almost $20 which is expensive for many people in developing countries • No Image description.
5	Mobraile	Allow user to connect the smartphone to the braille display as an output	• Its real-time accessibility for Bus information.	• It needs WI-FI connectivity to operate. • It requires training and • knowledge • It's expensive
6	Audio-book readers e.g audible	Reads audiobooks on iOS and Android	• It provides audio readability	• Limited to audiobooks only • No image description
7	Audio Browsers	User-guided by speech as they browse the screen, Access to web pages, personal documents and audio files. A speech guides user.	• Time-efficient design	• It is in a hierarchical structure and users prefer horizontal structure (Yeh *et al.*, 2014).

Recently, there has been increased usage of mobile devices in Tanzania because it makes accessibility easier in every sector including the education sector, and there is an increased number of mobile phone operator (Tigo, Halotel, Vodacom, Airtel, etc.,) which enable the usage of M- learning possible (Chambo *et al.*, 2013). With the improved utilization of smart devices, the government has made it easier for institutions to engage in design and developing m-learning applications by facilitating the development of ICT tools for teaching and learning (MoEVT, 2007). Higher education institutions have increasingly used we pages and Internet resources with necessary learning materials and online learning (e-learning) still visually impaired learners cannot benefit fully on accessibility (Ahmed *et al*., 2017). Nevertheless, visually impaired learners are facing barriers in using these assistive technologies, namely environment (Okonji & Ogwezzy, 2017), knowledge (Tomlinson, 2016), society perception (Csapó *et al*., 2015), remoteness (Perfect *et al*., 2018) VIL will use assistive technology to interact with other students and learning environments which will enable them in the accessibility of m-learning hence improvement in academic Fig. 4 Different barriers hinder visually impaired learners on the successful and effective use of Assistive Technologies which are available in smart devices for communication and academic purposes such as:

(i) Financial constraints (Ashraf *et al*., 2016).

(ii) High device costs (Kader *et al*., 2016).

(iii) Knowledge, skills and suitability issues in adaption constraints (Dube, 2015),

(iv) Lack of technical and emotional supports among learners (Mahali, 2019; Taouil *et al*., 2018).

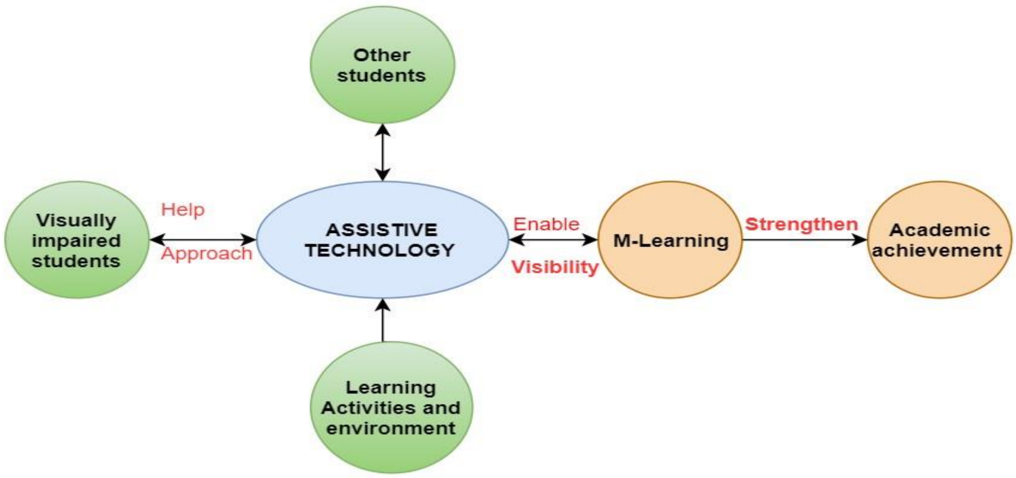

Figure 5: Conceptual Diagram for the Need for Assistive Technology (adapted from Butler *et al*., 2017)

2.6 Barriers and Enablers of M-Learning Adoption among Visually Impaired Students

According to Bhardwaj *et al*. (2017), most learners are reluctant about the usage of smart devices and are not rushing on needs of changes and priorities for as they entirely depend on braille and audio technology for learning purposes. Moreover, lack of information and chance to learn about available assistive technology in smart devices, the inability of AT to describe and read some graphical contents lead to the disuse of smart devices as shown in Fig. 5.

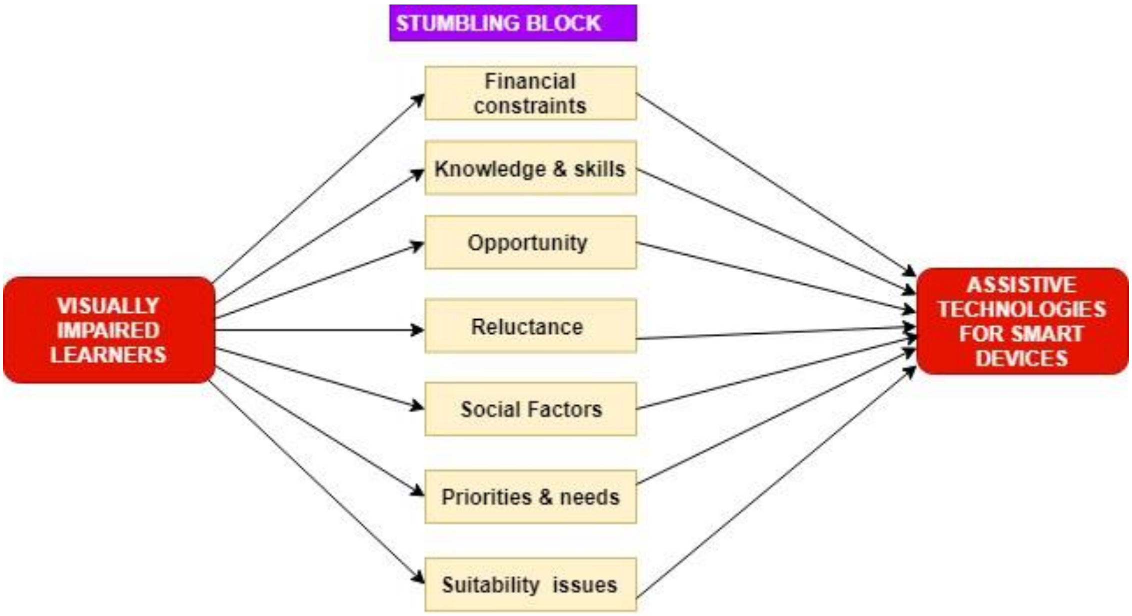

Figure 6: M-learning Adoption Barriers for VIL

2.7 The Concept of M-learning

M-learning technology has developed a different way of learning to cater to knowledge formation and skills expansion for learners in learning institutions. Using m-learning platforms also having specific skills to use smart devices for visually impaired learners will improve academic performance (Akcil, 2017). The extensive range use of mobile devices has fetched abundant chances to develop and design m-learning to be used in the education system. Different authors have a different point of view about m-learning around the world but the common idea based on the fact that it should be available at any time anywhere regardless of location (Heng *et al*., 2016; Wong *et al*., 2019). M-learning is an emerging technology in Tanzania, which will help to support education, especially in Higher Learning Institutions where most of the learners use mobile devices (Chambo *et al*., 2013; Mtebe *et al*., 2016). As mobile devices have increasingly become part of human life around the world as a tool for communication without limit in time and place hence the mobile user can accumulate knowledge on how to use it as a tool for learning.

The purpose of m-learning is designed to facilitate learners through information and resources (Khemaja *et al*., 2016) to improve their learning activities, and offer the opportunity for learners to the digital era and social inclusion (Alghabban *et al*., 2016). It enables the visually impaired learners to engage in self-learning and easier their academic environment (Kim *et al*., 2016). Various apps have been developed and come with phones are contacts, phone, calendars SMS but also in smart devices comes with different cloud servers, i.e., apple apps, Google apps which enable users to download and use them (Dhanalakshmi *et al*., 2014). M-learning provides visually impaired learners with the ability to live an independent academic life and achieve social interaction with other leaners in the platform (Kim *et al*., 2016). Higher learning in Tanzania will be able to develop these M- learning apps from e-learning platforms that they have to enable learners to learn anywhere (Mahenge & Sanga, 2016). Mobile learning can be implemented using cloud computing to allow students devices to perform well while using it for studying.

The primary purpose of m-learning is to make sure that learners can acquire knowledge from centralized resources form their Institutions free of cost except for network provider charges and provide flexible learning (Brown & Haupt, 2018). Others HLI, i.e., the Open University of Tanzania, University of Dar es Salaam Learners pay only tuition fees as regular learners but get advantages to access e-learning contents hence with the availability of m-learning, learners will be able to use it anywhere (Mtebe & Raphael, 2018). M-learning enables learners to learn on any topic of her choice in the learning management system available without interruptions (Mtebe *et al*., 2016). One of the best definitions of m-learning from UNESCO states that "is *the learning whereby learning is not staying in one location while taking advantage of learning opportunities offered in mobile technologies*." m-learning overcomes the problem facing most developing countries in education by providing affordability and mobility to primary low-income earners hence contribute to good quality in education. The essential characteristics of m-learning is mobility, abundant, private and portability, collaborating, immediate information, and blended learning (Abed *et al*., 2019). M-learning features are ubiquitous, portable, private (only one learner in its device) (Moonsamy *et al*., 2018), portability and mobility of devices (Bateman *et al*., 2018), collaborative to the users (Bateman *et al*., 2018). To get maximum efficient output, m-learning has essentials that make it usable, i.e., learners, instructors, learning resources, assessment & results, and the environment where learners get all learning material (Ozdamli & Bicen, 2014). By using m-learning in Tanzania, learners will be able to engage in their learning activities everywhere and improve academic performance. Using different Learning Management Systems available in the Higher Learning Institutions through Moodle, it will be easy to design m-learning to be used by students. In Africa, many apps have been developed for learners to enable them to learn anywhere example SamaSkull (Senegalese m-learning platform by which a learner can get access to a database of unlimited educational contents). EnezaEducation (Kenyan m-learning platform for learning educational materials in Swahili). Obami (is South African platform) which connects learners in their smart devices to a real-life teacher and so much more.

2.7.1 Mobile Learning Management Systems

A learning management system (LMS) is a software used for bringing, tracing, and managing education activities (Bartuskova *et al*., 2015). An extensive diversity learning that can be used to enable both distances, blended and traditional learning process (Mtebe *et al*., 2016). Learning management system is a progressively significant part of educational systems in Higher Learning Institutions in Tanzania and the world at large (Okonji *et al*., 2017) Different learning management systems are adapted from open-source software and customized depending on the needs of specific institutions. Most of existing mobile learning systems have been concentrating on allowing learners to access Learning systems such as Moodle (Ouadoud *et al*., 2016), Atutor (Mariana, 2016), Blackboard (Moonsamy *et al*., 2018), Vula (based on virtual environment) (Latif, 2016) using mobile devices.

Most used LMSs are commercial Blackboard and open-source "*Moodle*". Moodle "*is a learning management system that is intended to help Educators create an online classroom setting with opportunities for rich interaction and association with their students."*(Laabidi, *et al*., 2014). Moodle is an open-source learning platform which allows instructors to share resources through online setting via the internet (Rao, 2016). Moodle has different features depending on the nature of usage for example:

(i) Reading learning materials (lectures, reports, eBooks) which are uploaded by instructors (Mtebe *et al*., 2016).

(ii) Discussions and course concepts (chats, discussion forum) (Deepak, 2017).

(iii) Quizzes (assessments, quiz, test, etc.) (Badea *et al*., 2019).

(iv) Feedback, glossary, survey wiki and workshop (Ban *et al*., 2017).

According to the Moodle site, there have been 107952 registered Moodle sites around 229 countries, but in Tanzania, there are 40 sites where most are Higher Learning Institutions. Twenty were registered as private sites (Buzzi *et al*., 2009). Different institutions of higher education in Tanzania have embraced Moodle and adapted it to their teaching requirements and learning needs; for example University of Dar es Salam, Open University of Tanzania, the State University of Zanzibar, Mzumbe University. Some of them went the extra mile to try to adopt mobile Moodle for their learners to get learning resources in their smart devices regardless of the location as shown in Fig. 6. Nonetheless, these m-learning apps were designed for non-visual impaired learners where there are video, photos without alternative texts and unformatted audio which are challenges for visually impaired learners to understand and get accessibility to them.

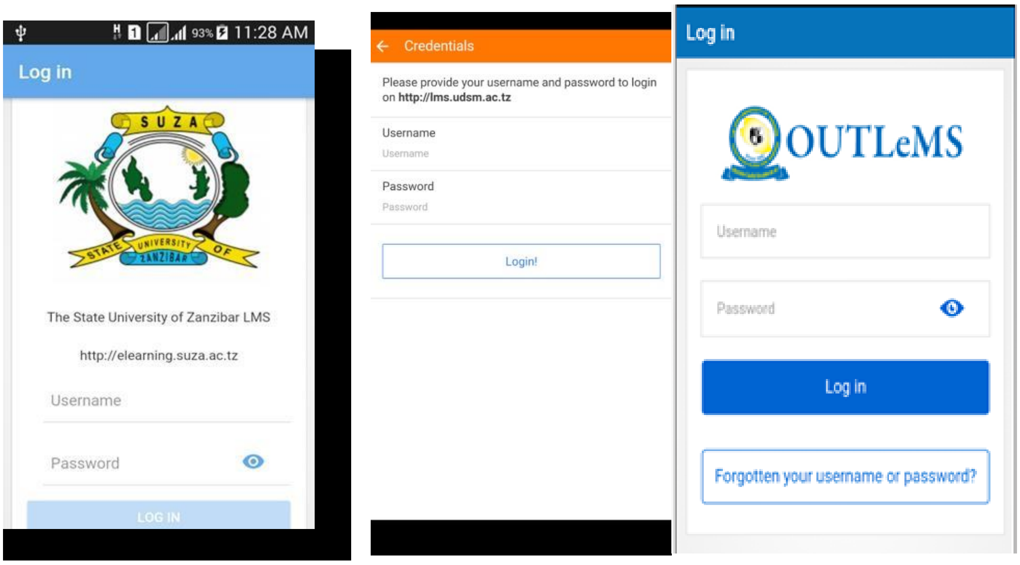

Figure 7: Homepage Interface for Mobile Moodle for HLI

Also, Blackboard learning management system is a commercial learning platform designed in 1997 by two academic advisors in the US with two marketing platforms as the "*Blackboard Commerce Suite and the Blackboard Academic Suite*" (Boshielo, 2014; Mouakket & Bettayeb, 2015). The purpose of the Blackboard Academic suite is to provide teaching and learning experience for learners in learning Institutions around the world with flexibility and mobility to learners (Kapetanakis, 2017; Karplus, 2017). Blackboard defined as *"the comprehensive technology platform for teaching and learning, community building, content management, and division, and measuring learning outcomes and consists of combined modules, with a core set of capabilities that work together."* It incorporates:

- Communication tools, such as notice board, chats and e-mail system (Kabassi *et al*., 2016).
- Graphics, video and audio documents (Fujita *et al*., 2018).
- Delivers learning tools to sustain course resources, for instance, references (Bartuskova *et al*., 2015).
- Dictionary self-test, also test segment.

According to Bradford *et al*. (2007) Blackboard provide learners with advantages of the learning process as it provides secure communication to users, tracking, increasingly reliability where learners can access their academic resources at any time with quick submission of their assessments, as well as it has the capability of giving automatic feedback quickly to the users while using it. Despite its advantages, it has a limitation, which makes it not so popular to the users. For first time users, it is difficult to learn it since most learners are not conversant with said technology especially in Tanzania education system (Tomlinson, 2016).

Likewise, Blackboard is restricted in some operating systems (OSs), e.g., Linus and cost of buying and operation are very higher that's why most Higher Learnings Institutions opt for open source software for customizing their courses (eM Elsawy & Ahmed, 2019). The homepage of blackboard provides information on overall courses and discussion board, which enable the learner to access courses more quickly and allow online interactions between learners and instructors (Liaw, 2008). Presently, the prevalent and used learning management system in Tanzania is Moodle and most Higher Learning Institutions have adopted Moodle since the cost of enacting Blackboard is higher than Moodle (Mtebe *et al.*, 2018). Machado *et al*. (2007) researched user perception of the learning system discovered that learners also preferred Moodle to Blackboard as it is easier to use it and is more effective and efficient in delivering learning content. Both LMS requires that the user be affiliated with learning organizations and have the login details to access instructional content (Rahimi *et al*., 2014).

2.7.2 Visually-Impaired Learners' Accessibility and Usability of M-learning

According to different authors, it is discussed that there are two key characteristics to consider when designing accessibility and usability of m-learning environments for visually impaired learners: that is technological and methodological (Asongu *et al*., 2018; Badani *et al*., 2018; Kaya *et al*., 2019; Ngirwa & Ally, 2018). Both of them are important in gaining a completely accessible online learning setting for VILs. Nevertheless, many assert that most of the learning technologies are not entirely accessible by visually impaired learners since the learning platforms are intended for visual learners (Devaner *et al*., 2016; Fonseca *et al*., 2018).

M-learning should be available to visually impaired learners by using credible assistive technology to keep versatile learning (Maćkowski *et al*., 2018) The movability of smart devices enables learners to be used as educational assisted tools that free the learner from a standard teaching room. Usability plays a vital role when designing m-learning for visually impaired learners as it enables them to engage in the self- learning process. Usability denotes the degree to which a platform is designed to be used by learners to attain an individual goal effectively and efficiently without obstructing learners (Ardito *et al*., 2006). Learners with different hardware and software devices should be able to perform the m-learning activities, perhaps through appropriate customization of accessibility (Chee *et al*., 2016; Zaied *et al*., 2015).

2.8 Cloud Computing for Smart Devices

Cloud computing has currently been a crucial concept in the information technology field that has been used in various industries such as schooling, manufacturing, health, and trade. Different authors (Almajalid, 2017; Dhanalakshmi *et al*., 2014; Pocatilu *et al*., 2010; Rahimi *et al*., 2014), have defined as a pool of computing resources, data centers that are delivered through web infrastructure which is integrated into a big data that is kept in distributed computers and provide services (storage, software, applications, hardware) to the clients. It allows the client to add capacity and infrastructure vigorously instead of buying separate devices. Cloud computing provides fast data processing and reduces lost time and misused spending on buying servers and additional computing devices. Cloud computing plays a crucial role in intelligent education, and its role is to provide resources with a low-cost usage rate. Most of the world's IT businesses such as Google, IBM and Microsoft, Azure and Amazon offer some cloud storage without charging for the education section like hosting e-learning systems and m-learning in the cloud, as to provide good quality of education anywhere when needed (Pocatilu *et al*., 2010). Cloud computing for mobile devices is exciting also actually profitable technology, which permits mobile devices to avoid limitations. Using cloud computing in Higher Learning Institutions has been useful to learners and presentations as it is price-effective and therefore efficient where resources are limitedly utilized. Besides, the viability of IT individuals improves with the use of cloud computing. Some examples of these services which is providing free of charge like mobile Apps calendars, emails, storage (Google Drive, Dropbox, Microsoft one Drive) contact, website creation services, as well as document-sharing services in smart devices (Almajalid, 2017).

The cloud computing offers several services based on the need of the customers such as Infrastructure as a service (IaaS), Software as a service (SaaS) and Platforms as a service (PaaS) depending on the needs (Almajalid, 2017; Lin *et al*., 2017) as shown in Fig. 6. The Infrastructure as a service offers storage and resources of computing, and it is in the bottom layer of physical devices. It is in charge of running applications such as operating systems, operation client devices, but it cannot manage cloud infrastructures. Characteristics include internet connectivity, dynamic scaling, and administrative tasks, which are automatic and virtualization; hence, the total cost of ownership is low (Abdul *et al*., 2013; Bigham *et al*., 2017). The SaaS makes sure that users can use different applications that run cloud infrastructure but not control the operating system. Additionally, its accessibility of applications to the user is intact, including web conferencing, ERP, i.e., emails among users. Its characteristics include security, rapid scalability, universal accessibility, and reliability. Some of the providers include Google, NetSuite, Amazon WebServices and Blackbaud (Liu *et al*., 2017; Majadi, 2012).

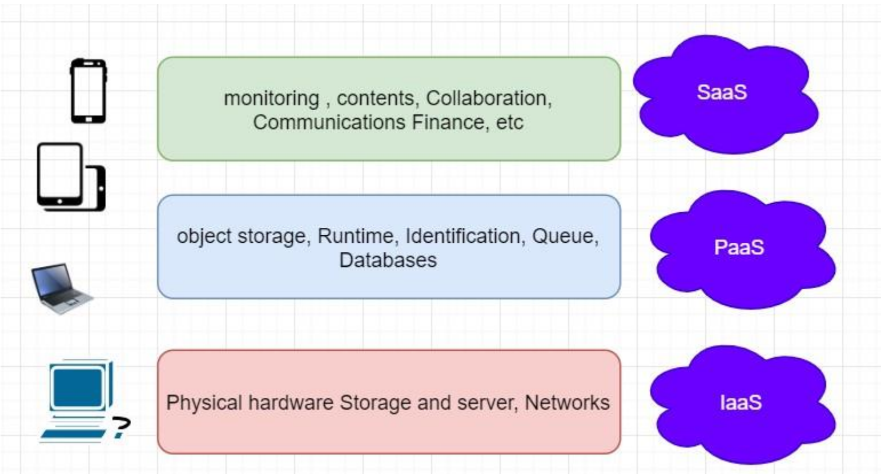

Figure 8: Cloud Computing Logical Diagram

The PaaS enables users to hire virtual servers and other services that are used as software as a service, which requires the operation of other services (Mwakisole *et al*., 2018). It gives users to control other applications without altering hardware or operating system and network topology. Its characteristics include condensed risk, secure distribution, and lack of software upgrades. An example is Google Apps, Microsoft Azure, iClouds Amazon etc.

Cloud computing is accepted due to its lower cost of operations, and in some parts, is free (Mwakisole *et al*., 2018). Google has been a significant player in promoting clouding computing with the provision of G-suite and is accessed through Google Apps. The usage of clouding computing is not only for computers and servers, but it can be used in mobile devices and terminals. On increased usage of mobile internet in education, cloud computing services enable mobile users to obtain infrastructure and platforms to use (Huang & Yin, 2012). The customer can get on-demand facilities, platforms, applications and other IT infrastructure products in the mobile cloud computing model. Cloud computing can provide substantial assistance for mobile learning systems by evaluating the characteristics of mobile learning, as all codes and records can be stored inside it (No & Reddy, 2013).

An emerging mobile learning platform created on cloud computing is more critical and connotation, hence codes and course materials will be stored in the cloud. The learner can get updated, instantaneous and explicit learning materials in the platform and collaborative learning between learners and teachers will be supported. The platform for mobile learning based on the cloud have characteristics such as delivering actual consumption of learning contents and use of it on-demand, it supports various applications that can be stored in the cloud for later use hence provides storage capabilities. Requests and processing are completed in the cloud.

2.9 Research Gaps

Heidi *et al*. (2016) explained the experience of visually impaired in higher learning and their problems they are facing in higher learning environment including familiarity and locality of classes. Also, Maćkowski *et al*. (2018), presents the available collaborating tutoring platform for math teaching and assessment, and experience in exploring in mobile learning . The results of said research confirm good understanding of math formulae described according to elaborated rules. Regardless of the level of complexity of the math formulae the level of math formulae understanding is higher for different structural explanation. For students who are visually impaired, math and pictorial thoughts have a unique challenge due to the visual nature of data embedded in graphs, charts, tables and plots and Bateman *et al*. (2018) developed electrostatic touch screen for visually impaired that provide information of mathematical concept by adapting user-centered design. Usage of smart device can compensate the challenge of lack of good infrastructures, locality and user dependency on others while studying (Joyce-Gibbons *et al*., 2018), hence Wong (2019) explained the benefit of mobile learning platforms using iPhone where by it provide consistency and efficiency of Visually impaired learners.

Despite encouraged efforts in some areas but there remains a lack of evaluated m-learning platforms for visually impaired learners in Tanzania and they lagging behind the technology itself and HLI had these platforms for visual leaners and created digital divide in Tanzania. Also Few studies conducted involves accessibility of m-learning for visual impaired there is no graphical description on other assistive technology used by Visual impaired (Yeh *et al*., 2014), and lack of integrating assistive technology model in smart devices for leaning purposes in Tanzania (Mtebe *et al*., 2018). Hence the study aims to design assistive technology that will reduce all the gaps.

2.10 Conclusion

This research aims at a mobile application that emulates a more significant m-learning scheme that reciprocates the process to users with visual impairment. By doing this, different m-learning stakeholders will be able to use assistive technology to get accessibility of m-learning through their smart devices, by browsing and storing learning contents and extract pictorial information in the document to get instant response on the text description of the particular image through a speech synthesizer.

On the process, learning, a VIL can download learning contents and be able to store it in the cloud to be used when offline. Also, the system will use an algorithm to identify the location and image a page and extract it with no alternative text in the document, and compare it with the dataset available in the Google cloud and give a textual description of the image provided while continuing reading through passage. Through reading and navigating on learning contents, all alternative text from the document shall be captured and used to create markers for all pictorials to avoid repetitive text descriptions. The user will be able to store learning materials in the cloud and use it later without connection to m-learning platforms. Cloud computing will be used as a base for the platform as the user uses the assistive technology for learning and will enable the user to integrate LMS contents in the platforms. The user will send an access request to the LMS as students with login credentials of his/ her HLI, which later the AT platform will navigate through and be able to read and browse the contents

CHAPTER THREE

MATERIALS AND METHODS

3.1 Stakeholders for Assistive Technology

This chapter presents the methodologies of the study, including the study participants and sampling procedures, study area, research design, target population, data collection tools and procedures and data analysis. The resulting assistive technology prototype that was designed and developed is then presented.

The study was conducted with four groups of stakeholders/actors who would benefit from the design of assistive technology. The first group was Higher Learning Institutions (HLIs), which are generally owners of learning systems for pedagogy purposes (m-learning and e-learning) and its where VILs were enrolled. The second group was visually impaired learners (VILs) in HLIs, as they are the target users of the technology and who were more vulnerable on the accessibility of learning contents. The third and fourth groups were the Ministry of Education and Vocational Training and the Tanzania Association of Blinds who are the policymakers and the organization responsible for the welfare of visually impaired persons in Tanzania, respectively shown in Fig. 9.

According to Noble *et al*. (2015) for the external validity of the research, the sample should be as large as possible liable on time for the study and its mission. We used a convenience non-probability sampling method because of the nature and availability of VIL who were scattered in different HLIs and regions. Out of a total population of 253 in Tanzanian HLIs, 33 participated in the study. Twenty-two participants 22 (66.7%) were male and 11 (33.3%) were female.

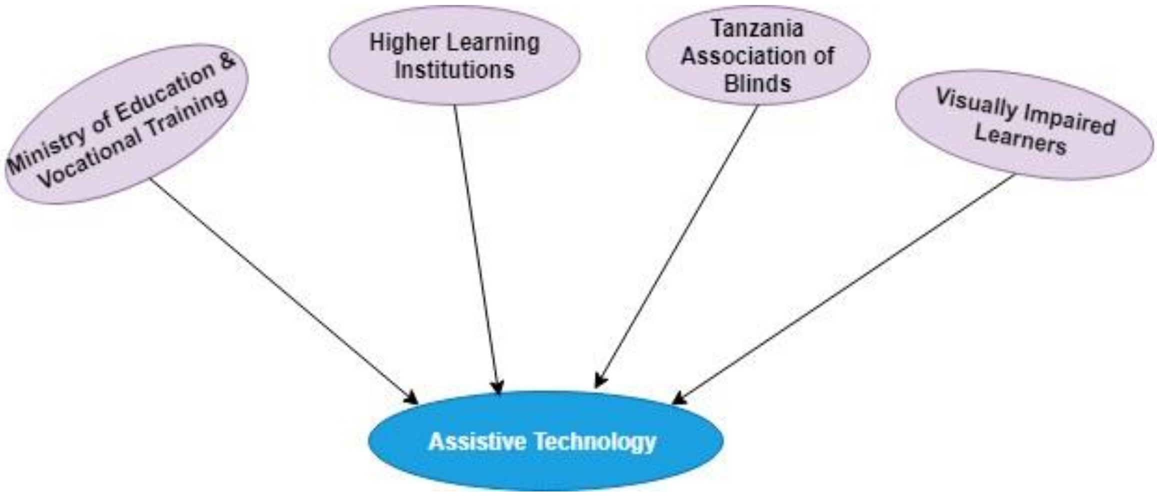

Figure 9: Groups of Assistive Technology Stakeholders

3.2 Research Design

The implemented research design was a descriptive survey. The objective of descriptive research was to observe, describe and document aspects of the situation as it naturally occurs (Kothari, 2004). With a detailed study, the conditions already existed and the researcher picked the essential variables for the breakdown of the relationships. Descriptive research is concerned with the requirements or relationships that exist such as determining the nature of prevailing conditions, practices and attitudes; opinions that are held; processes that are ongoing and trends that are developed. Quantitative dependence research variable were employed to determine on the level of awareness challenges and skills facing VILs in Higher Learning Institutions also their demographical features and course of study (Mishra *et al*., 2010).

The research was conducted in Tanzania's Dar es Salaam and Dodoma regions since a significant number of visually impaired learners are enrolled each year in these two areas. Data were assembled from the University of Dar es Salaam (UDSM), the Open University of Tanzania (OUT), the University of Dodoma (UDOM) and the College of Education (DUCE) at Dar es Salaam University, which all use e-learning platforms and supporting M-learning.

3.3 Participants

The participants were selected based on their disability, i.e., visually impaired. The participants were chosen based on the willingness to participate in the questionnaire, answering without disturbing their academic timetable. Before the interview, the researcher was granted consent from universities where the participants are studying.

3.4 Data Collection Tools

Data collection methods empower the researcher to methodically assemble data about the goals of the study (VILs) and their needs for it. The data collection instruments in this research comprised self-completion semi-structured questionnaires prepared to assist the researcher in meeting the study's objectives (Mukhopadhyay & Mandal, 2019). The semi-structured format questions were designed and accompanied by appropriate lists of options from which respondents selected the answer that best described the situation. These allowed the addition of closed-ended question items, which helped in answering open-ended questions (Fisher *et al*., 2016). Nevertheless, few open question items or options used to grasp on what extent visually impaired are facing challenges in accessing m-learning platforms using smart devices. Also focus group and interview were used to get the grasp of what are the user's requirements. To guarantee the validity of the study, the instruments were reviewed to make sure that the data collected have a meaningful end. It assisted in the examination of the content and the degree to which the tools gathered the intended information. This improved the content validity of the instruments.

3.4.1 The questionnaire, Interview and Focus Group Discussion Design

The questionnaires were used to collect data on the challenges and adoption of m-learning and using assistive technologies and how it catered for the VILs. The questionnaire was divided into two parts: The first part was used to fill a demographic survey and educational background, knowledge of M-learning, and usage of any assistive technology on mobile devices. The following part asked the following questions: Does your university have an m-learning platform? Do you know any m-learning platform in Tanzania? How do you participate in online learning using smart devices? Answers were recorded on the form.

After the relevant authorities permitted the research, the researcher personally visited the respective Higher Learning Institutions and administered the questionnaires and conducted the interviews using the confirmed tools. Questionnaires tool to the visually impaired were taken to the source center to be converted into Braille and subsequently distributed to them.
Semi-structured interview schedules (personal interviews) were developed for students from different Departments (Education, Sociology, ICT, etc.) who were involved in the study. The semi-structured interviews were used to ask to follow up questions about the challenges of using smart devices for learning purposes. Focus group discussions were also conducted

to gain an in-depth discussion and consensus on how the challenges should be addressed.

Focus Group Discussion may be a conversation of a gathering of individuals guided by a facilitator, or mediator, during which a group of 3/4 VILs talks unreservedly and precipitously a couple of specific points fixed earlier when it was difficult to be addressed during interview and questionnaire session. Focus Group Discussion were based on how the user requirements of the system will be formed and enable the researcher to understand the severity of the problem VILs are facing in HLIs learning environment.

3.4.2 Reliability and Validity of the Research

Efficacy is understood as the extent that a study calculates and knows what it intends to examine (Kumar, 2019). There are two known kinds of validity, which are external and internal. So, external validity is the ability to oversimplify the findings to the needed population while internal validity denotes the validity of the measurement and test itself. Together they possess an essential role in the analysis of the suitability, significance and practicality of research activity.

Moreover, in this context, the research fixated on the internal validity and not on the external validity since the focus is on providing solutions to the challenge facing visually impaired by designing Assistive technology necessary to access m-learning available in HLI. The following were the explanations concerning different ways of achieving validity in a research methodology:

(i) **Reliability**: This is the constancy and availability of the data used. Method of accomplishing this is to overlap needed methods and to make sure that the research has correctly provided and clarified them on features and scopes of research methodology used in examining assistive technology available (Fisher *et al*., 2016).

(ii) **Transferability**: The objectives of the study are based on contextual features. Generally, global research is not to produce actuality reports that can be widespread by others, other than to design descriptive, relevant to the context statements based on the data collected (Kothari, 2004).

(iii) **Integrity**: This stresses on the researcher's capability to justify all of the complications that arise during research study and to work with patterns that are difficult to understand. These include methods used to deal with respondents who are not willing to participate in the study, analysis and interpretation of data that provide a way to verify the credibility of data collected (Noble & Smith, 2015).

3.4.3 Data Analysis

Datasets were categorized based on traits and variables. Those classes of data were coded and then given meaningful descriptions. Data obtained from questionnaires was changed from braille format prearranged, corrected and presented. Pre-arrangement includes checking the information collected for precision, practicality also wholeness (Mihas, 2019). Then the prearranged data was organized in such a way that excel was used to record them in computable ways that simplified data tabulation.

R software was used for data analysis (Silverman, 2018). It is a computerized language software which is used for statistical data calculations, data study and graphical data depiction. It enables researcher to cleanse all complex data available, provide interaction's with other databases since was collected in google forms. Also, data from focus group discussion were analyzed by using Constant classical analysis tool where by researcher use this tool to determine specific words which fits user needs with given qualitative data. This tool is good because it is reliable and it tracks systematic measures to be simulated also it can be cover words, images etc. as source of data.

Frequency distributions, percentages and cross-tabulations were used to determine the level of awareness, knowledge and usage of M-learning. Charts, either histograms, pie charts, or bar charts were then plotted to properly visualize the distribution of answers. Data from open-ended survey questions, interviews and focus groups were independently coded using open coding on Excel. The focus during coding was on challenges faced and features suggested of specification of assistive technology, which would help them to reach their goals.

3.5 System Design

This part responds to the fourth part of the question on *How can a low-cost Assistive Technology prototype be developed to be integrated with cloud computing?* Mainly, Naik (2008) explained that usability is the degree whereby a system can be used by stated users to attain specified objectives stated. The designed system should give VILs satisfaction on its usage without any problem and should be as simple as it. Since people have different mental abilities, designing a working system is likely by putting the needs of the user first during the development stage; that is named as a user-centered project (Coleman *et al*., 2016; Galer *et al*., 2016).

Mainly, accessibility is the best quality of usability, as it is impossible to make product work if it remains inaccessible. Additional conditions from ISO standards are; competence, efficacy, natural learning, error lenience and approval from intended users (Bevan *et al*., 2016). For example, User experience denotes overall experience rise when the user uses the product, system, or environment. User experience can be changed by prospects, mental and physical state, setting where the system operates and features of the collaborative platform (Ghali *et al*., 2012; Hassan & Galal-Edeen, 2017). Figure 10 answers some inquiries asked and approaches used to develop an accessible platform.

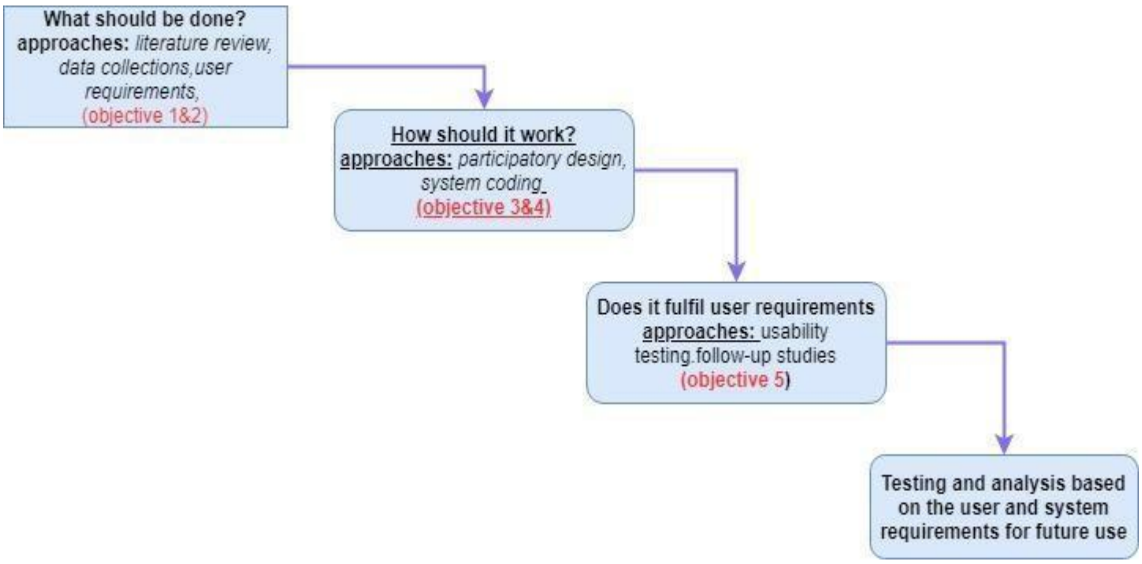

Figure 10: Questions and Approaches for Accessible AT Platform

3.5.1 First Question: What Should be Done?

In clearly, understanding the specifications and functionalities offered by the assistive technology m-learning system can be beneficial to VILs. The following methods have been implemented, including literature assessment, information collection, user requirements as well as a system requirements specification.

Through interviews and questionnaires process, VILs and system administrators from four Higher Learning Institutions acknowledged and engaged in information collection. Interviews were conducted in HLI System Administrators who manage Learning management platforms, questionnaires and observations were used for the visually impaired Learners who are studying different courses in HLIs. Additional understanding the users (VILs) platform aids, the need for Assistive technology were considered during the early stage of system development and how the user will be able to interact with the mobile platform in their smart devices (Bhardwaj & Kumar, 2017).

For Assistive technology, two categories have been designed where one of them is VIL who use learning platforms for learning purposes and one for the HLIs who provide learning resources to the students. Based on the user inquiry, system requirements were defined after that (dos Santos Soares & Vrancken, 2008).

Accordingly, user requirements were used as a manner to take particular system requirements that target users anticipated. The critical determination is to make the software product more usable (Camburn *et al*., 2017; Devadiga, 2017). To ensure that the system was constructed based on the requirements of the customers; user stories are essential to the prototype design. Since they create a communication link between system users and the development side of software, they also assist in identifying system functionalities based on the demands of the user (Courage & Baxter, 2005).

3.5.2 The Second Question: How Should It Work?

Approaches used to respond to this investigation include brainstorming & participatory strategy and system coding of VIL's AT platform. Brainstorming involves thinking beyond a realistic solution as it involves users from a group of special needs. For AT, adding a pictorial description to the applications will boost the system's user interest and device storage capacity.

Then, the participatory approach, wireframes were developed to connect the information flow in the system. Users and developers were working closely together to come up with the required prototype based on the user’s needs. The coding of the m-learning AT system is used with JSP (Java Server Page) and TomCat 7 for server-side applications and used Android studio for mobile apps. The database coded by MySQL and for pictorial description designed by Vision Google AI interfaced with Android studio. The decision on which database language and tool to use on the data model, according to Bjorklund (2018) data model is the logical inter-relations tool for describing data flow between entities and, relationships, semantics and consistency restriction while ensuring the excellent quality of data is obtained. Diverse authors (Bjorklund, 2018; Merino *et al*., 2016; Xiong *et al*., 2015) labeled various data models as; network, hierarchical, object-based, semi-structured and relational data models. By exclusion to the relational data model, other models have complications in upholding associations between data they store, problems in the modification of the databases and their unusualness in database sector which turn out to be tricky in their acceptance, development, and upkeep in future. The relational data model uses tables (relations) to keep and accomplish data interpretations and their behaviors. MySQL is an unrestricted relational database tool with recognized performance, consistency and can be used easily. Hence, it promotes relationship among data kept in the database, which aids in overwhelming laying-off (Győrödi *et al*., 2015).

3.5.3 Question Three: Does it Fulfill User Requirements?

The developed m-learning Assistive technology system was evaluated based on all data, goals and objectives set in achieving it in this research. Chosen methods in answering these questions involved system usability and user follow-up tests adapted from (Bartolotta *et al*., 2017).

3.5.4 Assistive Technology System Presumption and Needs

The following are the assumptions that were made when designing, developing, and technology choice of m-learning Assistive technology system. The system consists of two primary components, such as Text & Navigation and Image Descriptors, which are then clarified based on the system part. For the mobile platform implementation section:

(i) Visually-impaired learners have access to a smart device for learning and communication purposes.

(ii) All visually impaired learners who use a learning management system knows the contents of their courses.

(iii) All the application's smart host devices can provide access to the learning management system in their HLI.

(iv) There is a regular update of learning resources whenever HLI decides to change the course contents.

(v) The application is hosted on a server (to save documents for future use) that is accessible even when there are no internet connections to enable VIL users to learn at any time and anywhere.

3.6 M-learning Assistive Technology System Testing and Validation Methods

This section answers to the third study question, which states that "How is it possible to validate the built prototype based on its design requirements? Intentionally, the system is tested or validated to increase its value by acknowledging and operating on painful points and endorsements from various system user respondents (Deng *et al.*, 2017; Zein *et al.*, 2016). Test involves different methods in system validation for instance validation through simulation of the system, another way of usability test, what happens when the user is given the system/ application and tries to use it and see if there are problems arises during testing and measure its performance. Along with the validation and analysis of the concerned system by which participants who evaluated the system and provided feedback to the system developers and enable them to correct and make the system work better.

Still, the study focuses on usability testing for the authentication of the developed mobile applications systems. The purpose of selecting this usability test that, it tended to see on the user requirements and recognize the system problems when VIL uses it and provided feedback to work on, as explained in Fig. 10. There are different types of usability tests, which at the end will make the developer come up with a sound product/system. There is a usability test based on experts that evaluate the product and make recommendations also test that involves product/ system user who uses the product and sees if it is working based on the user requirements.

In testing the m-learning Assistive Technology, their criteria which involve using users (VIL) to check and see which faults and glitch needed to be rectified. VILs were given the smart devices installed an APK for Assistive technology and were asked to browse through the system and text were read and images were described into audio format. Due to the knowledge and skills capability of using smart devices, the research had to train VIL first before going for the usability test. Different phases of the usability test plan were involved in achieving this objective as described in Fig. 11 as the preliminary test and final testing stages. The endorsements and experimental glitches as of initial analysis used as means for enhancement of the system in the second testing stage.

After testing, the recommendation on the problems arises was used as a model for improving the required system. The guide from testing adapted from Rubin *et al*. (2018), whereby a minimum of five visually impaired users was selected since a large number of stakeholders for system testing and evaluation does not guarantee that there will be no errors. It involved actual users (Visually impaired Learners from HLI) selected to test for accessibility and usability of the system. Usability test through the usage of questionaries and observation during testing was used as reporting tools for data analysis. Traditional user satisfaction metrics have been used in making sure that data that was gathered during evaluation in observing user interface elements, navigations and speech quality. Also using areas of interest (text, audio picture) and knowledgeability of smart devices are followed during testing

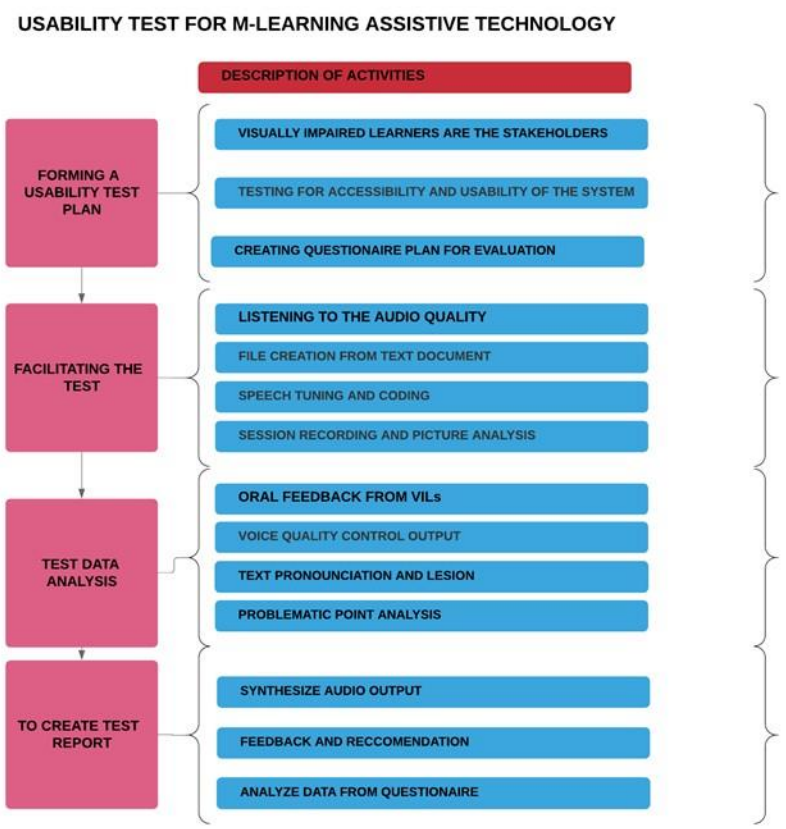

Figure 11: Usability Test Plan for m-learning Assistive Technology

3.6.1 Initial Testing of the System

The initial experiment of m-learning Assistive Technology involved VILs from the Open University of Tanzania, Dar es Salaam Regional. The evaluation was done using Techno Camon smart device installed on the android version 9.0 application. Initially, they were given pre-training knowledge and skills on the usage of smart devices. According to García-Peñalvo *et al*. (2018) the usability, scale test should be not less than 68% regardless of the user problems encountered, hence comments and feedbacks were collected so that the system can be redesigned to make it accessible to the stakeholders.

3.6.2 Approach Used

The primary purpose of the preliminary test was to see what errors are and glitches observed, and user comments and feedback raised during testing and enabled the developer to redesign the system. The system usability scale questionnaire was composed based on negative and positive metric questions. With each user, rating varies between one (1) for Strongly Disagree to five (5) for Strongly Agree on the magnitude of 5 Likert scales. The questionnaire was based on the negative and positive scale to balance the range of usability of the system. To compute, in each of the odd-numbered poll it was subtracted one from its original score and an individual even-numbered questionnaire, it was also subtracted its value from 5 at the end the rating where a total of all total ten questions was multiplied by 2.5 as shown in the equation below:

$$F(x) = 2.5 \times \left\{(Y_{(2x-1)} - 1) + (5 - Y_{(2x)})\right\}$$

Whereby:
F(x): System Usability Test Score
Y (2x-1): Sum of all score in odd-numbered poll.
Y (2x): Sum of all score from even-numbered poll (Lewis, 2018).

The thorough testing was based on the two vital requirements, a more accessible user interface, audio output quality parameter. After initial training on the usage and accessibility navigation in smart devices, participants are expected to learn how to navigate through the application and Login to request authentication to his/her HLI, and if she/he doesn’t have Login credentials the user will be able to navigate through learning materials available in the system web server. Browsing and opening documents available expected to be done in 10 minutes, reading through while synthesizing with audio output in 8 minutes. Participants were expected to be able to download and save learning contents for future use Also, participants required to go through voice features to quantify the pronunciation, to nation and sound quality for audio output parameters for 5 minutes. After testing and evaluation for the application, participants are required to answer user.

3.7 Ethical Consideration

Through data collection the researcher considered on ethical of the respondent whereby there was no participant's psychological, social and financial harm. Also, the researcher behaved according to the proper ethical standards and considered how this research may affect VILs as were grouped as sensitive participants. However, the researcher has to acquire the concert from all HLIs to have VILs participates in data collection.

3.8 Conclusion

This chapter shows the methods used in answering the research questions in chapter one as a building block for designing and developing an enhanced m-learning Assistive Technology to be used by visually impaired learners in Higher Learning Institutions. First section show method used to examine challenges facing visually impaired learners in the usage of M-learning, second part the designing user and system functional and non-functional requirements needed to develop a system. Thirdly, methods and parameters used to design and develop the Assistive technology using Android Studio 8.0; design parameters include user case diagram, dataflow, relational entity diagram and system block diagram for the required system. Lastly methods on how to test and validate the prototype that was done using Usability test by and follow-up observation. Hence, the methodology explained in this chapter produces the results discussed in Chapter 4.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results from Data Collection

This section presents the findings on challenges that visually impaired learners (VILs) face in Higher Learning Institutions (HLIs) in accessing m-learning platforms and content, the design requirements for an assistive tool to support reading of visual elements such as graphs and tables and the end-user validation results. A discussion on the implications of these results and recommendations for future work are then given.

4.2 Challenges of Accessing M-learning for VILs in Tanzania

4.2.1 Respondents' Demographics

A total of 50 questionnaires were sent out and 33 responses were returned. Of the 33 respondents (VILs), 22 (66.7%) were male and 11 (33.3%) were female. Fifteen (45.5%) of the VILs were aged between 20 and 29 years while 18 VILs (54.5%) were over 30 years of age. Also, 31 participants (93.9%) had full blindness while 2 participants were partially blind. The over-30 age group VILs were employed in public service jobs.

4.2.2 Respondents' Course of Study

Twenty-one VILs (63.6%) were enrolled in undergraduate studies in Sociology (n=5, 23.8%), Education (n=10, 47.6%) and Law (n=6, 28.6%). The remaining 12 (36.4%) VILs were enrolled in postgraduate degrees with 5 (41.7%) pursuing Master's in Education and 7 (58.3%) pursuing PhD in Education.

Respondents reported that the nature of their courses required a large amount of time spent in self-reading and that the reading material frequently included diagrams, tables and charts. Figure 12 shows the courses that the VILs were enrolled in.

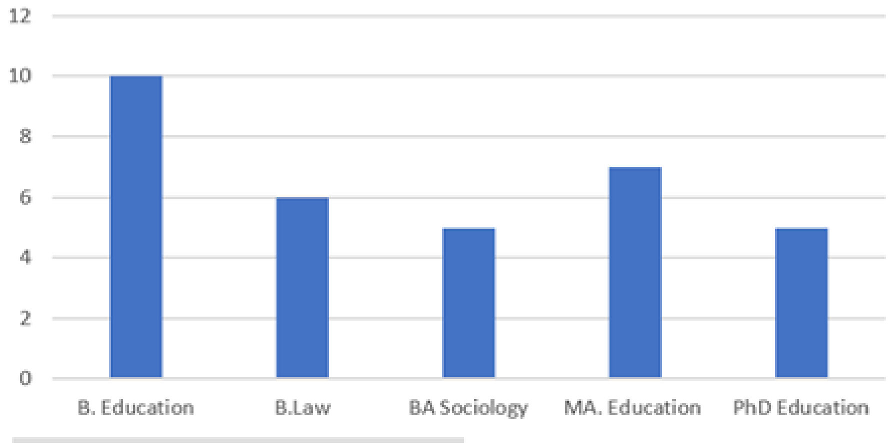

Figure 12: The Courses that the VILs were Enrolled in

4.2.3 Mobile Devises Owned and Usage

Eighteen (54.5%) VILs reported owning a smartphone while 13 (39.4%) owned a standard phone and the other 2 VIL were not sure if they have or not because they always use phones which are shared by their siblings at home.

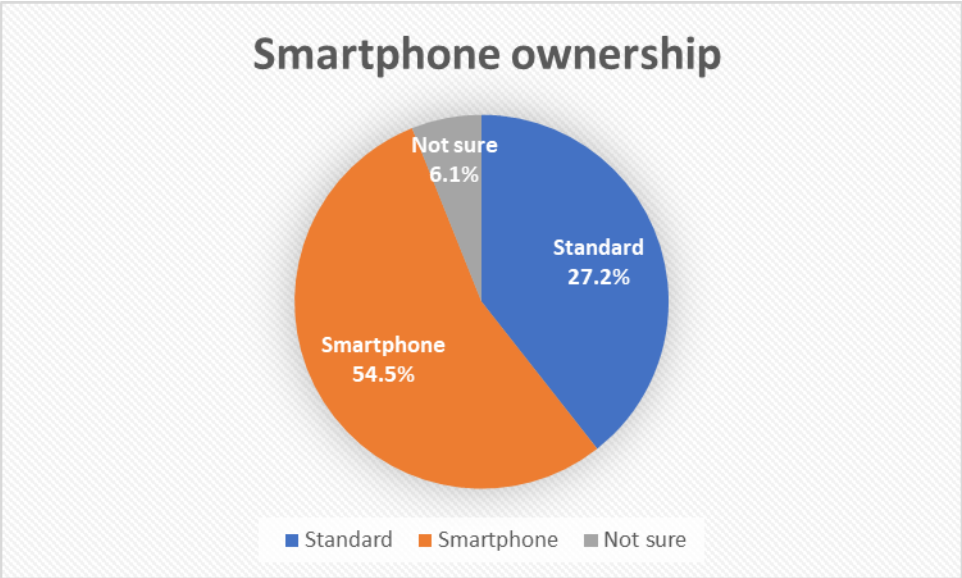

Figure 13: Mobile Devices Owned

Fifteen of the smartphones were usually connected to the Internet, 2 were sometimes connected and 1 was not connected. Apart from the respondent who did not connect to the internet, the rest of the smartphone owners used their devices for making calls and texting, downloading and reading documents and for browsing social media.

The number of years that the VILs had owned their smartphones varied. Four (22.2%) had owned smartphones for less than a year; 5 (27.8%) for 1 to 3 years; 4 (22.2%) for 4 to 6 years and 3 (16.7%) for more than 6 years. Two respondents did not indicate how long they had owned smartphones. Only 1 of the standard phone owners reported sometimes connecting to the Internet while the remaining 12 did not use Internet services on their phones because it was not necessary for them. All 13 standard phone owners only used their devices for making calls and texting.

Slightly more than half of VILs either always (n=13, 39.4%) or sometimes (n=5,15.2%) had their phones with them. Seven (21.2%) infrequently had their phone and 8 (24.2%) did not know how often they had their phones. The most common places the phones were used were at home and university campuses (n=17, 51.5%) or home (n=13, 39.4%). VILs also reported using their phones only at home and at work (n=1, 0.1%) or only at university (n=2, 0.1%). Self-consciousness while using the phones in the company was a concern for the majority of respondents. Six (18.2%) VILs felt very self-conscious, with half of them being amongst those who only used their phones at home, and 12 (36.4%) felt somewhat self-conscious. Out of the 11, 9 used their phones both at home and at university or work. The remaining VILs were either unsure about how they felt (n=8, 24.2%), did not feel self-conscious at all (n=6, 18.2%), or did not respond to the question (n=1, 0.1%).

In addition to phones, several VILs reported owning other mobile devices. Twenty (60.6%) respondents owned a laptop in addition to a phone. Of these, 2 also owned a tablet and 1 also owned a PDA. One respondent owned only a tablet in addition to their mobile phone.

4.2.4 Knowledge and Use of m-learning

Only 9 (27.2%) VILs had heard of m-learning while the majority (n=22, 66.7%) had never heard of m-learning and 2 (6.06%) answered maybe because they were not sure if what they heard is real m-learning or online learning. Those who reported never having heard of m-learning mostly used Braille-based learning content, which was given in hardcopy format. Those who did know m-learning had learned of it through various means:

(i) 3 learned of it due to their universities having a learning management system that was also mobile-based example OUT LMS which was introduced by OUT during first-year orientation week.

(ii) 2 saw the description on the Internet

(iii) 1 learned of it from a university colleague

(iv) 1 saw m-learning applications used in other colleges

(v) 1 through seeing m-learning phone apps

(vi) 1 participated in testing an m-learning application that was developed

(vii) 1 saw m-learning at their working place

(viii) 1 saw m-learning in use while attending training for secondary school students

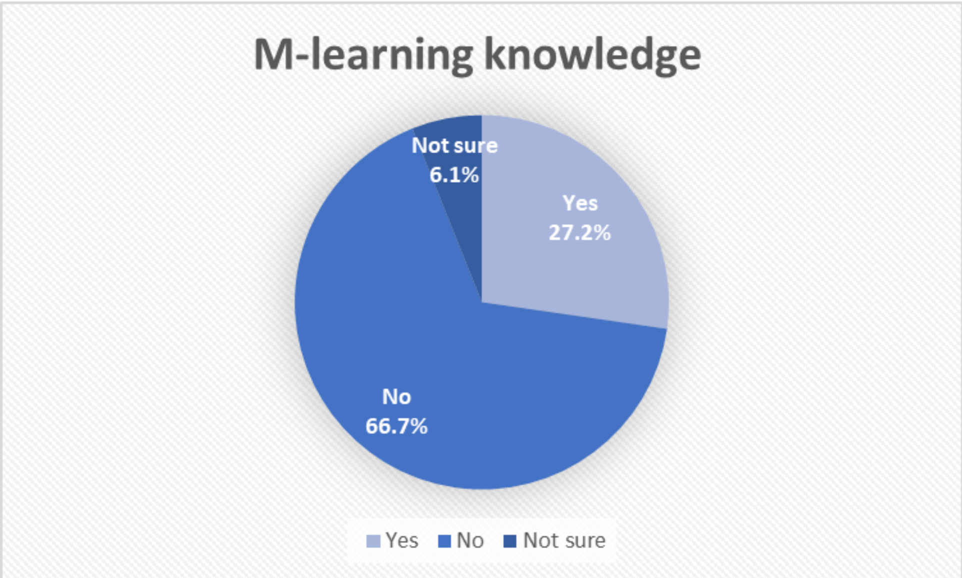

Figure 14: M-learning Knowledge by VILs

When it comes to the actual usage of different types of m-learning i.e. Using mobile devices to search for and read learning materials (self-learning) online, or Using online learning platforms or applications on mobile devices to download and consume instructor-provided content (instructor-led learning) or Using mobile devices for engaging with instructors and/or other students (communication), 2 did not respond while 16 (48.5%) reported not engaging in any form, with the main reason being not owning a smartphone (8 of 16 respondents). Of the remaining 8 respondents, 2 did not use the Internet.

The type of m-learning engaged in by the remaining 15 VILs and the means they use to access m-learning are outlined in Table 2.

Table 2: Types of m-learning VILs Engaged In and Devices Used

S/N	Types of m-learning Engaged In			Devices Used			
	Self-learning	**Instructor-led**	**Communication**	**Standard phone**	**Smartphone**	**Tablet/ E-reader**	**Laptop**
1	√					√	
2			√	√			
3		√			√		
4		√			√	√	
5		√			√		
6		√					√
7		√			√		
8	√				√		
9	√				√		
10		√			√		
11	√				√		
12		√			√		
13	√				√		
14			√		√		
15			√	√			

Overall, m-learning was almost evenly split between self-learning and accessing instructor-led content (n=5 vs n=7 respectively) either via online learning management systems or via documents provided in softcopies and smartphones were the primary device used to access this content (n=11, 73.3%). The most commonly used assistive technologies by smartphone owners were text-to-speech translators or screen readers (n=13, 72.2%). Only 2 VILs (11.1%) used Braille software.

4.2.5 Description of Challenges Met and Workarounds Used When Using m-learning

The VILs reported facing 8 main challenges when trying to engage in m-learning or when using mobile devices in general.

(i) Inability to Read Certain Contents and Navigation Commands

The most prominent difficulty faced was the inaccessibility of certain types of content namely charts, graphs, tables, maps, forms, equations/formulas. For the VILs who owned standard phones, the inaccessibility was mainly because their phones could not open such files while for the smartphone owners, inaccessibility was a result of the text-to-speech and screen reader applications not being able to properly read the content. Also, some VILs were asking other learners to describe them what is written in the tables, graphs also if there was an image, so the description was written manually in their braille machine.

Reading tables using screen readers requires more advanced experience than reading simple text (Badia *et al.*, 2019). Without table reading mode enabled, the applications typically read the caption, the number of rows and columns, column headings and the individual cell entries in a sequential format. In table reader mode, on the other hand, table navigation tools are displayed for the user to access a specific row and column and get the value in that position. Of the 13 text-to-speech and screen reading application users, only 2 (15.4%) used table reading mode. Despite this, they still faced challenges in accessing tabular information as: The tables were not structured following guidelines for accessible tables e.g. not using merged cells and they found it difficult to see and manipulate the navigation commands themselves. The remaining VILs remarked that the way tables were ready-made it difficult to grasp information as:

- It requires the listener (VIL) to either write or memorize all the column headings.
- Use a lot of mental effort to keep track of individual values to determine what row and column they possibly belong to.

Guidelines for making charts, graphs and maps accessible suggest providing a textual description of the chart e.g. explaining trends shown in a line graph or repeating data in charts in tables. Equations should be rendered using markup languages such as MathML, in order to be easily readable by screen readers while forms can be made accessible by ensuring all instructions on what fields are compulsory and what formats different data should take e.g. dates should be provided outside of the HTML form tags so they can be read by screen readers. However, most instructors assumed all learners had visuals and some of them provided audio files for the contents written. It was supported by Frost *et al*. (2019) that there is a need to develop a system that converts complex graphical notation and sentences to simple sentences and presents the relations among them to enhance the readability of online contents.

The main workaround used was to ask for help from sighted friends to read or describe the content (n=15, 45.5%). Other solutions included asking questions at group discussions and asking Braille translators to provide an interpretation that can then be read through Braille software.

(ii) Use of Headphones all the Time

Text-to-speech translators and screen readers produce audio of textual material and therefore necessitates that the VILs either be in a quiet place where they cannot disturb others and they cannot be disturbed or to use headphones all the time. The continuous use of headphones was disturbing because most of the headphones the VILs had been in low quality and hence create some noise and voice inequalities while using them. Some of VILs also experienced ear pain during the usage of headphones.

(iii) Inaccurate Translations

Although the official education language in Tanzanian Higher Learning Institutions (HLIs) is English, certain learning materials may be in Swahili.

(iv) Technologies Complicated to Use and Lack of On-Campus Training

Overall, the VILs found the assistive technologies that they knew about to be difficult to learn to use. This was compounded by the lack of training they could attend on: (a) different types of assistive technologies available on smartphones, (b) how to use assistive technologies and (c) how to use standard phones to also engage in M-learning.

The complications faced in using assistive technologies were also because of the HLIs not ensuring accessibility standards are met on their learning management systems. The HLIs relied on e-learning platforms rather than providing both e- and m- learning platforms or at least ensuring their e-learning platforms were mobile-friendly. It also resulted in the problem of instructors providing inaccessible content (challenge 1). It was felt that providing training programs to instructors and web developers could help overcome this challenge.

(v) High Cost of Technologies and Lack of Access In Libraries

VILs who did not have access to smartphones lamented on the high cost of the devices and the fact that they could not borrow such devices e.g. from university libraries, in order to benefit from M-learning.

(vi) M-learning not Appropriate for all Types of Visual Impairment

Almost half of VILs (n=16, 47.5%) felt m-learning and other ICT-based learning was not relevant as fully blind students would have difficulty in using the tools. Instead, braille machines would be more appropriate. Despite this, all these VILs felt they would likely recommend m-learning to other students, as they could understand the benefits.

4.2.6 Respondents' Recommendations for Improving Accessibility of M-learning for VILs

VILs made four (4) main recommendations on what would be needed to improve the accessibility of M-learning:

(i) Provide screen readers capable of reading different forms of data - text, image, video, etc.

(ii) Ensure simplicity in design for easier learning

(iii) Ensure compatibility with different phones e.g. low, mid and high range smartphones as well as standard phones

(iv) Provide support to gain new skills through the applications

4.3 System Design Requirements

4.3.1 User Groups and Scope of Offerings

The survey of VILs and HLIs revealed the following user groups should be considered during system design:

(i) VILs with partial sight,

(ii) VILs with no sight,

(iii) Instructors.

The scope of the ideal system would also encompass the following:

- A smartphone application capable of running effectively on low-end smartphones as well as mid and high range ones
- Support for interacting with standard phones e.g. via USSD

4.3.2 Functional Requirements

Reading Functionalities

Table 3: Reading Functionalities

S/N	Interface Design and Navigation
i.	The mobile application should provide a user with user-friendly and straightforward interface to use to get access to the m-learning platforms available in HLI
ii.	Utilize voice control as much as possible for navigation and input to enable even non-sighted users to navigate it
iii.	The application should have a comfortable mark-up language setting (case of navigation) and proper narrative tools (sound and vibration haptics)
iv.	The mobile app should display pictures and descriptions of the photograph to enable VIL to understand
v.	The platform application must be compatible with all smart devices
vi.	Text spelling lesion to allow the learner to get a grasp of the reading contents

Table 4: System Requirements

	System requirements
System Goal	To provide text to speech audio output when accessing learning contents provided from LMS and provide picture description to audio when the picture is embedded in the document
Learning credentials	Allow users to log-in into the LMS of their respective HLI. The system shall automatically document all logs per user things to do and enable users to access m-learning without Login credentials
Input	User input learning materials with different format pdf, doc, txt, ePub and create audio output saved in the cloud
Language switching	Allow language switching within the document if the documents have several languages. Moreover, secure server to client architecture mobility and floating bar to read the text in other applications.

(i) System requirements for accessibility part of AT

- There is no need for registration to access the AT, but access to HLI m-learning will depend on the conditions set by HLI.

- The system will inevitably document all logs per-app usage.
- The system shall automatically save the documents requested by users and data received from Vision Google AI authenticity requests and shall save details of the requester and the requested text descriptions.
- The system shall automatically reply with a sound all accessibility requests needed by users.

4.3.3 Non- functional Requirements

Diverse features of requirements have been enlightened by different authors (Khan *et al*., 2016; Kurtanović *et al*., 2017). The recognized requirements must be indistinct, reliable, changeable and perceptible to produce a superiority end product; hence; this study worked on the subsequent potentials as the defined Table 5.

Table 5: Non- functional Requirements

Requirements	***Description of AT***
Performance	The system must never be overstated as it should be installed in VIL's smart devices
Reliability	The system guarantees that user roles are adequately achieved as needed by the user, and it should be available.
User experience reviews	The assistive technology for m-learning supposes to deliver a great user experience that will be taken through a user satisfaction trial in software assessment to intended users (VIL).
Efficiency	The Assistive Technology system guarantees adaptability, learning, outstanding functionality, and ease of use for students with visual impairment.
The total cost of Ownership	The system will be owned by HLI to ensure that all VIL use it and be able to access m-learning platforms in their respective institutions.

4.3.4 Requirements Specification

Requirements specification relates to a solemn software design stage that defines the capabilities a software program is required to have (Lu & Liang, 2017). Moreover, specification plays a role in designing, coding also, as a base for software testing (Yang & Liang, 2015). Formerly designing of the mobile-based platform for m-learning Assistive

Technology for VIL, specifying requirements for it was crucial due to individual needs. Fundamentally, the requirements specification includes both functional and non-functional requirements for the system (Wiegers & Beatty, 2013). Technical requirements are declarations of the facilities the system should give to the user, how it must react to specific contribution and in what manner it must operate in particular condition whereas non-functional requirements are the constrictions on the functions which are offered by the platforms (Baek *et al*., 2019; Genc-Nayebi *et al*., 2017). The platform will need users to make sure it performs well and can provide services to it, as shown in Table 6.

Table 6: Requirement Specifications

Users	**Requirements**	**Metaphors**
VIL	Enter/update details of his/her HLI for user authentication. Save learning resources Read via speech recognition	The VIL shall be able to manage details of registered HLI she/ he studying VIL can save the document for later reading in the clouds. The user will be able to store audio files that have been learned from the text document.
System administrator	Monitor platform activities Manage system users Updates and work on the reviews	The system administrator must be able to monitor platform operations The system administrator must also be able to handle system users; enable user preferences to be accessed and updated.

Depending on the system and user requirements shown, the system for enhanced m-learning Assistive Technology was developed. It comprises two key segments, namely a mobile application and a database part.

4.3.5 The Data Flow Plan for the Designed System

Data flow diagrams (DFD) portray the flow of data in an information system. A level 0 data flow diagram displays data flow between external entities with the system while a level 1 data flow diagram displays information flow and procedures involved at the individual phase, as well as data stores required as soon as the process finishes. Also, Fig. 15 depicts the level 0 DFD for the m-learning assistive technology platform. Students use their mobile devices to convert text on documents hosted on a learning management system into audio and images in the document into textual descriptions to an audio output.

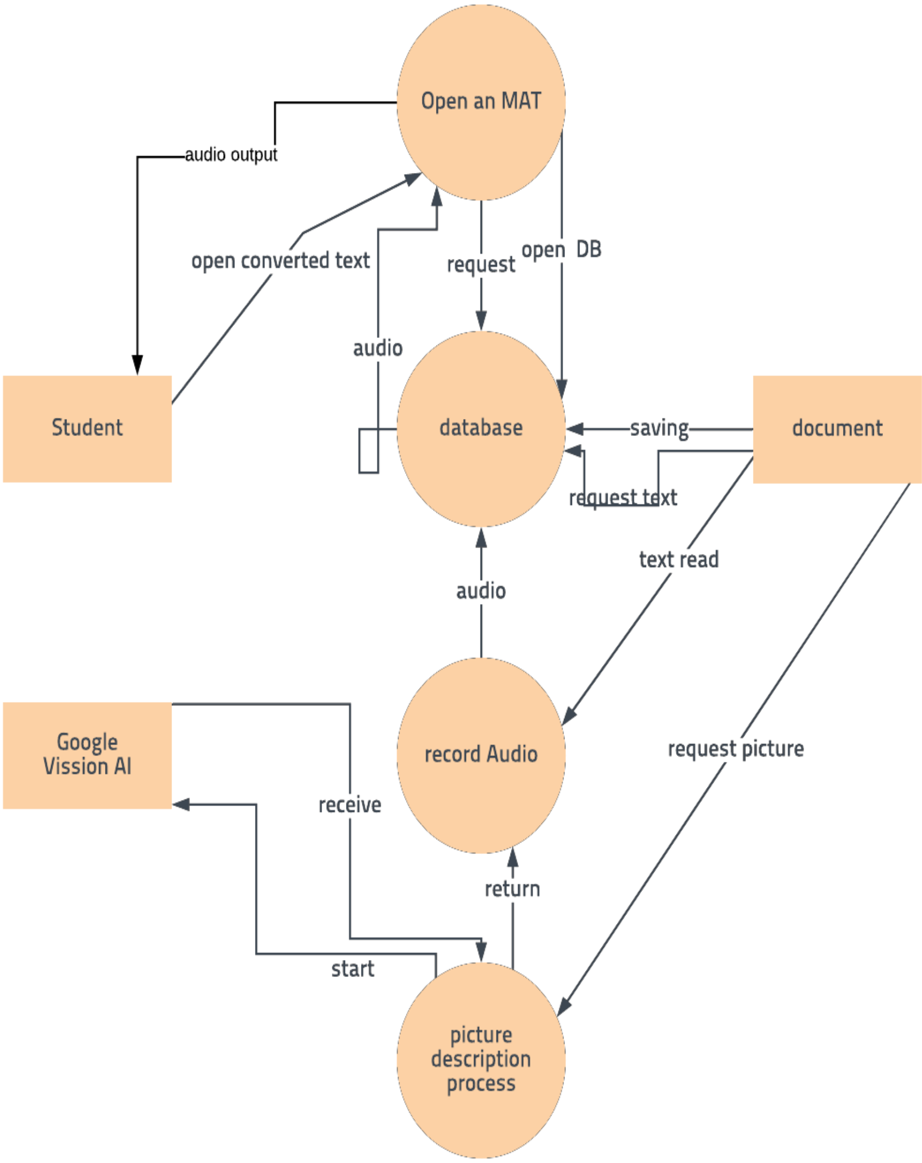

Figure 15: Level 0 DFD for Assistive Technology

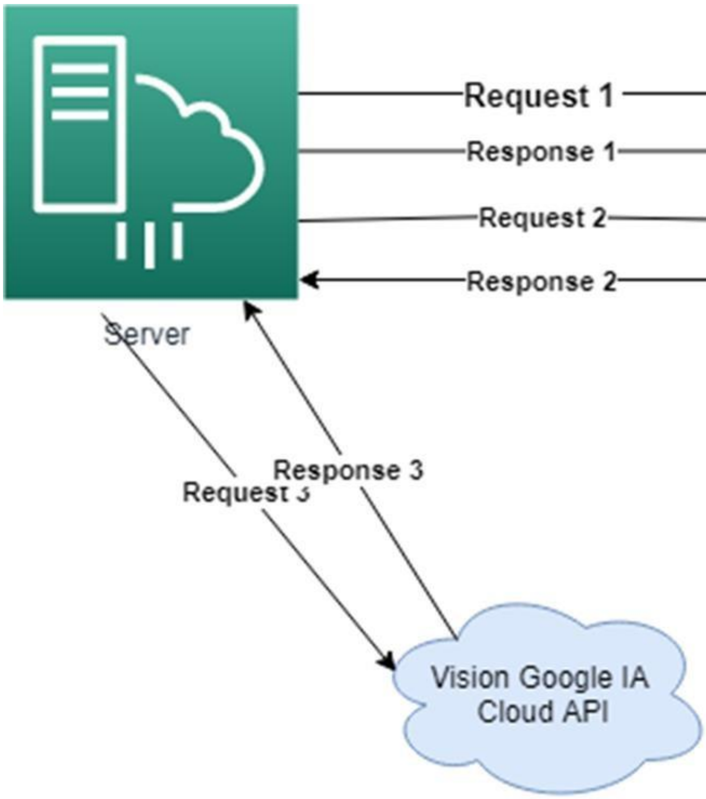

Figure 16: Level 1 of DFD for AT

From Fig. 16 the user requests the contents from the server to read, the server responds with the list of descriptions of the content available on the server. After the user has loaded the content description (menu), then the requested content at a choice as per list needed. The server processes the request and starts extracting the rich content, and if there is the availability of pictures, the server communicates with the Vision Google AI Cloud API to get more information on the image requested. Google Vision AI sends the responses to the server to compile all descriptions received together with other text contents extracted from document and pdf files available in the m-learning system and forwards it to the client.

4.4 System Overview

4.4.1 Conceptual Modelling of m-learning Assistive Technology

For most information systems, use cases were used in conceptual modeling. It represents user's interaction to the system and aids in portraying the system functionalities and essential purposes attained by system users; they elaborate what the system does and why it does not do (Rahman *et al*., 2018).

4.4.2 Use Case Diagram

Use cases that also include actors, use case symbols along with connecting lines. Nevertheless, actors are entities outside the scheme that can be an individual, organization, etc. and play a precise part, and are often outside the system's scope. In this platform, actors are HLI, System Administrators and VILs who work closely together to achieve a specific goal (teaching & learning) shown in Fig. 17. The connecting lines attach actors to the system outlined boundary involved in the Server-side platform. The user will be able to open an application and load study materials and read and listen through speech synthesizer (speech output), also using saved audio files in the cloud shown in Fig. 18. Also, on the server-side, there are three actors, such as instructors and students and system admin who are responsible for making sure that the core objective of HLI is attained.

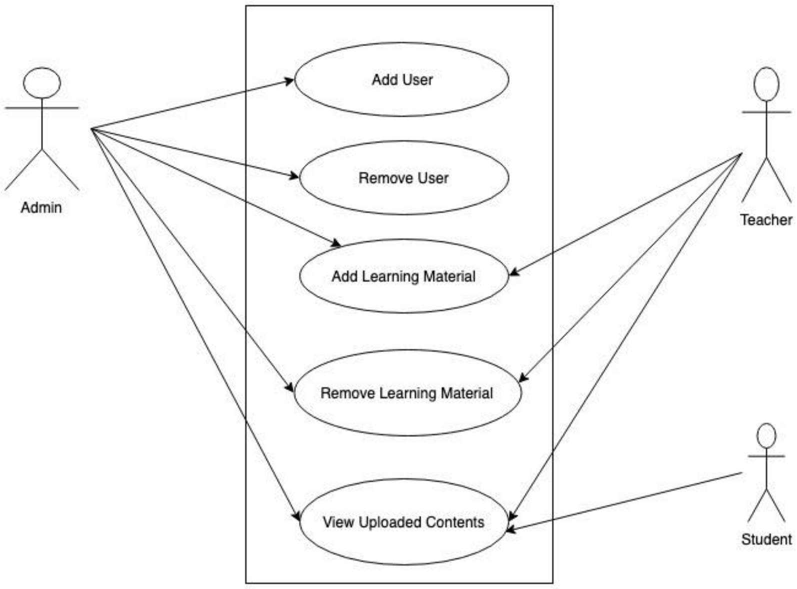

Figure 17: Server-side Use Case Diagram

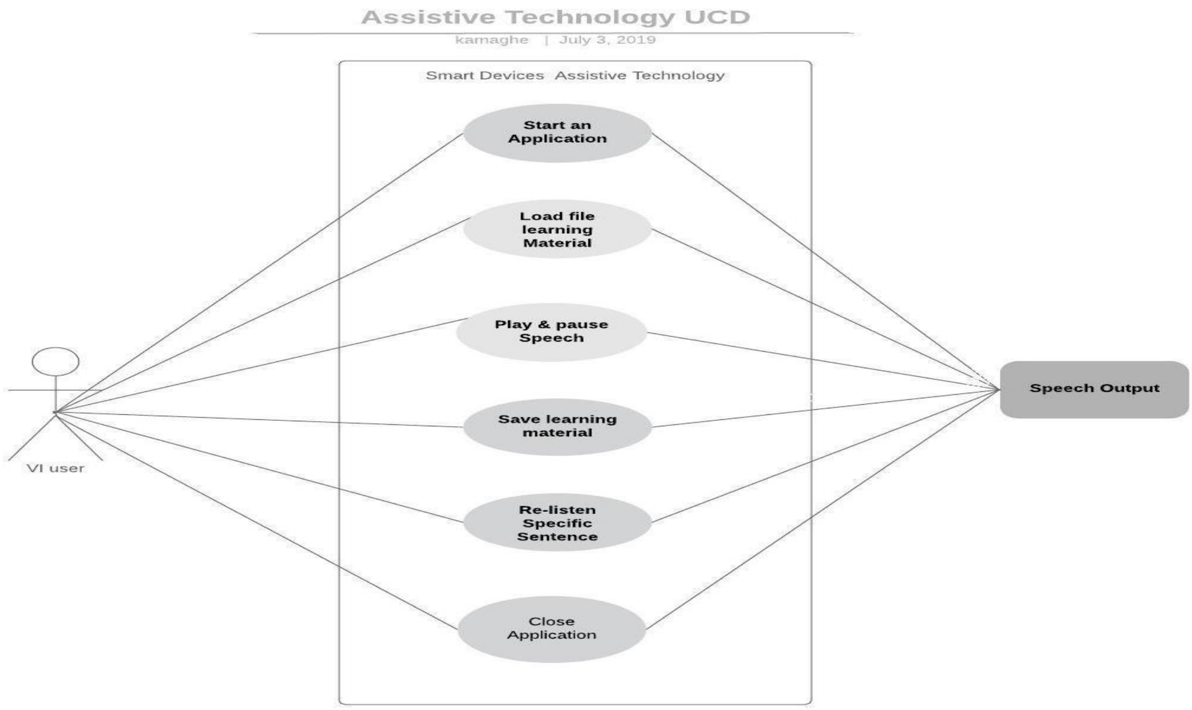

Figure 18: Use Case Diagram for Mobile App

4.4.3 ER- Diagram

The entity-relationship diagram relates to sketches that help to understand the direction and constraints of the scheme by showing the entities and characteristics used (Javed & Lin, 2018; Yuen *et al*., 2019).

Moreover,an entityrelationship diagram describes relationships amongst objects and assists in creating queries in a database and information system built on the layout (Barnouti, 2016; Perfect *et al*., 2018). Moreover, Figure 18 below demonstrates the m-learning Assistive Technology system entity-relationship schematic. Functionalities of entities arise, such as instructors prepare a list of teaching resources and view the reported requests resulted from VIL from the Smart Devices Apps. Then, the VIL authenticates his credentials to be able to log in in his/her HLI Learning system and load learning resources to the server and request for speech synthesizer to audio format.

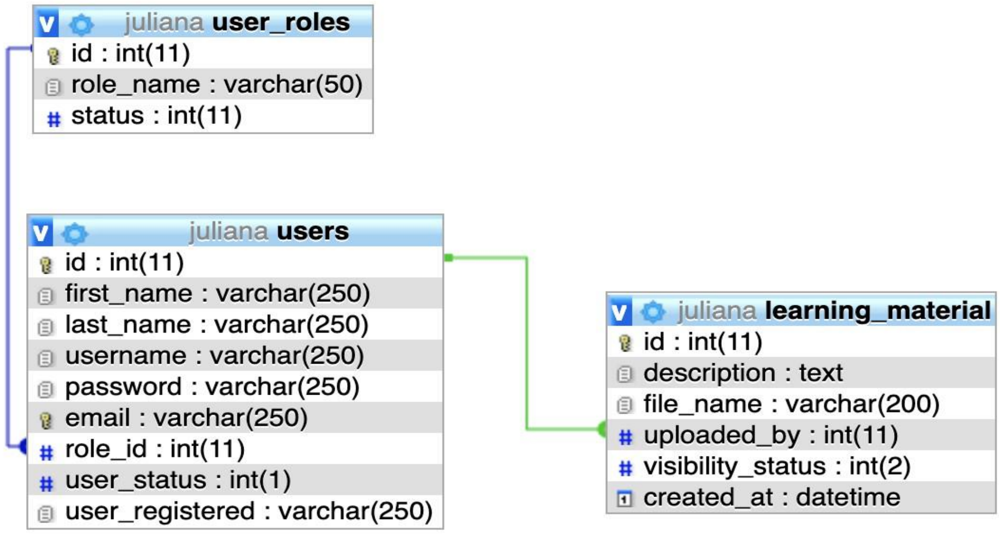

Figure 19: ER Diagram

4.4.4 System Block Diagram

A system block diagram is a hardware-oriented flow diagram used to show and emphasize the functionalities and interlinkage of the system in the devices and separates the overall system in the different subsystems to be understood by developers (Desai & Adams, 2015). It displays a high level of functional model that is used to compose a system to make it work. In m-learning Assistive Technology, the out of the system is the speech, which makes it more accessible for the user to comprehend the triangulation and contents available in the applications. The input of the system is divided into two categories as a text reader and pictorial descriptor, which has Vision Google AI APK as input. The working part of the system is the Text analyzer (comprises the morphological analyzer, Contextual, Syntactic-prosodic Parser, Letter to sound, Prosody generator) as shown in Fig. 20.

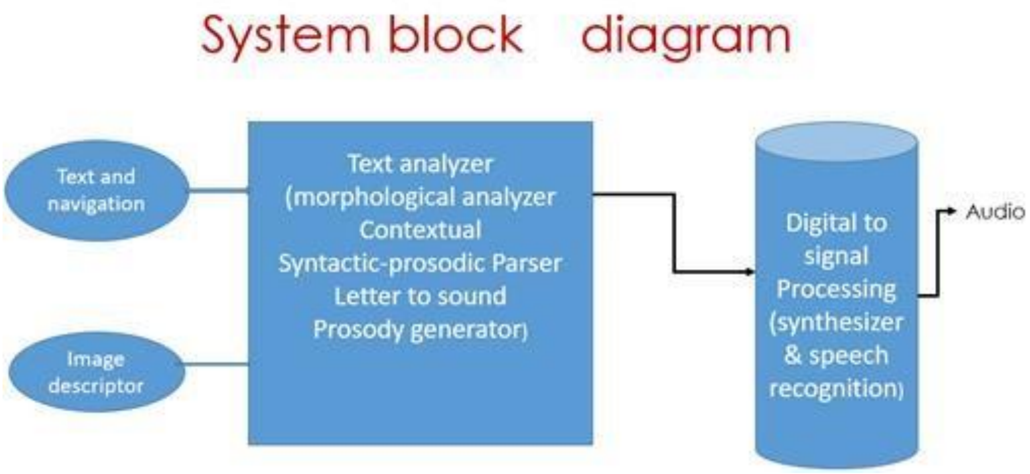

Figure 20: System Block Diagram

4.4.5 User-side of m-learning Assistive Technology

An audio-based multi-touch technique allows VILs access touchscreens in smart devices and enables a user to have access to HLI m-learning Application.

The developed system consists of three parts, which are the text emulator, speech synthesizer and image descriptor. The text emulator allows VILs to have a visualization of sentence lines, which is synthesized to the audio output. This enables learners to understand the concept and meaning. The emulator is also responsible for detecting errors in text conversion and allows the user to navigate to the line which has not been converted. The text emulator modules are written in JavaScript, to control the arrows and swipe navigation in smart devices. The user uses double-tap to open the documents that need to be read, and the user can select paragraphs using double finger navigation.

The speech synthesizer provides the audio output for the selected paragraphs. The app allows the user to add document files to the database. When the app is loaded, the home page shows a list of all stored documents. When a document is selected, it is automatically analyzed and the appropriate speech output for the text contained is read. The user can save the audio output in MP3 format offline so that it can be used for later reading or for sharing with other learners who do not have smart devices. Moreover, MAT allows VILs to add their own text whereby it will then analyze using its synthesizer similarly to add a slideshow PPT, from HIL's Learning Management Systems. When analyzing, the app loads the document and from the server part of the platform and parse it so that it can create audio output, as shown in Figs. 21 and 22. In speech synthesizer, the databases consist of audio output that been interpreted and produced from the phonological tree of each sentence in a document. As the W3C consortium aims to make sure that web-based information is accessible for speech interface, the synthesis is achieved by producing a phonological hierarchy that is also called the target hierarchy, even probing the database of different trees to search for the language used the same regime. The synthesizer is implemented to an improved phonetic into parse text received inform of the waveform that in turn generates speech output. The speech generated was tested to make sure that there at least error-free so that learners can understand words from documents. Prosody and pitch have been considered to make sure that the quality of voice produced is simple and can be understood by VIL.

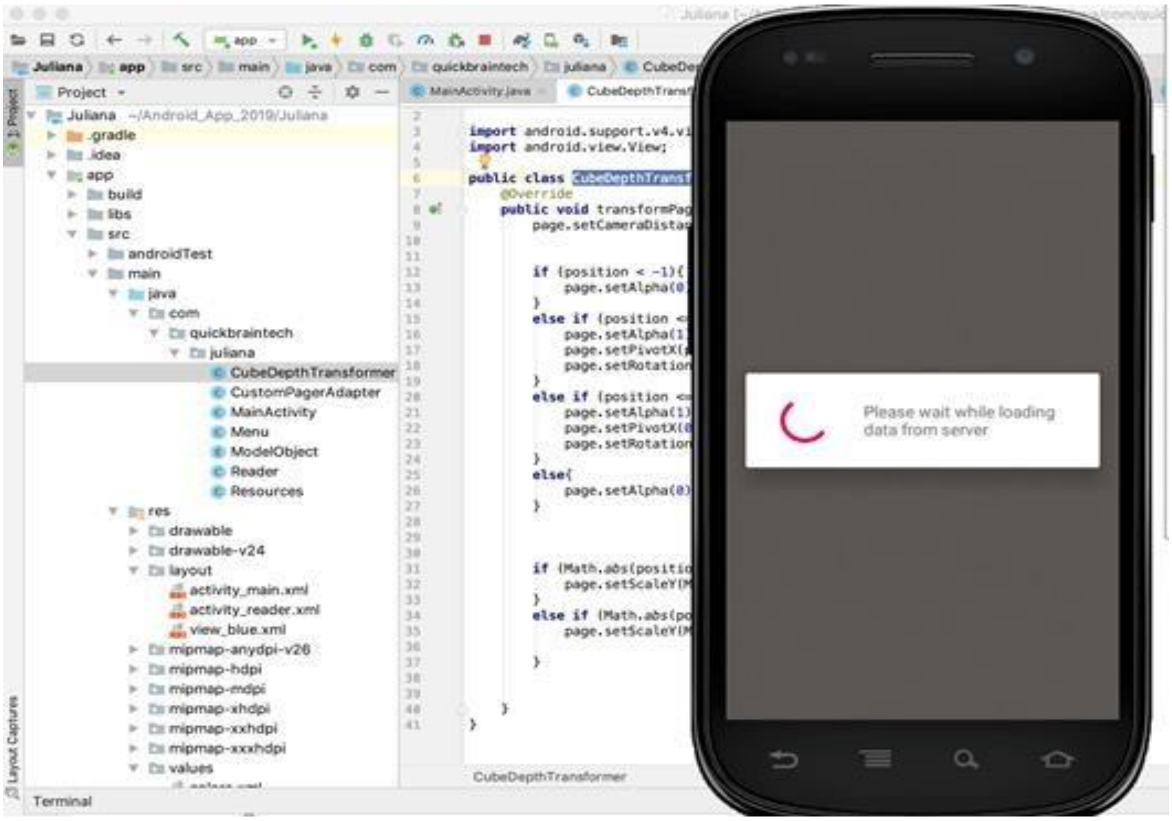

Figure 21: Prototype Loading Learning Contents from Server

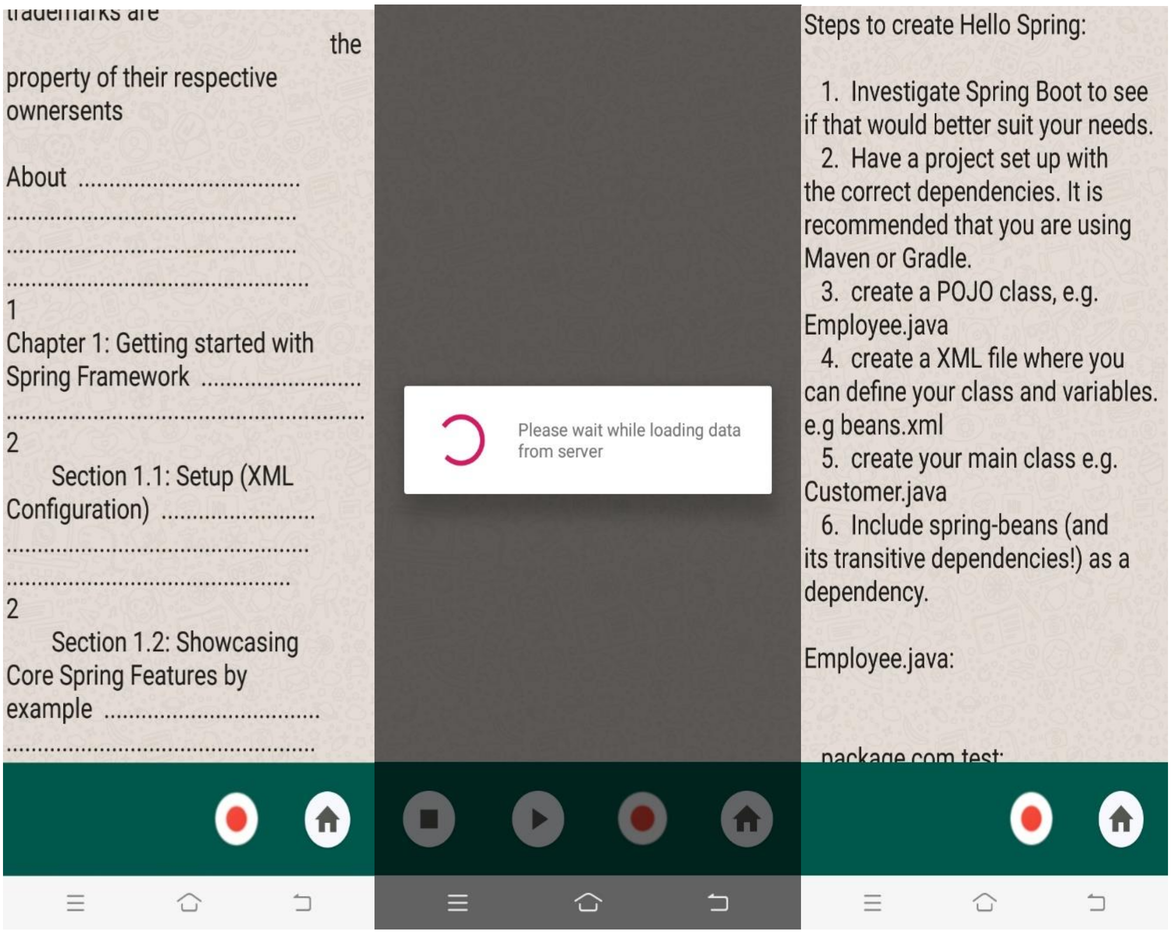

Figure 22: Audio Generation from the Text Document

Chart and graph were able to be described in simple text to Audio output and visually impaired learners understood them well.

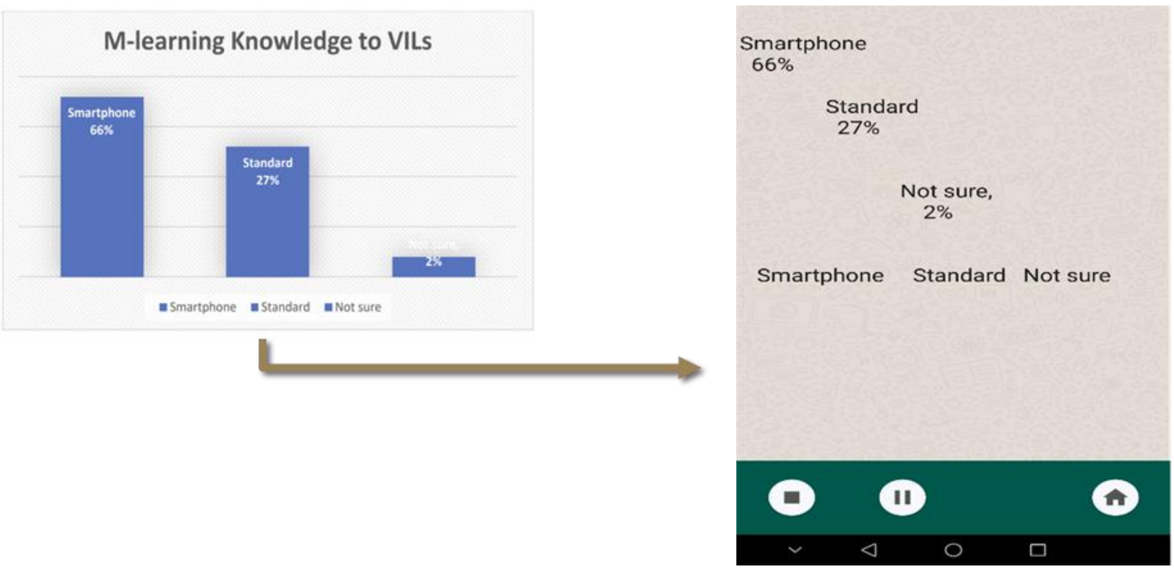

Figure 23: Graph into Text Format on Assistive Technology Output

4.4.6 Server-side of M-learning Assistive Technology

The server is responsible for saving all data and the Audio output generated also is capable of keeping all text descriptions of an image extracted from the documents. It is integrated with Google clouds and Google Vision AI APIs. Google Vision AI API uses machine learning to learn about an available image and compare them with the model requested and provide text description which relates to the image by the probability of 0.8 of real description (Hassaballah & Awad, 2016). The app request for information from the server and server reply with the list available documents saved by the user loads them so that a user selects and opens the one needed to be opened. Then the server processes the document and if there is an image in the text loaded. The server sees if there is an alternative description in its database, and, if there is no description, then the server communicates with Google Vision AI API, to get more explanation of that image. Google Vision AI receives an image and analyze it with deep learning (neural network) then send the description back to the server. Server compiles and add it to other text contents from the files and send them to the client (Mobile App). Also, the server is responsible for saving the audio output in Google Cloud for the client to use offline.

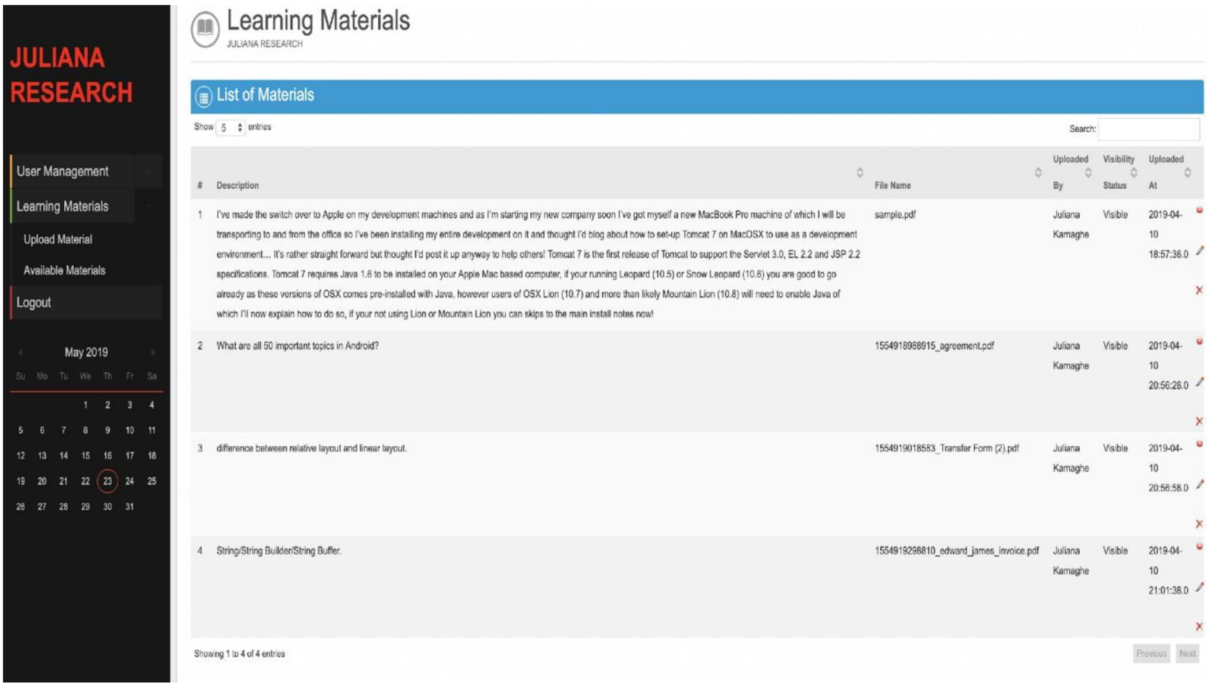

Figure 24: Learning Materials List from the Server's Database

4.5 System Validation Results

The system was validated with users in two sessions/runs. The first validation session revealed improvements needed by the VILs and the second validation was used to determine how well these improvements had been done.

4.5.1 Results from the Initial Validation

Overall, all seven participants understood the operation and navigation modality of the system designed and were satisfied with the current system of managing learning contents through assistive technology. They argued that by using m-learning assistive technology will make their study life more comfortable.

The test assessed two user requirements: voice quality and a more accessible user interface. Four of the seven VILs made the following recommendations:

(i) The system should provide a dropdown menu of learning contents instead of website format to reduce the burden of searching and going through results.

(ii) The system should have visible links to the articles, notes, forms and others to make the interface more accessible instead of a mixture of both contents.

(iii) Links to HLI websites should be included in the app so that they could access any learning material directly from the app rather than the browser.

(iv) Lastly, the system should be having options to user-friendly and ready to switch language through text and be able to adjust the audio output volume while reading the document.

Generally, all seven respondents appeared to be attracted to using the apps regardless of minor navigation shortcoming through various connections and buttons and the respondents managed to access teaching materials from their HLIs and save them in the app. However, their discomfort and misunderstanding of how to operate smart devices hindered their efficiency in terms of the time needed to finish these tasks.

4.5.2 Post Questionnaire Results from Initial Validation

The System Usability Scale (SUS) consisted of 10 official statements with five possible responses (ranging from 1 to 5, where 1 for Strongly Disagree and 5 for Strongly Agree.

Questionnaire responses were coded and the overall score obtained was 72.5 out of 100, as shown in Table 7, which exceeded the standard results for usability, which is 68% (Lewis & Sauro, 2017; Lewis, 2018). This indicates that the developed m-learning assistive technology was perceived as usable and acceptable by VILs despite the limitations observed.

Table 7: System Usability Score Test Score for Initial Test

Participant	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	SUS Score
P1	5	2	3	3	5	1	3	1	4	4	**75.0**
P2	4	2	4	3	4	1	3	2	2	4	**65.0**
P3	4	1	5	2	3	2	4	1	4	4	**72.6**
P4	5	2	4	2	4	2	4	2	4	2	**75.3**
P5	5	1	4	1	5	1	4	3	5	2	**82.5**
P6	4	1	4	2	3	4	2	3	2	3	**55.0**
P7	5	2	4	1	5	1	4	2	3	2	**82.5**
Average Score											**72.5**

4.5.3 Results from the Final Validation of the M-learning Assistive Technology

The recommendations from the initial validation were implemented and the revised system validated with the same participants from the initial session. During this final session, participants were first asked to analyze the speech output and ability of the system to integrate with their HLIs systems. Five parameters, namely unaffectedness, responsiveness, text lesion, numerous languages switching and interoperability were therefore used. These parameters comprise both segmental and prosodic features (variations in pitch, loudness, tempo and rhythm) of speech, which can affect motivation, engagement and understanding. VLIs listened to the speech output from a textual document and then gave an opinion score ranging from 0-5 on each parameter. A score of 0 meant unsatisfactory, 1 meant poor, 2 meant fair, 3 meant good, 4 meant very good and 5 meant excellent. The graphs of all opinion scores for each parameter were plotted and the mean opinion score (MOS) calculated.

Unaffectedness refers to how much audio speech from smart device Assistive technology relates to human voice?) of the words and MOS obtained was 4/5 signifies that the output speech was associated with the human voice. The individual VILs' opinion scores are plotted in Fig. 25. The responsiveness parameter was concerned with how much VILs felt the assistive technology accurately described images. The individual results are plotted in Fig. 26 and the MOS was 3.8/5, which indicated a very good ability to describe images. The third parameter was text lesion, which assessed how much the user understood the text being read by the system based on the melody, rhythms and intonation of the speech output. The MOS was 4.2/5, with 2 individual scores of 3/5 and 5 individual scores of 5/5, as shown in Fig. 27.

Numerous language switching was about how well the system could recognize the different languages in the text that was being read and switch the segmental and prosodic features in the output. The opinion scores given are plotted in Fig. 28. The MOS was 4.4/5.

Last to be assessed was interoperability i.e. can the system be integrated with the learning management system available in the VLIs' HLI? Figure 29 depicts the individual opinion scores, which overall gave a MOS of 4.7/5.

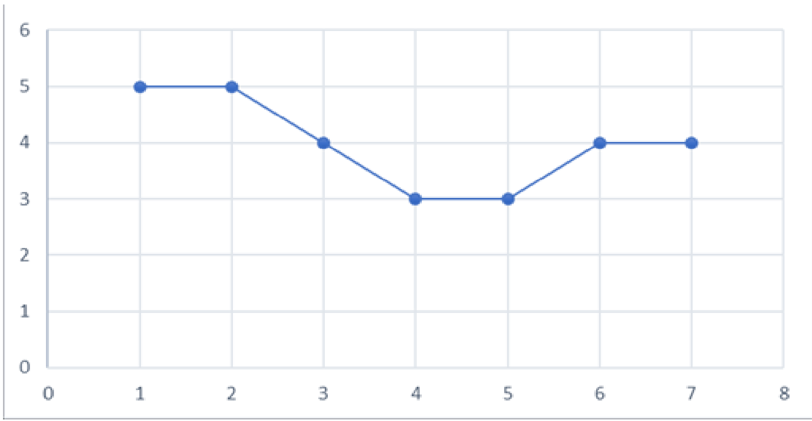

Figure 25: MOS for Unaffectedness

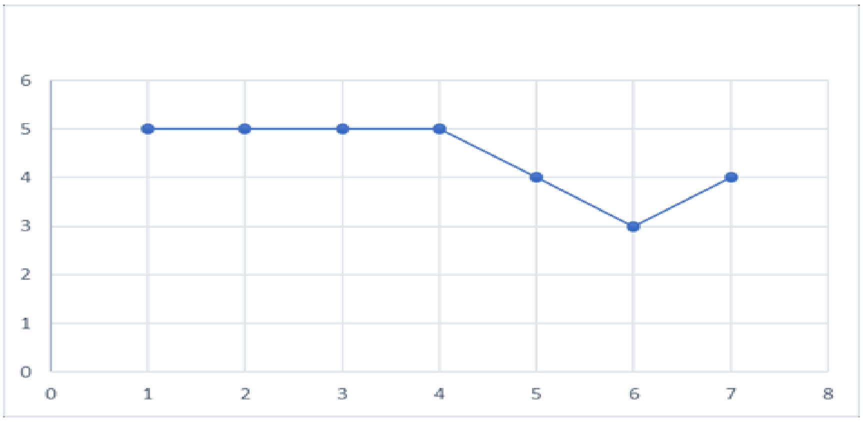

Figure 26: MOS for Text Lesion

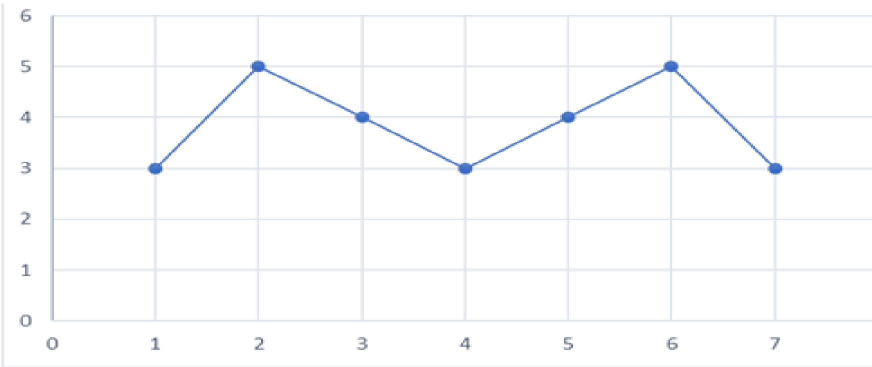

Figure 27: MOS for Responsiveness

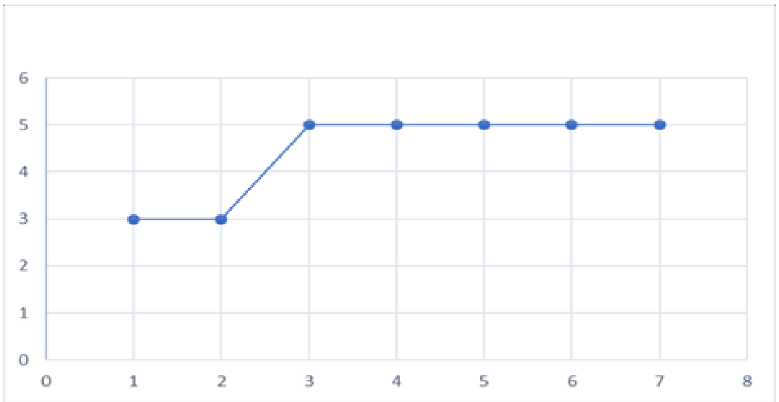

Figure 28: Numerous Language Switching

Figure 29: MOS for Interoperability

The second part of the validation was on overall the usefulness of the system and user satisfaction, which were assessed through the number of assigned tasks completed without the help and within a given time frame and through the standard system usability scale (SUS) test, which required VILs to give a score ranging from 0 to 5, with 0 being the lowest satisfaction level. The overall scores are shown in Table 8.

Table 8: User Satisfaction for each User Results

Participants	No of Task Completed (Of 7)	(A)User Satisfaction (0-5)	(B) System Usefulness (0-5)	Average A&B
1.	4	4.5	4.3	4.4
2.	3	3.9	4.3	4.2
3.	7	4.4	4.3	4.55
4.	6	4.0	4.7	4.12
5.	5	4.0	4.0	4.0
6.	6	3.7	4.3	4.0
7.	3	4.3	3.9	4.1

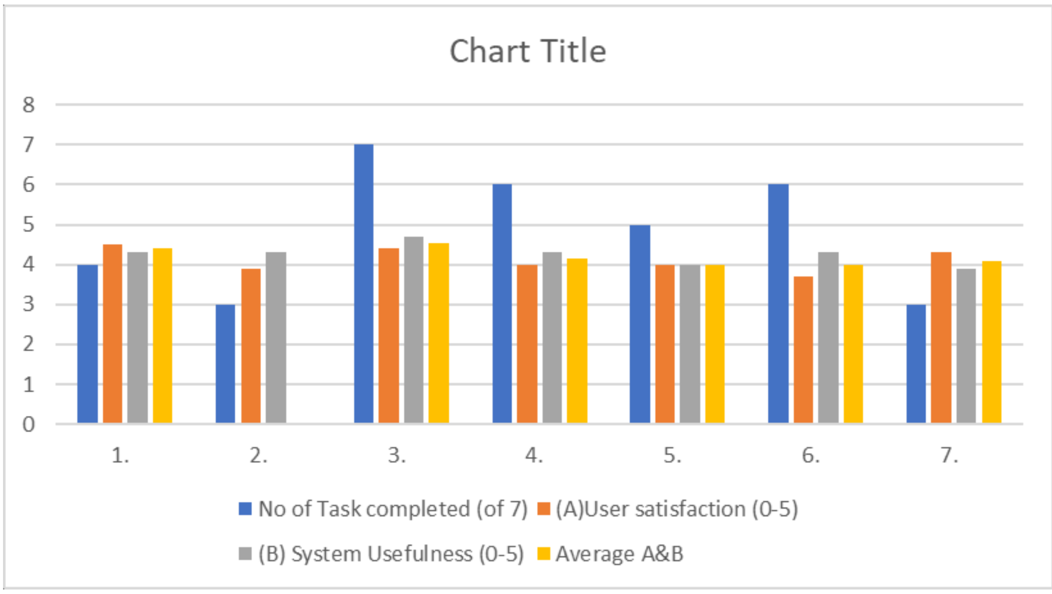

Figure 30: User Satisfactory and System Usefulness Chart

From the Figure 30, it shows the system acceptance by the user and how they were able to complete a task that was given to them in a specified duration. Participants were able to work on their tasks without help from the research and even were able to use the Assistive technology for an added job that was not scheduled i.e. adding documents to the server from other clouds and other memory sources. Participants accomplished additional duties on time, excluding the first assignment, involving participants in determining the place of the implementation in the smart device and what is all about and where to begin apart from launching an app from the home screen of a smartphone. The average time taken for all seven respondents to complete the tasks was 4 minutes 30 seconds, which was a full 30 seconds shorter than the anticipated time of 5 minutes. The average user satisfaction from the participants shows that Assistive technology will be of help to the students, and it needs to be used in Higher Learning Institutions.

The results overall show that participants were satisfied with the system and were able to see the usefulness of the m-learning assistive technology to their daily studies in the Higher Learning Institutions. The results from the final validation were better than those in the first validation, showing that the recommendations made were important. The app assessment on the user performance with a voice speech analyzer showed it to be functional. In addition, test for acoustic modeling for the speech synthesizer in terms of prosody design and grapheme-to-phoneme conversion whereby prosodic makers accumulate a phonetic string of the word from the documents and convert it to speech to make waveforms for audio output. The validation stage of m-learning Assistive Technology has been a success as the SUS score exceeded the score limit as supported by (Kaya *et al*., 2019). Mean opinion score proves that the need for Assistive Technology for visually impaired in Tanzania in higher since they are facing challenges while studying their courses in Higher Learning Institutions.

4.6 Discussion

4.6.1 Challenges Faced by VILs in Tanzania

The challenges met by VILs in Tanzania's HLIs were severe compared to other countries like India Nigeria etc (Okoye *et al*., 2019; Omede, 2015). Several reasons may be responsible for the situation. One is the relatively lower smartphone ownership rate in Tanzania is 46% of the population (Ngirwa *et al*., 2018) vs Nigeria 66.5% and India 77% (Mukhopadhyay *et al*., 2019; Okoye *et al*., 2019). ICT policies for supporting visually impaired persons in Tanzania include Information & Communication Technology (ICT) policy for basic education of 2007. However, the implementation of this policy for VILs in HLI is very low compared to the sighted learners because most leaners are sighted and HLIs cater VILs with braille contents.

Lack of training of HLI's administrators in issues of disability on challenges faced by the visually impaired students. From results obtained during an interview with HLI's system administrators, it was observed that even though they design LMSs for sighted students it was as used by the blind but the system used to design did not provide VILs with facilities to access it since they assumed that all contents are given by their instructors in class as D'Atri *et al*. (2007) and Quirke *et al*. (2018) supported. Web accessibility and usability have been extensively studied for blind web users. The focus has usually been on making it technically likely for blind users to access content, or on helping to make the web more usable (Bigham *et al*., 2017). However, the digital divide provides barriers to web accessibility in 1990 but was prevailing by developer introduced Braille reader and text readers and implemented policies some developed countries to remove the digital divide on VILs. Moreover, the inaccessibility of some of the learning contents shared on LMSs is due to the lack of knowledge on VILs and lack of training to both administrators and instructors on how to prepare learning contents to suit the needs of visual and non-visual Learners. Moreover, some challenges involve technical know-how of smart devices including applications, physical attributes of mobile devices and network and memory capability.

The study was done in Delhi universities whereby it was concluded that there was a barrier inaccessibility of web contents faced by VIL in Libraries systems. Moreover, the study done in Australia believed that there was barrier faced visually impaired learner on the accessibility of graphical in web data and this is the challenge facing learners worldwide (Butler *et al*., 2017) hence there was a need to for developers to consider this group of learners when developing learning platforms

M -learning Assistive Technology will be beneficial for HLI and Visually Impaired learners since learners will be able to participate in learning at their own pace. These results suggest that some respondents might have thought that the user m-learning system training before starting their course work approach would provide them with the skills and knowledge, they would need to be prepared to be independent while attending HLIs. Sezer *et al*. (2019) described this approach as not as effective as regular motivation and follow up will be needed for adaption of m-learning Assistive technology designed. Many of the respondents argued to the need for support, encouragement, motivation and time for processing and practicing accessibility and skills as described by Frost *et al*. (2019), García-Peñalvo *et al*. (2018) and Quirke *et al*. (2018)

Knowledge about VILs needs is essential for the design and implementation of effective m-learning Assistive Technology platform and with the rapid pace of technology change, researchers must stay up-to-date of how this new technologies encourage changes in VILs educational development and, also, what features of effective learning system needed at this pace as depicted by Asongu *et al*. (2018) and Crompton *et al*. (2016).

4.6.2 Attitudes of VILs Towards M-learning and Challenges they Pose

The study revealed that almost half of VILs (n=16, 47.5%) felt m-learning and other ICT-based learnings were less relevant than traditional technologies like Braille, as they could not be used by learners with no sight at all. During the study, this attitude led to a reluctance to participating in both the design and validation of the proposed assistive technology. To design the best accessible system, it is necessary to include the users who know the extent of the problem they faced and what they needed. Due to the rapid development of ICT tools, it will allow VILs to enter comprehensive and barrier-free educational content (Seifert, 2019). Visual impaired Learners in HLIs were reluctant because of the nature of their educational system that they depended on the contents given by their instructors and the price and affordability of smart devices. This is similar to the study which was done in Kuwait on acceptance of m-learning (Alhunaiyyan *et al*., 2016) and found that the use of mobile technology in learning is not as widespread as the devices themselves as most of the devices are used as means of communication and social media. So, there was a need for availability of open education resources for mobile learning like Moodle Mobile, Blackboard Mobile to be customized to fit the need of learners and making access more affordable to the students.

4.6.3 Acceptability of Image, Chart and Figure Descriptions and their Implications

The available assistive technologies are lacking the capability to read and describe the graphical contents i.e. photos, charts and graphical representation only text-based and some navigation can be translated hence for visual impaired becomes difficult for them to use alone without asking for help from others hence no privacy for VILs. As a result, there was a need to develop assistive technology or the interface which can describe the graphical contents in their smart devices and the cost of the system should be low with simple and affordable. The system provides VILs with the capability of reading text and pictorial notations since some of the learning materials are in graphical representations. The designed system has two-part ie the user side and server-side where all contents converted to audio format will be saved in the cloud and the learner will be able to access the converted document any time. The system is connected with google vision API so that it can provide a real-time graphical description to the use since most of the pictorial notation available in many learning materials are available in google image, and it is very helpful to VILs. The Google Vision was used to catch pictorial notation and do image processing by relating with other images available in the cloud, the results were translated to text then to audio format. With this platform, VILs can learn and also it can increase learning abilities through smart devices. During system testing with VILs, images were captured in the documents and descriptions were provided within shot time and learners were happy with the results and said they will be eager and ready to use it.

4.6.4 Limitation of the M-learning Assistive Technology system

The results, shows that the designed system provides a user with the capability of using a smart device without asking for help from other learners. Also, there are Institutional challenges whereby utmost HLI are not yet in adopting and usage of m-learning platforms even though some of them have been using E-learning for teaching and learning. Also, all HLIs visited were not eager to connect their LMS with this platform hence provide the researcher with difficulties in designing it hence weakened the targeted objectives. The research also found that the attitude and behavior of leaners towards the usage of smart devices for learning can hinder the usage of m-learning platforms hence HLI does not see the benefit of having it.

Likewise, to eradicate readability challenges instructors should be able to design learning contents which will provide more screen reader with friendly learning materials e.g. less picture with more text are alternative text (Badia *et al*., 2019; Crompton *et al*., 2016; Lewis, 2018; Virgili *et al*., 2018). This platform should be used together with HLIs learning management systems to improve the performance of VILs, also instructors and administrators should be provided with training on how to prepare learning content to fit the educational needs of VILs.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

It becomes challenging for visually impaired learners to acquire knowledge when the concentration is made more on the graphical presentation of core learning contents. This research examined the factors that hinder visually impaired learners in accessing m-learning through their smart devices in an HLI. Also, designed and developed an m-learning assistive technology for VIL and tested and validated it with visually impaired learners who were eager to see the prototype. Increasing investment in IT and communication techniques and applications in HLI for visually impaired learners will assist in boosting and enhancing their adjustment of the latest m-learning assistive technology and thus improve VILs enrollment. It is confirmed that accessibility, knowledge and skills are the principal concern with respect to the adoption and usage of learning technology for visually impaired learners. They are an obstacle for VILs to engage themselves in adapting and studying at HLIs without requiring help from others. The obtained findings show that most users of m-learning are hesitant or lack usage capabilities due to the assumptions of system admins for m-learning and instructors of courses that most of the learning contents are made for sighted learners instead of both sighted and non-sighed learners. Due to this, the m-learning Assistive Technology prototype was designed and developed to meet the need for accessibility. Users were trained to use Technology and enabled them to engage in self- learning at their own time and pace. A significant contribution to this study, the Assistive technology would allow learners to get a text description of pictures available in the learning resources since most instructors use graphical presentation in course delivery

The sustainable use of Assistive Technology for M-learning through smart devices will motivate visually impaired and enable them to be more competitive comparable to sighted learners without any help from others. Also, it will motivate instructors of courses to prepare more learning content without worrying about the readability of the material by VILs. Additionally, the research acknowledges the vulnerable group in the HLIs hence add a positive contribution to the education sector. The contributions MAT will give new hope for other learners (primary and secondary education) who were struggling in getting timely education and at their own pace. Therefore, the study presented not only solve the issue of inaccessibility and knowledge but also it increases the on-time completion rate for visually impaired in higher learning since they will have access to learning materials in time and engage themselves in making sure that they learn everything needed hence increase enrollment for VI. Two papers were published in international refereed journals in September 2019 and January 2020 titled as; Usability *test for cloud-based m- learning assistive technology for visually impaired learners in Tanzania's Higher Learning Institutions*. Published in International Journal of Advanced Technology and Engineering Exploration, Vol 6(57) ISSN (Print): 2394-5443 ISSN (Online): 2394-7454 http://dx.doi.org/10.19101/ IJATEE.2019.650049 (Appendix I) and, *The Challenges of Adopting m-learning Assistive Technologies for Visually Impaired Learners in Higher Learning Institution in Tanzania.* Published in *International Journal of Emerging Technologies* (iJET) – eISSN: 1863-0383, 15, 01 (2020). https://doi.org/10.3991/ijet.v15i01.11453 (Appendix I).

5.2 Recommendations

Based on the findings described in the dissertation it is recommended that:

(i) Further research should be done on language translation switching with text documents and how this system will be integrated into all HLI learning management systems at once.

(ii) It will be beneficial for HLI to sign a deal with smartphone makers to design smart devices at a low price and sell/ distribute them to visually impaired learners.

(iii) Ministry of Education, Science, and Technology over its agencies should enact policies and regulations that will ensure there is the availability of ICT tools to make sure that visually impaired use m-learning instead of audio tapes and CDs hence VILs can benefit from learning technologies.

(iv) Also, it can be used as a benchmark to emphasizes on the usage of Assistive Technologies for teaching and learning in the educational sector, especially in m-learning and e-learning Models hence reduce the time and cost needed to produce audio notes and give them to VILs.

(v) The study recommends that learners must be motivated by using a smartphone for learning, also provide m-learning assistive technologies knowledge and skills to them so that they can be able to apply it as explained by Abolfazli *et al*. (2015) that challenges needed to be rectified.

(vi) Policies should give more attention on levitation awareness on m-learning technologies which are compatible to visually impaired learners as supported by Quirke *et al.* (2018).

(vii) More training should be provided either as short courses or embedded in their universities training on the usage of m-learning which are recommended for visually impaired learners.

(viii) The prototype can be further re-validated and used in HLI and re-enhanced to be used by other users like deaf-blinds, deaf, etc.

(ix) In addition, it will be interesting in a long-term study to observe, and make follow-up visually impaired learners who have started using the MAT platform for their studies then track their technical development and how they share the knowledge with others.

(x) Lastly, further research should be done in designing a learning platform and integrating them with Assistive technology for secondary education in Tanzania and adding more security features to protect the privacy of users.

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APPENDICES

Appendix 1: Enhanced M-learning Assistive Technology to Support Visually Impaired Learners in Tanzania. The case of High Learning Institution

PhD in Information and Communication Science and Engineering (ICSE)

Demographic

Please tick (/) in appropriate box.

1. Name

   ……………………………………………………………………………………………………
2. Gender
   - □ Male
   - □ Female.
3. Age
   - □ 18 - 23 years
   - □ 24- 29 years
   - □ 30 - 35 years
   - □ 36 & above
4. Marital status
   - □ Single
   - □ Married
5. What is level of education?

   ………………………………………………………………………………………………..
6. Which course you taking at the university

   ………………………………………………………………………………………………..
7. When did you get this problem?
   a. After knowing how to read and write
   b. Before knowing how to read and write

Technology awareness

1. Do you have smartphone?
   - □ Yes
   - □ No
2. Is your connected to the internet?
   - □ Yes
   - □ No
   - □
3. Which of the following device do you own?

- ☐ Mobile phone
- ☐ Laptop
- ☐ Desktop
- ☐ PDA
- ☐ Tablet
- ☐ Others

  Specify ……………………………………………………………………………

4. For how many years have you been using smartphone at home or places other than university? Tick one box only
   - ☐ Less than 1 year
   - ☐ Between 1 to 3 years
   - ☐ Between 4 to 6 years
   - ☐ More than 6 years
5. Do they have internet access for you to use?
   - ☐ Yes
   - ☐ No
6. What mobile activity do you do in your phone?
   - ☐ Making calls and texting.
   - ☐ Download and read documents
   - ☐ Social media
   - ☐ M-learning
   - ☐ Play games
   - ☐ Others

     Specify
     ……………………………………………………………………………………
7. How often do you have your phone with you?
   - ☐ Never
   - ☐ Infrequently
   - ☐ I don't know
   - ☐ Sometimes
   - ☐ Always
8. When do you always use your phone
   - ☐ Home
   - ☐ University
   - ☐ In the bus
   - ☐ Others

     Specify …………………………………………………………………………...
9. How do you feel self-conscious using mobile phone in the university?
   - ☐ Very
   - ☐ Somewhat
   - ☐ I'm not sure
   - ☐ Not

9\. Which of the following contents you unable to access
- ☐ Picture
- ☐ Calls
- ☐ Tables
- ☐ Forms
- ☐ Maps
- ☐ Graphs

- ☐ Charts
- ☐ Others

  Specify ………………………………………………………………………………

10. If selected any of the above, explain why?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………

11. If you able to access contents in 9 above, state how?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………

M-LEARNING AWARENESS AND CONTENTS

1. Have you heard about M-learning?
   - ☐ Yes
   - ☐ Not sure
   - ☐ No
2. If Yes how did you hear about it?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………

3. Have you ever used any m-learning platform?
   - ☐ Yes
   - ☐ No
4. Do the university have e-learning platform?
   - ☐ Yes
   - ☐ No
5. How do you use e-learning for your studies?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………

6. Is the university have m-learning platforms?
   - ☐ Yes
   - ☐ No
7. Do you know any m-learning platfrom in Tanzania?, if Yes name it

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
………………………………………………………………………..

8. How do you participate in online learning using smartphone?

……………………………………………………………………………………………
……………………………………………………………………………………………
…………………………………………………

9. What type of mobile tool/ application do you use to access online contents?

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
………………………………………………………………………………

10. How do you enroll in online learning?

……………………………………………………………………………………………
……………………………………………………………………………………………
………………………………………………

11. What type of e-content do access online?

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
………………………………………………………………………………

12. Do you use your smartphone for m-learning purposes?

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
………………………………………………………………………………

13. For the moment can you tell me, what means do you currently use to access online contents especially e-learning

……………………………………………………………………………………………
……………………………………………………………………………………………

11. Do face any challenges when access online contents?

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………..

12. Which type of contents you are able to access online?

……………………………………………………………………………………………
……………………………………………………………………………………………
…………………………………………………

13. If you are using m-learning for learning what are the challenges facing when accessing contents?

……………………………………………………………………………………………
……………………………………………………………………………………………
…………………………………………………

14. Are you able to read the graphical representations?

 - ☐ Yes
 - ☐ No

15. If Yes, explain how?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………

16. What do you think are challenges facing the accessibility and usability of m-learning in HLI?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………

17. Would you agree that having course material ie slides notes , assignment, to be available in you phone that will be beneficial for your studies?

    - Completely agree
    - Somewhat agree
    - Not sure
    - Somewhat disagree
    - Completely disagree

18. Can you invest your personal time learning to use software that could make all resources available easily in m-learning for your studies?

    - No
    - I'm not sure
    - Yes

19. Would you agree to purchase a device which wil help aid you in using m-learning for your studies?

    - Yes
    - Not sure
    - No

20. How do you participate in online assessment i.e. quiz. Assignment, projects using your mobile phone?
…………………………………………………………………………………………………
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21. Do you involve in the discussion forum using your mobile phone?
    - Yes
    - Not sure
    - No

22. How do you interpret pictorial representation?
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Recommendations

23. Do you think that, m-learning needs to be supported so that it can enhance teaching and learning in Higher Learning Institutions?
    - ☐ I Strongly agree
    - ☐ I agree
    - ☐ Not sure
    - ☐ I disagree
    - ☐ I strongly disagree
24. Are you ready to use m-learning when made available?
    - ☐ Yes
    - ☐ Not sure
    - ☐ No
25. Do you encourage m-learning as tool for learning at anytime anywhere?
    - ☐ Yes
    - ☐ Not sure
    - ☐ No
26. What is your suggestion on what specifications m-learning platforms should have in order to enable VI students to use it
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