Designing a digital educational library in a West-African context

With a special focus on Ghana

Master thesis Business Informatics

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Abstract

Purpose – This research aims to address the challenges and opportunities of integrating Information and Communication Technologies (ICTs) into education, particularly within Education for Development (EDU4D) in developing countries, with a specific focus on West Africa. By developing design knowledge of digital educational libraries within the context of EDU4D and the unique challenges of West Africa, this study aims to enhance the learning outcomes and experiences of students in underprivileged communities. Through providing a comprehensive overview of the contextual landscape, which includes the quality of education, limitations in ICT implementation, and the impact of innovative technologies, the research aims to formulate design principles tailored to the specific needs of digital and physical library implementations in West African. By developing design knowledge tailored to this specific context, the ultimate goal is to contribute to the enhancement of career opportunities for young Africans and catalyze economic growth in West African regions by leveraging ICT across all aspects of education.

Design/methodology/approach – This research utilizes the Design Science Research (DSR) approach by following the three DSR cycles, including problem statement, design, and validation. The basis of the digital library design in a West African context is formed through deriving User Stories from user, expert, and researcher input. These User Stories are formed through various sources. Subsequently, design requirements and principles are developed and validated through scientific literature and expert interviews. The research phases follow the design cycle of Wieringa by encompassing the problem investigation, treatment design, implementation, validation, and evaluation. A Systematic Literature Review (SLR) was performed to inform the design process, which is strengthened by the results of the case study research in Ghana in collaboration with the NGO Maxim Nyansa Foundation. The Community Needs Tech Assessment (CNTA) validates the design requirements, involving user and expert interviews. The study utilizes evidence-based software engineering (EBSE) principles, the SLR and interviews to inform the design process. The multiple-case study employs a qualitative and quantitative data collection strategies to ensure validity and reliability for the design process of digital educational libraries in a West African context.

Findings – This research developed design principles for digital libraries in the educational domain within the context of West Africa, with a specific focus on Ghana, by addressing six sub-research questions. It investigated the educational landscape in Ghana and West Africa, by involving the factors of availability, accessibility, acceptability, and adaptability. The study explored the potential of various innovative technologies, such as cloud computing, AI, gamification, and mobile learning, to enhance the usability and knowledge building of educational resources, particularly in regions with limited internet connectivity. The research identified the components of a digital library with features like content management, user management, workflow management, and the publication process to ensure the quality and usability of educational resources. Through requirements engineering, the research identified 55 User Stories and 36 design requirements, categorized into functional and non-functional requirements. Subsequently, the requirements are translated into 11 design principles and 5 local design principles. Subsequently, the design principles are validated by cross-referencing with three scientific papers and four expert interviews. Overall, the research provided a structured framework for designing digital educational libraries in West Africa, aiming to enhance accessibility, usability and knowledge building in underprivileged communities.

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1 Introduction

According to Mandela [1], education is not only a fundamental human right but the most powerful weapon which you can use to change the world. Nevertheless, the global educational landscape faces significant challenges. Despite four years in school, approximately 125 million children worldwide are not acquiring functional literacy or numeracy. In low-income countries, the average student performs worse than 95% of the students from wealthier OECD countries [2]. At primary education level, 62% of Ghanaian children score below 'basic' in mathematics and 50% score below 'basic' in English. Despite Ghanaian children attending 12 years of education, the poor learning outcomes result in an effective schooling of only 6 years [3]. One of the contributing factors is the insufficient allocation of resources to education in many developing countries. In Ghana, for instance, the average allocation is approximately $20 per child, which is a sharp contrast with an average of $7500 per child in the United States. Despite the eagerness and motivation of children for learning, this financial disparity hinders their ability to access education [4]. The West African region also faces poor educational quality, even with an increase in school enrolment. Although there has been progress in increased access to education, the rise in enrolment does not guarantee quality education [5]. Goczek et al. [6] found that earlier education quality is a significant growth factor for the Gross Domestic Product (GDP) of a country, which can be a game changer for developing countries.

The rise of information and communication technology (ICT) has transformed both developed and developing countries affecting societal, political, technological, and economic aspects [7]. Economic growth in developing countries is influenced by several components; information and communication technologies (ICTs), academic research, and foreign direct investment (FDI) are considered as the most important. The main drivers for economic growth include physical capital, technology, human capital and public capital [8], [9], [10], [11], [12], [13], [14]. FDIs impact both human capital and technologies, playing a significant role in job creation, capital building, and knowledge transfer [12]. Nevertheless, ICT is a more recent driver of growth compared to foreign direct investment as the positive impact of FDIs can only be achieved if advanced technologies are available in the country [12], [13].

In recent times ICT has emerged as an important driver of growth. However, the implementation of ICT requires substantial funding through foreign direct investment. Several studies [15], [16] found that ICT enhances economic growth in Africa resulting in additional positive effects that generate macroeconomic benefits. These additional positive effects could include job creation, improved education, better information resources and other benefits that did not come with the initial use of ICT. The general idea is that ICT has a multiplied effect on the economy because of the additional positive effects that come with the implementation of ICT [17], [18].

Besides the two factors mentioned above, Ngongalah [14] found that insufficient research efforts in the continent of Africa is a major barrier to economic growth. As the continent of Africa produces less than 1% of global research, the full potential of Africa is far from reached. By providing African students with research-based education, they are encouraged to engage in research and therefore deliver more robust and efficient research. Building a strong research foundation can foster transformative possibilities and opportunities in Africa [14].

Among the affected aspects, the social dimension is particularly important as it gives a boost to human development. The rapid developments in ICT have generated an optimistic belief among developing countries promising a better future ensuring a better standard of living, improved healthcare systems, better educational facilities, and increased political engagement [19]. However, to reap the benefits of implementing ICT these countries require substantial funding to invest in ICT, presenting a significant challenge for developing countries like Ghana and Burkina Faso. Consequently, these challenges aggravate the gap between the developing and developed world [19]. Moreover, the adoption and diffusion of ICT in developing countries has been slow

due to limited access to basic equipment, low internet connectivity, and minimal participation in ICT development [20].

To address these challenges, research on ICT in developing countries emerged in the 1980s, also known as 'ICT for development' (ICT4D). ICT4D plays a crucial role in tackling the aforementioned challenges in developing countries by showing the potential of ICT for social and economic development [21], [22].

Education plays a crucial role in stimulating the development and creating an impact on underdeveloped regions. In this context, ICT4D initiatives in the field of education, from now on called EDU4D, can have a transformative impact on the lives of individuals and communities in developing countries. EDU4D has the potential to become a powerful driver for growth in Africa [23]. The potential of information and communication technologies (ICT) is enormous as it enhances skill development, engages students in active learning, establishes school and job opportunities, stimulates economic sustainability, enhances educational innovation and establishes global connections [24], [25]. Nonetheless, the widespread use of ICT is hindered because of a lack of access to electricity and limited computer literacy amongst the majority of people in developing countries [26].

In recent years there have been multiple initiatives to improve ICT in the field of EDU4D. EDU4D initiatives try to bridge the gap in the digital divide. However, many of these initiatives faced several challenges and failed to become successful, for example: the one laptop per child policy in the early 2000s, which failed because of political reasons [27], [28], [29], [30]. Local support is one of these challenges and it is essential for the success of technological initiatives [31]. Another challenge is the lack of implementation of design principles referring to usability, which causes the systems to be hard to use [32]. Diniz [33] and Heeks [34] discovered that the failure of ICT projects in developing countries is caused by the gap between designers' perceptions of the technology's functionalities and the actual needs of the users for the technology.

Despite the challenges and many of these initiatives being unsuccessful, there have been successful initiatives in EDU4D projects [28], such as: Maxim Nyansa's learning transformation programs and eLibrary [35], and The Basic School Computerization Policy of 2011, to supply ICT resources in schools [36]. ICT initiatives can be grouped in three different categories: 1) National initiatives, 2) Regional initiatives and 3) E-content initiatives. These ICT initiatives in higher education are significantly important for the development on a national scale. However, for a well-coordinated and networked learning environment the intervention of the government is necessary, as government policy has a great influence on ICT4D and EDU4D initiatives through laws, regulations, and funding. Furthermore, universities should also play a key role in providing e-education strategies into laws and regulations [37]. According to Peter et al. [38] the following aspects have to be considered to have a successful implementation of an ICT4D project: 1) Authentic local needs, 2) Local ownership, 3) Realistic limitations, 4) Competence network, 5) Formulation of an effective communication strategy, 6) Planning horizon, 7) Documentation and measurable results, 8) Ensure resources and sustainability and 9) Incorporating fun and motivation components.

The demand for online resources in education has increased significantly with the arrival of the World Wide Web (WWW) and as a result introduced concepts like online learning (e-learning) or e-education. E-education is the result of the integration of ICT in the educational fields [39]. Especially with the impressive penetration of current upcoming technologies, such as mobile phones, this could be the way education is given in the future [40], [41], [42]. The role of the teacher is required in e-learning [43]. In fact, Leijen [44] found that the role of the teacher in guidance and feedback on students' work in education is crucial for the success of e-learning.

Mobile technologies, where the mobile phone is the most prevalent, make it possible to provide easy accessible and available learning opportunities through mobile learning (m-learning) [26], [45]. The mobile phone can also be called the 'PC of Africa', because of their programmability, powerfulness, and their accessibility to internet. Mobile phones have evolved over the years transforming into powerful technology that, when used correctly, has the potential to significantly enhance learning outcomes [26], [45], [46], [47], [48].

1.1 Problem statement

As stated in Section 1, developing countries are faced with several challenges and potential opportunities when it comes to the integration of information and communication technologies (ICT) in the educational domain. There is significant amount of literature when it comes to ICTs in everyday life, however this topic is frequently absent in most of ICT4D and EDU4D literature [49]. This research will attempt to increase the design knowledge of digital educational libraries in the field of EDU4D. The EDU4D is a growing research area and because of the limitations in developing countries this research can have a significant impact on the development of young underprivileged children [23]. There are several key research problems in these countries that can be identified:

Quality of education
Quality of education in developing countries has been a growing concern. Despite a positive development of increased access to education, the quality is still lacking. This problem is shown by the poor performance of students in low-income countries compared to students from wealthier OECD countries, i.e., a student in a developing country is performing worse than 95% of the wealthier countries [2]. The student's perception of educational quality is influenced by factors such as institutional infrastructure, the qualification of teachers, financial or other types of support and attitude of staff towards students [50]. Limited computer literacy among teachers is a significant limitation to the effectiveness of implementing ICT in education [26].

Limitations for implementing ICT
The adoption and implementation of ICT in developing countries pose a big challenge as they have several factors that limit the possibilities to have a significant impact on education, such as limited access to basic equipment and low internet connectivity [20]. These challenges first have to be improved to provide accessibility and scalability to online education. ICT plays a significant role in the growth of high and upper-middle income group countries but fails to contribute to the growth of the lower-middle income group countries due to these factors [51]. The potential of e-education and mobile learning in providing education for many students is promising. However, developing countries suffer from resource constraints and therefore hamper the technological developments [20].

Community, family and external support
The potential benefits of implementing ICTs are significant for every country in the world. However, to tackle the challenges developing countries face, they require substantial community, family and external support, both financially and practically, to enhance the ICT infrastructure and educational technology [19]. These support mechanisms lack in West African countries.

ICT4D Initiatives
Many ICT initiatives in the educational domain, or known as e-education programs or EDU4D, have started in previous years with both successful and unsuccessful efforts aimed at implementing ICT into education within developing countries and their local communities.

However, they faced several challenges and failed to achieve their intended objectives. To make these initiatives more successful, we must understand the reasons behind these failures. Identifying successful initiatives and their solutions is essential for guiding future adaptations and local implementations in the EDU4D research area. More successful initiatives are essential for enhancing education in Africa.

Impact of Mobile Technologies

Mobile phones, often referred to as the 'PC of Africa,' have the potential to significantly enhance learning outcomes through mobile learning (m-learning) [26], [45], [46], [47]. To take full advantage, for example in efficiency and effectiveness for educational purposes, or the power of mobile technologies, further research has to be done in the m-learning research area to effectively address the challenges and opportunities for technologies in a West African context.

The current state of research in Africa

As stated in the introduction, Africa only produces less than 1% of global research output. A solid foundation to engage in research is minimal and therefore the future of African research is not bright. Several challenges must be tackled to facilitate the ability to conduct research [14]. The lack of research poses a problem for researchers ready to conduct research in developing countries, as access to relevant information of these countries is limited. It is anticipated that this research will face similar challenges due to the limited research output in Africa. To address this challenges, expert and researcher interviews are conducted to assess the current situation in West Africa. By understanding and addressing the current research landscape in West Africa, this study aims to contribute valuable insights in the current research landscape that can foster future research and enhance the conditions and opportunities for underprivileged communities in West Africa.

Designers' assumptions vs the real needs

Many of the EDU4D initiatives have shown to be unsuccessful. According to Diniz [33] and Heeks [34], the failure of EDU4D projects in developing countries is caused by the design-reality gap, referring to the gap between designers' perceptions of the technology's functionalities and the actual needs of the users for the technology. The design-reality gap poses a significant challenge for implementing innovative technologies into underprivileged communities.

Design knowledge of digital educational libraries are missing

Despite the success of digital educational libraries in developing countries, its development is lacking an evidence-based scientific foundation, prompting the need for research to establish design principles for digital educational libraries in the West African context. Kitchenham et al. [52] suggested software engineering researchers should adopt ''Evidence-based Software Engineering" (EBSE), which aims to use an evidence-based approach to software engineering research and practice [53]. This research specifically focuses on the West-African context due to limited IT availability and accessibility of data across many African countries [28], [54].

In summary, the research problem revolves around improving the quality of education in developing countries (EDU4D), teacher's quality, limitations regarding ICT adaptation and initiatives in education, opportunities regarding e-education and m-learning and limited design knowledge on digital educational libraries. Resolving the challenges around EDU4D can increase effectiveness and accessibility of educational opportunities in developing countries. Concludingly, this can lead to the creation of career opportunities and a significant growth of the GDP [6].

1.2 Research aim

The aim of this research is to develop design knowledge regarding digital educational libraries and as a result increase the usability of such libraries and its knowledge building. Currently, there is a lack of general knowledge around the design of digital educational libraries and its local implementations. By developing a set of standard design principles, we can expand the knowledge of digital educational libraries and therewith increase the quality of such libraries. Consequently, this will lead to increased knowledge building and therewith a knowledge gain of young individuals in West Africa.

1.3 Research questions

In this Sub-section the research questions will be defined and elaborated upon. The primary objective of this research is to formulate the design principles of digital educational libraries in a West African context. The research questions will explore the state-of-the-art design principles, methods, and techniques for digital educational libraries to answer the following main research question:

MRQ: ***What does a design for digital educational libraries in a West-African (ECOWAS) context look like that leads to usability and knowledge building?***

To answer and position the main research question the following sub research questions have been identified:

SRQ1: *What is the current educational landscape regarding 21st century knowledge and skills in West Africa (ECOWAS)?*

This research question explores and aims to understand the educational landscape in West Africa, with the focus on Ghana. Through rich picture modelling, literature review, and expert interviews, the goal is to provide a comprehensive overview of the educational context, which includes the challenges and opportunities of new upcoming technologies and changing community needs. By gaining in-depth insights into the current situation, this research question provides the foundation for designing digital educational libraries that effectively address the specific needs and limitations in West African regions.

SRQ2: *What are the current state-of-the-art technologies used for digital educational libraries within the domain of ICT4D?*

This research question explores the current state-of-the art technologies and tools utilized in digital educational libraries worldwide and investigate how they can be tailored to the specific needs and challenges of West Africa. ICT4D initiatives and improvements has shown to play a significant role in making impact on societal, economic, and educational development in both the developed and developing world [21], [22]. The goal is to identify innovative technologies that can potentially enhance the digital educational library in underdeveloped regions, particularly countries in West Africa. Through a systematic literature review and expert interviews, this research aims to provide a comprehensive overview of the current state-of-the-art technologies, This overview will inform the design of digital educational libraries tailored to the West-African context.

SRQ3: *Which concepts and characteristics are currently included in digital educational libraries?*

SRQ3 aims to engineer the concepts and characteristics of digital libraries through UML class diagramming, which displays the components of digital libraries and their relation with one another. These insights are gathered from interviews, design documents, and the systematic literature review and inform the engineering process for digital educational libraries in a West African context.

SRQ4: *Which requirements should a digital educational library fulfil in order to increase usability and knowledge building?*

This research question aims to identify and construct the design requirements essential for optimizing usability and knowledge building in digital educational libraries in a West African context. By conducting interviews with both researchers, domain experts and users, as well as conducting a systematic literature review, the goal is to gain in-depth insights into the essential functionalities and constraints of digital educational libraries in a West African context which contribute to effective educational outcomes. These requirements serve as the foundation for designing digital libraries tailored to users in a West African context.

SRQ5: *What are the design principles for digital educational library in a West African context?*

This research question aims to identify and formulate the design principles for digital educational libraries tailored to the West African context. The formulation of design principles is an essential step in answering the main research question and serve as the foundation for designing and implementing digital educational libraries to enhance usability and knowledge building.

SRQ6: *What are enhanced design principles for local implementation of a digital educational library in a Ghanaian context?*

This research question aims to identify and formulate local design principles (LDPs) specifically tailored to the physical implementation of digital educational libraries within local communities in West Africa. By conducting interviews with experts, researchers, and users, these tailored design principles are developed to provide the essential guidance for successfully implementing digital educational libraries within these communities, thereby enhancing usability and knowledge building.

SRQ7: *What do validated requirements and design principles of digital educational libraries in a Ghanaian context look like?*

This research question focuses on validating and enhancing the design principles formulated for digital educational libraries in a West African context. Expert and researcher interviews are conducted as well as cross-referencing with relevant scientific literature, to develop the necessary design principles addressing the specific needs and limitations of the regions. Validation of the formulated design principles is essential to ensure that the design effectively enhances usability and knowledge building in the West African context.

1.4 Research contributions

This research has the following contributions:

- Providing a comprehensive overview of the current educational landscape in West Africa (ECOWAS) with the focus on the digital infrastructure to understand the context in which the digital educational libraries will operate. This helps in identifying specific challenges and opportunities that needs to be addressed in the design process. This contribution is essential as most research in West Africa is outdated or irrelevant.

- Providing an overview of the state-of-the-art advancements in digital educational library technologies within the domain of EDU4D, which serves as the foundation for designing innovative solutions tailored to the West African context. It ensures that the design principles are based on current best practices and technologies.

- To identify the essential features of digital library systems, which helps to understand the functionalities that are relevant to the stakeholders' needs in West Africa.

- By enhancing the access to educational resources through digital libraries, the research contributes to knowledge building among (West) African countries and therefore enhancing the prospects of young Africans despite the existing limitations.

- Providing the design requirements/functionalities of relevant stakeholders to ensure that the digital educational libraries meet the specific needs of stakeholders in West Africa, which enhances usability and knowledge building.

- Designing and conducting a case study research project in Ghana to increase the potential of digital educational libraries in a local environment. By executing this project, we can gain insights in the local challenges and opportunities regarding the design of digital educational libraries and therewith enhance usability and knowledge building.

- Provide in-depth insights into the needs and challenges of individuals in local communities in West Africa.

- A set of design principles for digital educational libraries tailored to the West African context. Based on these design principles, digital educational libraries in this context can be enhanced and therewith enhance the knowledge building for, in this instance, lower developed countries with poor educational quality. The design principles are based on evidence-based software engineering (EBSE).

- Enhanced design principles for a physical implementation of a digital educational library in local West African communities.

1.5 Research outline

In this Sub-section a complete overview of the research outline is given. The structure of the research is the following: the last part of Section 1 addresses the timeline and milestones for this research. After that, the research approach is elaborated upon in Section 2, which is followed by the research methods, involved protocols and validation metrices in Section 3. Section 4 elaborates on the outcomes of the systematic literature review. In this part, we lay the foundation for informing the design process. Subsequently, Section 5 discuss the educational landscape in West Africa and Ghana, including its rich picture, to provide a comprehensive overview of the

challenges and opportunities in this context. Section 6 revolves around the design process of this research by formulating design principles for digital educational library in a West African context, which is build upon User Stories and requirements. Furthermore, Section 7 provides the answers to the main and sub-research questions. Lastly, Section 8 discusses the limitations and future research for this research.

1.6 Timeline and milestones

The first phase of this research project incorporates the initial set-up of the project in terms of project goals and scoping, building the relationship with the involved organization and volunteers, and investigating the possibilities for this project in collaboration with the organization and my supervisor.

In the second phase, we focus on exploring relevant literature and existing state-of-the-art designs and technologies of digital educational libraries to understand the challenges and opportunities of digital educational library approaches and to inspire ideas for potential improvements around the topic of digital educational libraries. 21st century opportunities, such as widespread availability of smartphones and internet connectivity in West-Africa, are taken into account to provide the best overview of current cutting-edge technologies related to digital educational libraries.

The third phase consists of imaging the current situational aspects related to education in Western-Africa by using rich picture modelling. Additionally, a deeper dive into the Ghanaian context is given to image the current situation in Ghana specifically.

In the next phase, the state-of-the-art approaches and scientific literature of the second phase together with the conducted interviews are transformed into design principles to create the scientific foundation for a digital educational library in a West African context. The plan is to deploy these scientific design principles after finalizing the research.

Lastly, we extend these design principles by testing them in a real-life environment in Ghana in collaboration with the NGO Maxim Nyansa Foundation. This case study involves exploring scientific literature for enhanced design principles regarding the local implementation of digital educational libraries in the developing world. These enhanced design principles are crucial as they provide the local library, consisting of computers within the digital educational library, with enhanced usability and knowledge building. This case study focuses on the potential of digital educational libraries in supporting a local community in a developing country.

We propose the following timeline and milestone for this thesis:

1. **Exploring scientific evidence**: This project involves exploring cutting-edge technologies regarding digital educational libraries and their associated requirements related to educational purposes aiming to enhance usability and knowledge building, for example: by implementing gamification or Artificial Intelligence (AI).
2. **Interviews**: In this research semi-structured interviews will be taken to research various aspects of digital educational libraries. This ranges from current cutting-edge technologies regarding digital educational libraries to the experiences of using these cutting-edge technologies. Therefore, we will interview three distinct groups of people: (1) Experts in the field of digital educational libraries, (2) Current users and future/potential users of the digital educational library in a local environment in Ghana, (3) Academic and experienced researchers involved in the field of EDU4D. A more detailed description is provided in Sub-section 3.2.
3. **Conceptual approach**: after gaining knowledge from scientific literature and having processed the information from the interviews (experts, users, and researchers), we can formulate design principles for digital educational libraries. The goal is to create a comprehensive overview of how a digital educational library should be designed and developed to enhance the usability and knowledge building.

4. **Design and implementation**: In the third step, design principles for digital educational libraries will be designed. As discussed in the introduction, the accessibility to a digital environment is limited in developing countries. Therefore, this research also provides enhanced design principles for the local implementation of a digital educational library through ICT centres or schools. The enhanced design principles are created in collaboration with the NGO Maxim Nyansa Foundation, which provides learning transformation programs for young Africans to create future career opportunities [55]. The following steps will be taken to create these enhanced design principles:

   Foundation of the case study in collaboration with Maxim Nyansa

   Maxim Nyansa Foundation developed the foundation of the three cases for the case study research, which includes the school selection, funding and provision of the necessary equipment and devices. A more thorough explanation of this foundation is described in Sub-section 3.4. The case study research is designed by the researchers to ensure the implementation and assessment of the proposed enhanced design principles in a physical environment in a developing country, i.e., Ghana in Africa, to reach an effective outcome. This tailoring is based on the assessment provided in the proposed enhanced design principles and more thoroughly described in Sub-section 3.4.

   Implementation of the design principles

   In collaboration with Maxim Nyansa, the proposed local design principles for the digital educational library are implemented in local communities in Ghana, in specific the Community Engagement. The local design principles are tested on three schools in Ghana, respectively in Accra, Adanwomase and Gambibgo. The project incorporates these design principles to assess the implementation of a local digital library into local Ghanaian communities. This environment ensures the assessment and validation of our approach and ideas accordingly. This approach is described in Section 2.

   Validation

   Interviews are taken with expert, such as digital librarians, school directors, and teachers, to investigate the usability and knowledge building of the proposed design principles for digital libraries in a West African context. Additionally, scientific literature is employed to self-validate the design principles.

Research phase	Deliverable	Deadline
Problem investigation	Research questions	31-05-2023
	Short proposal	31-06-2023
	Section 1: Introduction	01-07-2023
	Research approach	31-07-2023
	SRQ1: Literature review	31-08-2023
Treatment design	SRQ2: state-of-the-art technologies	31-09-2023
Treatment design (Ghana)	SRQ3: Concepts and characteristics	31-09-2023
	Set-up case study research	31-09-2023
	Researcher interviews	30-11-2023
	Expert interviews	30-11-2023
	Execute case study research in Ghana	30-11-2023
	SRQ4: Requirements	31-12-2023
	SRQ5: Design principles	31-01-2024
	SRQ6: Local design principles	31-01-2024
Treatment validation	SRQ7: Literature review	29-02-2024
	SRQ7: Expert interviews	29-02-2024
Dissemination	Thesis report	31-03-2024

Table 1: Research timeline.

2 Research approach

This research follows the Design Science Research (DSR) approach by Hevner [56]. The DSR approach consists of the three cycle design science process. Design science research is an essential component to research in the domain of Information Systems (IS). Figure 1 shows the steps to carry out Hevner's DSR approach.

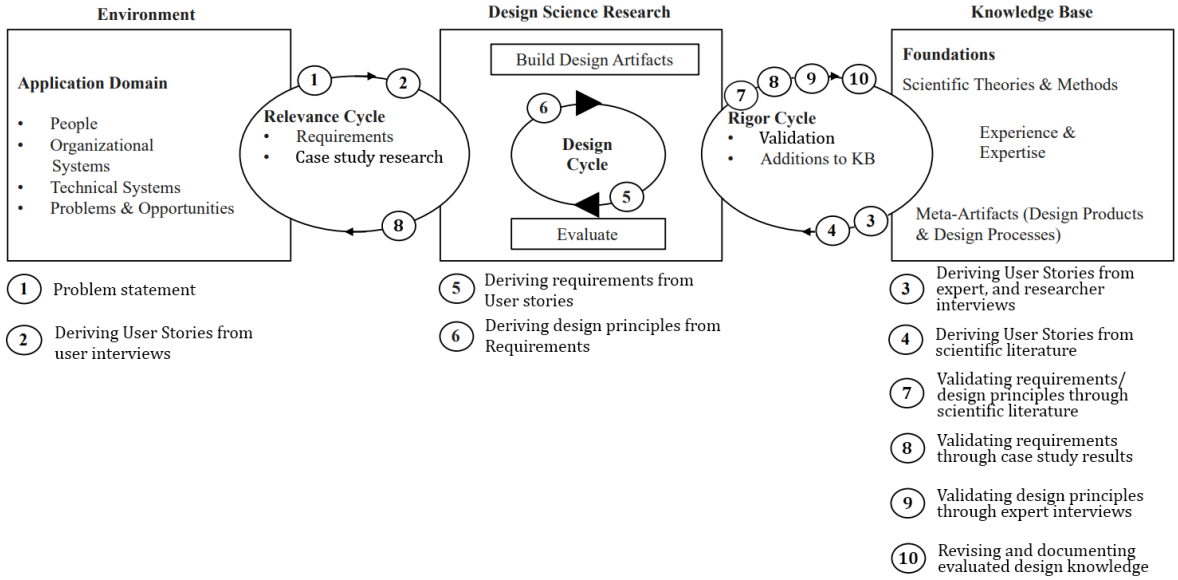


Figure 1: Three cycle design science process [56].

The first step of the DSR cycle includes the problem statement. The problem context is described in Sub-section 1.1. Sections 4 and 5 complement the identified problems by gathering a comprehensive local context of Ghana and West Africa to ensure the elicitation of all design requirements relevant to this context. The problem context is derived from expert and researcher interviews, and scientific literature.

The second step involves the design cycle, which is further elaborated in Sub-section 2.1. The problem context serves as the foundation for the formulation of User Stories. A detailed description of the utilization of User Stories within this research is provided in Sub-section 6.1. The problem context is derived from user, expert, and researcher interviews, as well as scientific literature. Subsequently, the User Stories are derived from the problem context for the design of a digital educational library in a West African context in steps 2,3, and 4.

In the fifth step, the design requirements (RQs) are derived by addressing the identified User Stories in steps 2, 3, and 4. Subsequently, the sixth step derives the design principles (DPs) from the derived design requirements. Step 7 validates the identified requirements and design principles through relevant scientific literature in the domain context. Step 8 validates the identified requirements through the case study results and step 9 validates the constructed design principles through expert interviews. Lastly, the developed design knowledge is documented in step 10.

The Relevance Cycle bridges the problem context and user interviews with the design cycle activities by imaging the current West African educational landscape and state-of-the art technologies with regards to digital libraries [56].

Furthermore, the Rigor Cycle connects the design science activities with the knowledge base of scientific literature, experiences, and expertise in the relevant research domains [56]. Validating the design requirements and principles through scientific literature is an important aspect of the Rigor Cycle. Additionally, the Rigor Cycle also ensures the validation of the design principles through expert interviews.

Lastly, the main Design Cycle, discussed in Sub-section 2.1, iterates between the design cycle activities of developing and evaluating the design artifacts and the two supplementing cycles of the DSR approach [56].

2.1 Research phases

This Sub-section includes the DSR approach and the research methods used for this research. This research will be conducted based on the design science cycle as described by Wieringa [57]. This research is divided into three tasks, i.e., problem investigation, treatment design and treatment evaluation. This is called the design cycle, while researchers in a design science project iterate over these tasks many times. The design cycle is part of the larger engineering cycle, which is a rational problem-solving process as visible in Figure 2. This research will use the engineering cycle, because it aims to develop and implement design principles for the described context in Section 1 [57].

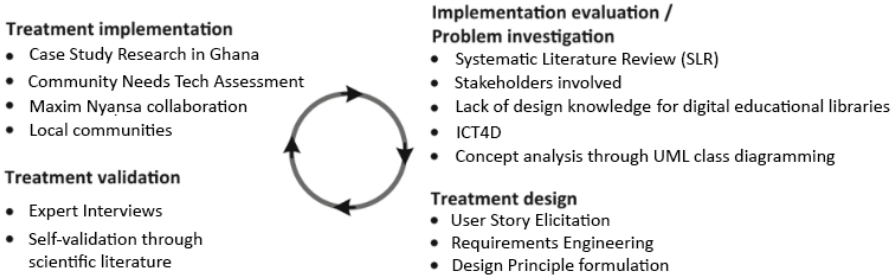


Figure 2: The engineering cycle retrieved from Wieringa [57].

Since this research is creating design knowledge, the research phases proposed by Wieringa [57] will be used (Figure 1). This research will consist of the following phases:

- **Problem investigation**

  The initial phase involves investigating the problem context of digital educational libraries in a West African context. Building upon these identified problems, the research aim is formulated, and the research questions are specified. Furthermore, the research approach is further specified to align with the identified objectives and research questions.

  The problem investigation phase consists of conducting a systematic literature review (SLR) to explore the context of digital libraries in the West African educational domain, which informs the digital educational library design process for the treatment design phase. The problem investigation phase focuses on exploring the different learning approaches, the opportunities and challenges of e-learning, mobile learning and distance education, the current educational landscape with its challenges and opportunities, and emerging state-of-the-art technologies in the digital library domain. The educational landscape is an essential component as it provides the foundation for the treatment design phase with its focus on the West African context. The educational landscape is visualized in a rich picture to provide a comprehensive overview of the factors influencing the educational domain. This phase also consists of constructing a UML class diagram that incorporates the core concepts and characteristics of digital educational libraries. Academic literature, together with expert and researcher interviews, are the primary resources to gain insights into the domain-specific concepts related to digital educational libraries in a West African context.

- **Treatment design**

  The treatment design phase involves developing design solutions to address the problems identified during the problem investigation phase. This phase consists of the design process to develop the design of digital educational libraries in a West African context that leads to usability and knowledge building. In this phase, we conduct additional semi-structured interviews with existing and potential users, domain experts, and researchers to inform the design process.

Through these interviews and relevant literature, User Stories are constructed to form a foundation to subsequently construct user and technical requirements necessary for the design process. These requirements are implemented in our case study research in Ghana to validate and refine the design requirements, i.e. treatment implementation phase. The requirements serve as the foundation to develop the final stage of the design process, which is a comprehensive set of design principles (DPs). Additionally, enhanced local design principles (LDPs) are designed to serve as a baseline for the physical implementation of digital educational libraries in West African communities.

- **Treatment implementation**

  In this step, a local implementation of the developed design for the digital educational library is performed in a real-world environment in a developing country, i.e., Ghana in Africa. This phase is in collaboration with Maxim Nyansa Foundation. Maxim Nyansa plays a key role in facilitating the execution of our case study research by providing a selection of schools, the preparation of ICT labs, and funding for the project to ensure a successful implementation of the design in a physical environment. These features are designed by Maxim Nyansa and tailored by the researchers to answer the corresponding research question, i.e., research question 5 and 6. The case study research is performed on three public schools, referred to as cases, in Accra, Adanwomase and Bolgatanga in Ghana. Case studies are conducted with the goal of enhancing knowledge and also bring change to the identified problems in Sub-section 1.1 to enhance education in developing countries [58]. A more detailed description of the case study protocol can be found in Sub-section 3.3. The proposed design requirements are implemented in the case study research and improved based on the results. These design principles will initially be developed and designed in a West-African context with the potential for future expansion to other developing countries.

- **Treatment validation**

  Our developed Community Needs Tech Assessment (CNTA) aims to validate and enhance the proposed design of digital educational libraries, in particular the design requirements. A detailed description of the CNTA is provided in Section 6.3.4. The Interview-Surveys with both existing and potential users and the Asset Inventory is an important component of the CNTA to validate the design requirements. Potential users, includig teachers and students, have important insights in the workflow of the digital educational libraries, which can inform the digital library design.

  Furthermore, self-validation, for both the design requirements and principles, is performed by investigating relevant scientific literature in the research domain.

  Lastly, experts and researcher interviews are conducted to provide insights in how design principles can be utilized in digital educational libraries in practice and whether these are viable based on their expertise in their domain and the local context. According to their feedback, changes to the initial design might be made.

- **Treatment implementation evaluation**

  The effects in education take a long time to be shown due to the difficult way of measuring the impact of technology in education [59]. Therefore, we will not have sufficient time to evaluate this in a real-world environment. An interesting area for future research is investigating how to effectively measure the impact of innovative technologies in education.

- **Dissemination**

  The final stage of the study involves documenting the research findings. In this sub-Sub-section, we discuss the results by elaborating on all research questions and the final conclusions for the main research question (MRQ). Additionally, we take a closer look at the implications of the research and elaborate on any limitations encountered during the study. Furthermore, we discuss potential future research areas. The complete thesis report will be the deliverable of this phase.

3 Research methods

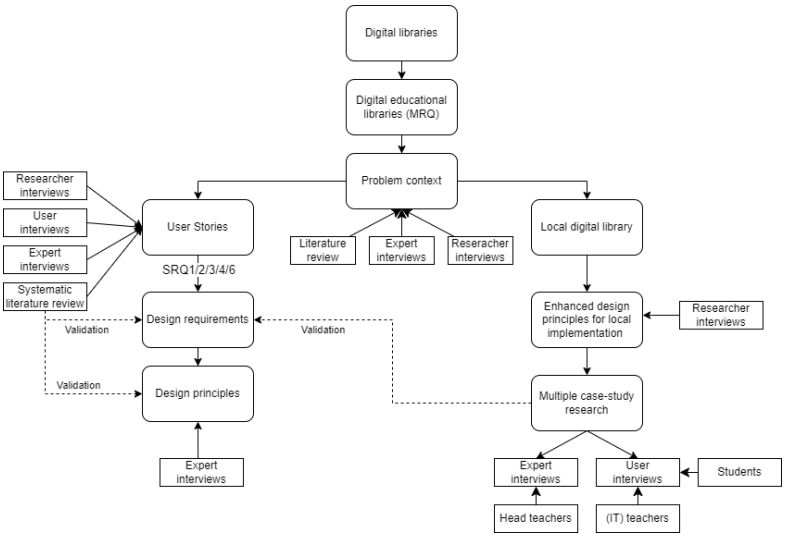


Figure 3: Research method overview.

As explained in the Research approach, this research consists of seven phases based on the engineering cycle proposed by Wieringa [57]. To answer the different research questions, different research methods are used. The different research methods are shown in Table 2. The remainder of this Section is dedicated to a more detailed description of the research methods.

	Problem investigation	Treatment design			Treatment validation/ implementation		
	SQ1	SQ2	SQ3	SQ4	SQ5	SQ6	SQ7
Systematic Literature review	X	X	X	X			X
Back- forwards snowballing	X	X	X	X			
Interviews	X	X	X	X	X	X	X
- Expert interviews	X	X	X	X	X	X	X
- User interviews		X	X	X	X	X	
- Researcher interviews		X	X	X			X
Case study		X	X	X	X	X	X
- Case study research		X	X	X			X
- Expert interviews					X	X	
- User interviews					X	X	
Community Needs Tech Assessment (CNTA)					X	X	X

Table 2: Research methods used for answering research questions, including the engineering cycle.

The data of this research can be accessed through the Yoda portal of the Utrecht University by contacting the researchers.

3.1 Evidence-based software engineering (EBSE)

Digital educational libraries are a part of software engineering. According to Dyba [60] software engineering researchers should adopt evidence-based software engineering (EBSE). As software is taking a more prominent place in everyday life, EBSE is becoming a more important and

growing research area [52]. EBSE focuses on applying an evidence-based approach for software engineering and practices [53]. The goal of EBSE is: *''To provide the means by which current best evidence from research can be integrated with practical experience and human values in the decision-making process regarding the development and maintenance of software"* [60]. *Evidence* is defined as the combination of the highest-quality scientific researches on a specific topic or research question. The aim of EBSE is to enhance decision-making in software development and to be able to assess the best evidence and insights from both research studies and experience in practice [61]. This process entails to find the most appropriate technology for certain specific circumstances or organizations. EBSE seeks to close the gap between practice and research by focusing on practical relevance and methodological rigor [62]. The EBSE process consists of the following five steps [62]:

1. Define an answerable question by converting the relevant problem.
2. Explore existing literature based on the best evidence to answer the question.
3. Critically assess the evidence in terms of its validity, impact, and applicability.
4. Combine the assessed evidence together with practical experience, customer' values, and circumstances to execute practical decision-making.
5. Performance evaluation and provide possible improvements.

3.2 Systematic literature review (SLR)

A crucial element of academic research is conducting a literature review. Fundamentally, the advancement of knowledge comes from the foundation of previously existing research. By investigating previous literature, we gain in-depth insights in existing research and the gaps to explore in the future [63]. Digital educational libraries are part of the field of software engineering. As Dybå et al. [60] suggested, software engineering researchers should adopt evidence-based software engineering (EBSE). The primary evidence-based approach is to implement a systematic literature review (SLR). Besides the objective of an SLR to gather all available evidence on a topic, it also aims to encourage the development of evidence-based guidelines for practitioners [53]. The systematic literature review is based on the guidelines as proposed by Kitchenham [64]. By performing the literature review in a predefined systematic manner, it images the full picture of existing academic literature, and it ensures that other researchers can replicate the process. Ultimately, the goal of Evidence-Based Software Engineering (EBSE) is to create good solutions for specific software engineering contexts by making use of Kitchenham's [64] guidelines. As stated in Section 1 and Sub-section 1.1, there is a lack of scientific research in Africa and therefore the information provided in academic research revolving around Africa is mostly insufficient and outdated. For example, updated information regarding the educational situation of Western Africa and current cutting-edge technology for digital libraries is not available. Therefore, grey literature is addressed to fill the missing information in areas such as technology and education. The proposed guidelines of Garousi et al. [65] are used to include the grey literature. The quality assessment criteria are based on the AACODS checklist [66] and can be found in Appendix L.

The purpose of this systematic literature review is to investigate and image the full picture of the current state-of-the-art technologies regarding digital educational libraries, the educational situation in Western-Africa and the concepts and characteristics in digital educational libraries. The literature search protocol can be found in Appendix A. This research uses the snowballing method from Wohlin [67]. This method refers to using the reference list of a paper to find additional papers relevant to the subject. The SLR includes inclusion and exclusion criteria from the literature search protocol, which are also visible in Appendix A. The inclusion and exclusion criteria specify which studies will be *included* and which will be *excluded* from the systematic review to ensure that relevant studies are incorporated into the literature review and that no study is excluded without a proper evaluation [68].

3.3 Interviews

Interviews are considered one of the most effective techniques for eliciting requirements in various fields, including software engineering, business analysis, and research [69]. The semi-structured interviews are used to gather information to engineer design requirements in a specific context. The semi-structured interviews provide both a structure and flexibility to gather a complete response from a participant and still having the ability to form its own story. The aim was to document, transcribe and categorize the interviews appropriately. These are performed for the researcher and expert interviews which are conducted online. These interviews are recorded and transcribed. Unfortunately, unforeseen circumstances in Ghana hindered our ability to record the local interviews in Ghana. The main challenge included time limitations and precipitancy imposed by my Ghanaian supervisors, leading to the decision to focus on accurately and comprehensively document interviewee responses. Due to these time constraints, I had to involve additional interviewers to conduct my interviews without being involved in my research. Secondly, safety measures for travelling around Ghana to the project locations contributed to the time limitations, such as the potential danger of driving by night. Lastly, Maxim Nyansa's local contacts faced challenges to gather community members for interviews without clear communication to our researchers, which posed on-site challenges to organize interviews with the intended interviewees taking valuable interview time. As visible in Figure 3, the stakeholder interviews conducted for the SLR are expert interviews, user interviews and researcher interviews. The interview protocols can be found in Appendix A.3. In this research, the following interviews will be taken:

3.3.1 Expert interviews

Expert interviews are conducted to create a complete overview of the current educational landscape in Africa and cutting-edge technologies regarding digital educational libraries. A total of 11 expert interviews are conducted with experts in several domains, i.e. EDU4D, ICT4D, digital educational libraries, interactive learning, digitization in education, and innovative technologies supporting digital educational libraries, such as AI. An overview of the experts, together with their expertise(s) and conducted interview are summarized in Appendix B.1. Expert interviews are used, because they can provide valuable insights for problem investigation, evaluation, and validation of the design artefact [57]. Therefore, we conduct the expert interviews for both the literature review and the validation phase.

3.3.2 User interviews

In this research both existing users and future/potential users are interviewed to gain an understanding of their experiences, thoughts, and feelings about both the digital educational library and its design principles. Understanding the needs of users is one of the most important aspects in the design phase as elaborated in Sub-section 4.3.1.3 [30]. A total of 24 student interviews and 30 teacher interviews are conducted on different schools across Ghana following primary school, junior high school and senior high school. The user interviews consists of teachers and students. The User Interview protocols are visible in Appendix B.2. The User interviews will provide us in-depth information about the users and their preferences.

3.3.3 Researcher interviews

To have a better understanding of current cutting-edge technologies and improvements regarding our design principles, we will interview researchers in the field of ICT4D and EDU4D that have been working on software applications for developing countries. A total of five interviews are conducted with researchers from different domains, i.e. EDU4D, ICT4D, digitization in education, and innovative technologies for digital educational libraries. The researchers, together with their studies and conducted interview are summarized in Appendix B.3. As elaborated, the researcher interviews are used for the literature review.

3.4 Multiple case-study protocol

A multiple case-study is conducted to asses our approach and evaluate the proposed enhanced design principles in a real-life context. Yin [70] defined a case study as: *".. investigates a contemporary phenomenon within its real-life context"*. A case study protocol (CSP) provides a set of guidelines that is used to structure a case study research project. The design of the case study protocol is based on the guidelines of Pervan and Maimbo [71]. Pervan and Maimbo [71] presented a specific case study method tailored to the context of information system research. This case study is considered a holistic multiple-case design, and based on the Yinian perspective, as this research contains multiple cases with a different context [70]. This context is described in Sub-section 3.4.1. The case study is carried out under the supervision of the same organization, i.e. the NGO Maxim Nyansa Foundation. Runeson et al. [58] also provides additional context for software engineering. Case study research should include a clearly defined research question, a clear context of the selected cases and multiple data collection sources. The most important aspects of multiple case-study research according to Yin [70] and Runeson et al. [58] are presented below:

- The cases must represent a relevant software engineering concept. This can range from a software development process to an insight into a theoretical or practical problem, to a software product.
- Data analysis should be based on a framework, method or other artifact that fits the research question.
- Triangulation should be used to validate the findings of the case study research. Triangulation is important in both quantitative and qualitative research to increase the accuracy and strengthens the validity of the research [58]. Runeson et al. [58] defines triangulation as: *"taking multiple perspectives towards the studied object and thus provide a broader picture"*. This can be achieved by using multiple data resources or interviewees (Data triangulation), using multiple observers (Observer triangulation) or using multiple data collection methods (Methodological triangulation). In this research, triangulation is achieved by conducting multiple user and expert interviews across different cases [58].

This Sub-section provides the case study context, data collection measures, how the data is analyzed and how the findings will be incorporated in the research. As it is a multiple case study, it's possible that the specifics of the case studies may slightly change as the project progresses, based on new insights gained during the case study.

3.4.1 Context

The holistic multiple-case study will be conducted from the head office of the NGO Maxim Nyansa Foundation in Accra, the capital of Ghana. Maxim Nyansa is a non-governmental organization (NGO) established in 2016. The NGO Maxim Nyansa Foundation is located and active in several countries across Western Africa, i.e. Ghana, Burkina Faso, Nigeria, Gambia, and Sierra Leone. In 2021, they have opened the new branches, besides Ghana, in the 4 other West-African countries where they are implementing the same program. They also just opened doors in South Africa and preparations are underway for other countries in Africa too. Since their successful implementation of their 'Learning transformation program' they have taken ICT to over 60 schools in Ghana [35], [55], [72].

The mission of Maxim Nyansa is: *"Creating career perspective for young Africans with the use of information technology; by giving young Africans, who are less fortunate, a chance to be educated and equipped for their professional lives".* They believe that these young Africans possess great potential, and by giving a little push, they can thrive both personally and professionally [35]. Maxim Nyansa is supporting the sustainable development goals (SDG) of the United Nations (2016) and young Africans in three ways: 1) providing financial support for West-African schools (SDG 4), 2) promote underprivileged young Africans to become IT professional by organizing training programs (SDG 8), and 3) actively gathering, providing and reusing

European hardware in local schools in Africa [59]. Maxim Nyansa creates career perspectives for young Africans by providing education through learning transformation programs for schools and an electronic library (i.e. eLibrary or digital library) [35]. Digital content in the eLibrary remains up-to-date by content creation of teachers, business people and Maxim Nyansa's staff. A brief overview of the programs that Maxim Nyansa provides is presented [55], [72]:

Professional bootcamp for driven young Africans
This intensive program integrates hands-on practical training, real-life ICT projects, development of soft skills (e.g. communication and time management), international certifications, and three years of personal career coaching. The program can be followed by 15-20 young Africans and it takes four months to finish the bootcamp. Experienced IT trainers/business people provide voluntary training containing of the latest advancements in technology.

The learning transformation program
Maxim Nyansa Foundation has developed an integrated approach to improve the quality of education across African schools [73]. As of 2017, almost 100 school projects and approximately 30.000 students have been reached with this program. This program consists of the following interventions:

- Maintenance school; by providing school furniture.
- Building an ICT classroom; by providing computers, internet, and technical support.
- Digital skills Teacher training; so that teachers will be able to provide students with the right digital skills and information and to make sure that the ICT classroom will be correctly maintained.
- Digital library with interactive educational content. Their open digital library offers open access educational learning materials, including IT skills, soft skills, project management, general subjects such as biology and mathematics, literacy, and comprehensive reading. In 2021, the African Union have recognized the platform as one of the promising innovations in education in Africa.

Local digital library
In 2022, Maxim Nyansa introduced a new concept: local digital libraries, merging the learning transformation program with their eLibrary. These local libraries, equipped with computers or laptops equipped with Maxim Nyansa's eLibrary resources, will be accessible to local students and community members. The scarcity of traditional libraries and books in African schools is enormous, some schools are not even equipped with a library. Printed books are expensive, hard to distribute, and most of the time the content is completely out of scope with the African school curriculum. A growing number of Africans have smartphones, making e-books a more accessible option. Maxim Nyansa, therefore, aims to create a user-friendly eLibrary that ensures the young Africans to gain as much knowledge as possible. Maxim Nyansa continually seek for quality, free-of-copyright publications. They are collaborating with teachers and authors to expand their content to have a wide variety of content for every member of the community, including parents, teachers and students [72], [74].

3.4.1.1 Use cases

A total of three cases have been selected for the case study research to provide a variety of insights from different domains. The cases vary in terms of location of the school, whether it is located in a rural or urban area, and the absence or presence of an ICT lab. All the selected schools are public schools, given that private schools already possess the required resources, as summarized in Sub-section 5.1. The explanation of these terms can be found in Sub-section 5.1. Although subjected to change, the list of cases currently is as follows:

- Case A: Adanwomase Municipal Assembly Junior High School.
  This school is located in the middle of Ghana in Adanwomase; a town in the Ashanti region in Ghana, which is an rural area. Adanwomase has a population of 5000 inhabitants. This school is in the preparation phase of the local digital library.
- Case B: The asofan clusters of school in Accra.
  The asofan cluster is a cluster of four public schools. The asofan cluster is located in the Ga West Municipality. The Ga West Municipal District is one of the twenty-nine districts in Greater Accra Region and has a population of 315.000 inhabitants. The asofan cluster is in an urban area. This school is in the implementation phase of the ICT lab and the eLibrary.
- Case C: Gambibgo primary & Junior High School.
  The school is located in the north of Ghana in Gambibgo, a village in the Bolgatanga Municipal District, which is in the Upper East Region and an rural area. This school is in the implementation phase of the ICT lab and in the preparation phase of the local digital library.

3.4.1.2 Data collection

The data collection process for each individual case within the multiple-case study is constructed from a three-step strategy. No specific sample size is defined for the data collection.

First, contextual document related to the local digital library project are gathered, including documents, reports, presentations and other relevant data from the project implementation. This step has already been carried out in the context of Sub-section 3.4.1.

Second, the raw data sets collected during the case study research are retrieved. The retrieval step employs our developed Community Needs Tech Assessment (CNTA) framework. The assessments of the CNTA are mainly conducted offline due to the poor on-site internet connectivity in most areas. Each assessment in the CNTA, except the Interview-Survey, is conducted once with an undefined number of stakeholders, if implemented correctly. There is no sample size defined for the data collection in the Interview-Survey, which involves expert and user interviews. The user interviews are divided into teacher interviews and student interviews. The conducted number of Interview-Surveys per case are summarized in Table 3.

Stakeholder interviews	**Case A**	**Case B**	**Case C**
Head teacher (expert) interviews	1	1	1
Teacher interviews	15	18	18
Student interviews	17	15	16

Table 3: Number of conducted interviews on both private and public schools for the Interview-Survey.

Lastly, data will be collected through a series of semi-structured interviews for each case with relevant stakeholders for the interviews in Sub-section 3.3, including experts, user and researcher interviews. As multiple semi-structured interviews with different stakeholders are conducted, Roberts' guidelines [75] are followed and tailored to the specific context and stakeholder. These interviews aim to gain insights into the needs of local stakeholders with regards to digital educational libraries. It's noteworthy that the explanation provided in Sub-section 3.3 is applicable to the case study as well. The semi-structured interviews and the Interview-Surveys of the CNTA provide both a structure, for quantitative analysis, and flexibility to gather a complete response from a participant and still having the ability to form its own story, for qualitative analysis.

The proposed three-step data collection strategy from various sources using different methodologies allows for increased validity and reliability of case study-based research through the triangulation of evidence [58].

All gathered data can be accessed in the Yoda portal of the Utrecht University by contacting the researchers.

3.4.2 Data analysis

The data analysis will be both a quantitative evaluation as well as a qualitative evaluation. The varying circumstances of the cases and the various range of the data collection causes the descriptive and explanatory power to be maximized through case study synthesis [76]. Consequently, the analytical approach involves cross-case analysis to gain insights from the unique cases, especially when substantial differences exist among them [76]. Furthermore, the evidence presented in the qualitative data analysis will be elaborated upon and this will be part of the foundation of the case study reports and analysis. This method is also used to provide logical justifications based on findings of the semi-structured interviews and the involved stakeholders.

3.4.3 Ethical considerations

Case study research that involves working with sensitive data from either human participants or organizations, require ethical considerations in the design process [77]. At the start of the research, an Ethics and Privacy Quick Scan of the Utrecht University Research Institute of Information and Computing Sciences was conducted to visualize the ethical considerations for this research, as elaborated in Appendix K.1. Whilst the Quick Scan identified issues, this thesis project was allowed to proceed after additional human scrutiny by the program management of the MBI programme. The approval mail can be found in Appendix K.2.

Furthermore, a Work Place Agreement (WPA) has been established by the involved researcher, Maxim Nyansa and the University of Utrecht as a case study will be performed in Ghana. The involved researcher will, in collaboration with Maxim Nyansa, execute three months of his research as a participative intervention in case study research regarding digital educational libraries in Ghana. More detailed information about the case study research can be found in Sub-section 3.4.

Lastly, the participants involved in different interviews together with involved organizations will be presented with an informed consent form to sign beforehand. This form is visible in Appendix K.3.

3.5 Threats to validity

Johnson [78] found that there are five types of threats to validity; 1) Descriptive validity, 2) Interpretive validity, 3) Theoretical validity, 4) Internal validity and 5) External validity. The validity refers to which extent the results of the study participants represent the true findings amongst others outside the study [79]. The following types are identified in this research:

Descriptive validity

Descriptive validity refers to the accuracy of reporting the facts by researchers [80]. The main questions are: did the reported facts by the researcher actually happen? As elaborated in Sub-section 3.4, the aim was to document, transcribe and categorize the interviews appropriately. However, due to the unforeseen circumstances in Sub-section 3.4, we were not able to perform these for the local interviews with both user and expert interviews. To address this challenge, the interviews consisted of multiple observers during the taken interviews.

Furthermore, the interviews performed outside of Ghana which were not in-person were recorded and transcribed through Amberscript6. Lastly, participants' quotes are used to create a detailed overview of the findings as a result of this study.

Interpretive validity

Interpretive validity refers to whether the researcher accurately portrays and understands the participants' viewpoints, thoughts, feelings, intentions, and experiences [80]. This research, including the interviews and the case study, is predominantly performed in Ghana and therefore the threat to this validity is relatively low. Despite the fact of the research being mostly performed in Ghana, the cultural disparities and the language barriers still create a potential threat. English

proficiency in Ghana is of a high standard, as it is their national language, influenced by the rise of mobile phones and improved English education, especially for the younger generation. These factors all contribute significantly to overcome the language-related barriers. Nonetheless, challenges can arise in rural areas lacking proper education or where people are not feeling confident in their English proficiency, leading to communication difficulties. To address this issue, a translator was present to create a free and open environment for sharing their experiences and feelings.

To address all of the challenges, we conducted a systematic literature study and performed interviews with potential users of the digital educational library, as well as experts in the field of EDU4D. These domain experts have first-hand experience in executing these EDU4D projects in developing countries.

Furthermore, our collaboration with the NGO Maxim Nyansa provides us with a local cultural perspective as well as a way to improve our interpretive validity. The collaboration ensures an in-depth understanding of the Ghanaian context providing us with accurate interpretations in our research.

Internal validity

Internal validity refers to whether a researcher can conclude that a treatment causes the outcome. The question is whether the researcher is justified to conclude that there is a causal relationship [80]. Several measures are taken to increase the internal validity, a systematic literature review (SLR) is performed based on the results of the exploratory literature search, this ensures that all relevant concepts and requirements are considered. By comparing the interviews with the findings of the SLR, we are able to validate the concepts found in both literature and interview and address the threat to internal validity. Furthermore, the aim was to prevent stakeholder bias to occur by conducting interviews with a wide variety of stakeholders. The fact that Maxim Nyansa was the organizer of the projects made it more difficult to achieve this. However, by ensuring random selection of participants we addressed the threat to internal validity.

External validity

External validity refers to which extent the results of a study can be generalized to other situations, groups, or events [80]. The threat to external validity is present as we use the digital educational library as a general concept. In general, the proposed design principles and method are designed in such a way that this can be adapted to a specific project and its environment. However, it should be taken into account that our method is based on the domain of education and the limited amount of cases for this research. Due to time limitations we are not able to conduct interviews with every domain in the field of digital libraries and therefore we base our outcomes on digital educational libraries specifically. To address this problem, we conduct the user interviews with different (types of) schools with randomly selected users. Furthermore, the expert and researcher interviews are partly randomly selected as the interviewees are selected by members of Maxim Nyansa without any interference by the researchers. These interviews, together with the scientific literature, are important to provide a solid overview of the EDU4D domain. The results should be broadly applicable to provide other developing countries in the future with the concept of digital educational libraries. Furthermore, our proposed method is tested in practice during a case study in Ghana. Data collection is retrieved from three different projects in Ghana.

4 Literature review

As elaborated in Section 2, Sections 4 and 5 lay the foundation for the design process and the formulation of the design principles in Section 6. This section provides a comprehensive overview of relevant scientific literature with the focus on designing digital educational libraries within the context of West Africa, supported by Design Science Research (DSR). First, it delves into the methodology of formulating design principles for Information Systems. Following this, ithe domain of Information and Communication Technology for Development (ICT4D) and Education for Development (EDU4D) are explored by looking into the challenges and opportunities that developing countries face in this domain. This exploration provides practitioners, designers, policymakers, and developers with valuable insights into Information System design and the reason why most EDU4D projects currently fail in Africa.

The following sections delve into the evolution from traditional learning into digital learning and the future prospects of ubiquitous learning. While the potential of digital learning is extensive, the ICT infrastructure in West African countries is lacking. By addressing these challenges, education in developing countries can significantly benefit from the transformative potential of mobile and digital technologies. Education and innovation are shown to have an essential role in driving economic development. Additionally, the main design objectives, i.e. usability and knowledge building, are explored.

Moreover, this Section explores the fundamental role of (digital) libraries in education. Together with the emergence of the internet and innovative technologies, there is a promising opportunity to bridge information gaps and the digital divide. Subsequently, the concepts and characteristics of digital educational libraries are explored through UML class diagramming. The visualization of the conceptual structure of digital educational libraries informs the design process by showing the essential components and needs of these information systems.

Lastly, state-of-the-art innovative technologies for digital educational libraries are explored to gain insights into future technological advancements for these platforms, such as Artificial Intelligence (AI), Natural Language Interaction (NLI), Gamification, Mobile Learning and Cloud Computing. These technologies are discussed in terms of their potential to revolutionize students' learning journey and address the challenges in education, particularly in underdeveloped environments.

4.1 Formulating Design Principles for Information Systems

One of the main components of this research is answering the main research question by formulating design principles for digital educational libraries in a West African context. Design Science Research (DSR) has gained significant attention over the past few decades as it plays a crucial role in shaping the future of products, services, systems, software, and architecture [81]. Design-based research is a combination of research, theory, and practice [82]. The aforementioned solutions are all relying on the evolution of design knowledge, which consists of a solid foundation of formalized understanding and providing the possibility for practitioners to innovate. An essential aspect of design science is the formulation and application of design principles [81]. The book *Universal Principles of Design* [83] utilizes the following definition for developing design principles:

"A design principle provides fundamental guidelines or rules that function as a compass for the product and for future design activities" – [83]

Design principles are statements that consist of laws, guidelines, human biases and general considerations. The design principle can originate theoretically, or empirically. They provide a framework for designers to follow and help to make choices to achieve a successful and meaningful design. These principles can be tailored to a specific domain or design [81], [84].

Moreover, the purpose of these design principles is to represent design knowledge and a prescriptive component from the design theory with taking re-usability into account. Re-usability is a crucial concept in design knowledge as design principles should be re-usable across different contexts [85]. Figure 4 shows the evaluation criteria of reusability for design principles.

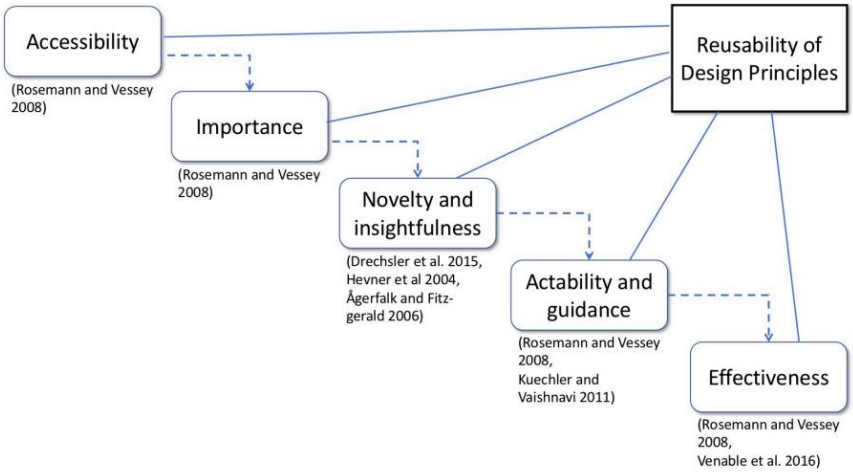


Figure 4: Evaluation criteria of reusability for design principles domains [85].

However, reusability cannot be taken for granted due to the problem of inconsistency, i.e., inconsistency in their orientation towards action or material, and the problem of imprecision, i.e., incomplete, or misleading [86], [87]. Inconsistency poses a challenge in the application of design principles to artifact building as it can develop an incorrect interpretation and reduce clarity of the formulated design principle. The problem of imprecision is caused by the imprecise formulation of design principles. The correct use of words is crucial to make sure that the formulation of the design principle is fully understandable and not ambiguous [86]. To address the challenges of inconsistency and imprecision, Gregor et al. [88] constructed a framework for formulating a design principle, as elaborated in Table 4. The framework involves four actors: Implementers, Users, Enactors, and Theorizers. Firstly, *Implementers* are individuals/teams responsible for translating abstract needs into tangible and concrete design principles that can be implemented into the real-world context. Secondly, *Users* are individuals or groups for whom the design is intended to serve through their goals and needs. Thirdly, *enactors* are individuals that perform the actions within the design context to achieve the intended aims/functionalities of users. Lastly, *theorizers* are individuals who reflect on the concrete design context and aim to capture the underlying design knowledge. *Theorizers* and *Implementers* can be the same individual.

Structure	*Components*
For **Implementer I** to achieve or allow **Aim A** for **User U**	**Aim**, **Implementer**, and **User**
In **Context C**	**Content**: Boundary conditions, implementation setting, further use characteristics.
Employ **Mechanisms** M1, M2, M3…, Involving **Enactors** E1, E2, E3…	**Mechanisms**: acts, activities, processes, architecture, manipulation of other artifacts. **Enactors**: Subsidiary components that can have their own design principles.
Because of **Rationale R**	**Rationale**: Theoretical or empirical justification for the design principle

Table 4: Formulation of a design principle by the framework of Gregor et al. [88].

Additionally, Cronholm & Göbel [89] have developed three guidelines that form a unified framework to guide the development process of formulating design principles. The guidelines are adaptable based on the specific situation at hand. The guidelines and explanations are visible in Table 5. By following these guidelines, we are able to formulate the design principles in a correct manner.

Meta-design principle	Definition	Includes
Content	Gaining informative, intelligible, and transparent content.	All justified with argument(s): • The purpose/goal of the artefact. • The action/process concerning the building of the artefact. • The boundary/context specifying where the artefact can be used. • The artefact properties. • The action/process concerning the evaluation of the artefact.
Structure	Creating a homogenous structure.	• Congruent (directed to the same artefact). • Logically connected (directed towards different aspects of the artefact that together form a wholeness). • Consistent (having uniformity).
High- and low-levels of abstraction	To create an increased understanding and to facilitate support reusability.	• Be formulated on both high- and a low-levels of abstractions (including examples). • Explicitly describe the class and the instance of the artefact

Table 5: Enhanced guidelines for formulating design principles [91].

4.2 ICT4D

The impoverished regions in the world are suffering the most from the current issues in the world, such as climate change, conflict and terror, diseases, and lack of resources. Additionally, these countries are suffering massively from poverty with nearly half of the world's population surviving on less than 2 dollars per day. The introduction of the internet stimulated research on how we can leverage ICT to benefit developing countries [90].

Information and Communication Technologies (ICT) in combination with the World Wide Web (WWW) were a gamechanger for today's world and impacted every aspect of life. These technologies shape the future of knowledge sharing and information exchange [91]. Most of the initiatives in developing countries aim to lift people out of poverty are currently based on ICT [91]. ICT research for developing countries, also called ICT for development (ICT4D) emerged in the 1980s. The early researchers on ICT4D shared the belief that computers were able to address the challenges faced by developing economies and societies in government, education, and health [92]. Studies have shown that ICT4D is of great significance in the current world [93], [94], [95]. ICT4D research proves the indispensable role of technology in deploying innovative processes, products, and services to make the society a better place [96]. ICT4D attempts to leverage ICT tools to bridge the digital divide and transform the lives of the disadvantaged into a better place by intervening into the opportunities of societies, for example: improving government services and economic activity, in developing countries [7]. Information and communications technologies (ICT) are considered to be essential for achieving socioeconomic, for example: poverty (economic) or social connections (social), progress for developing countries and disadvantaged individuals [97], [98] [98]. The fundamental of ICT4D is the ability and willingness of individuals to use these technological resources to improve their society [99].

Unfortunately, a substantial portion of studies and initiatives in the field of ICT4D research has shown to be unsuccessful in improving the livelihood of Africans and therefore fail to achieve their intended outcome [100]. Several studies have elaborated upon the implications associated with realizing the potential benefits of ICT4D projects [101]. These implications are described in Sub-section 4.3.1.3.

4.3 EDU4D

An important area of stimulating development and impacting the developing world is the field of education. ICT4D projects within education is called education for development (EDU4D). EDU4D can have a transformative effect on the development of individuals and communities in developing countries. EDU4D has the potential to be a powerful driver for growth in Africa [23]. ICT has the potential to improve the quality of education, enhance skill development, engage students in active learning, connect schools to the job market, create economic viability, drive school transformation, and facilitate global connections [24], [25]. However, challenges such as lack of electricity, lack of government budget towards ICT infrastructure (i.e., hardware and software), funding, and limited computer literacy among teachers and students hinder widespread ICT usage [19], [26]. A detailed description of additional challenges and opportunities in EDU4D research can be found in Sub-section 4.3.1.3.

EDU4D projects range from donating much needed hardware and software to schools to ICT training for teachers. The efficiency and impact of these interventions are influenced by several factors or Key Performance Indicators (KPIs) [59]. Smulders [59] developed an assessment method to assess the situational impact of a specific EDU4D project by selecting relevant method fragments or Key Performance Indicators (KPIs). Le [102], [RI.4] enhanced this method in practice by designing and implementing a tool that simplifies and supports the application of this impact assessment method.

4.3.1 ICT interventions in education (EDU4D) in Ghana

The Millennium goals of 2000 set by the United Nations were the start of the development and deployment of ICTs from international developing agencies, such as UNESCO and the World Bank, in the developing world. These Millennium goals were the kick-starter of the ICT4D movement and the ICTs were seen as “magic development solution” to poverty [30].

Since then, several ICT4D projects have been deployed into developing countries. The initiatives for ICT4D in African countries, for example in Ghana, are both initiated by governmental and non-governmental organizations. A non-governmental organization (NGOs) is typically a voluntary group or organization with a social mission, which can be corporate institutions, donors, Parent Teacher Associations (PTAs), or philantropists [29].

Furthermore, Tourey et al. [19] found that one of the main problems for executing projects in education in developing countries is the lack of funding, which hampers the implementation of ICTs in Africa. As elaborated in Sub-section 5.3.1.3, the total government spending on education in Ghana is far below the global benchmark. Collaborative efforts has been made on the national level, by involving regional and district officers to overlook the ICT coordination, while adhering to the instructions of the National Inspectorate Division (NID) and the curriculum of the Ghana Education Service (GES) [103].

4.3.1.1 Governmental initiatives

- **One laptop per child policy (OLPCP) project**

The mission of the one laptop per child policy (OLPCP) was to provide one connected laptop for every school-age child to empower the children of developing countries by facilitating learning and expanding their access to the opportunities of the outside world. Owusu-Ansah [4] found positive changes in education because of this project, such as: increased enrollment in schools, decreased absenteeism, increased performance, and increased classroom participation. However, it is uncertain if these advancements were the result of the project because of non-systematic and non-independent evaluations. Problems during the project were mainly revolving around the lack of qualified teachers, poor maintenance, lack of electricity and poor infrastructure (computer labs). The project was discontinued because of political reasons [29].

- **Basic School Computerization Policy**

The Basic School Computerization policy was introduced in 2011 aimed to the massive deployment of ICT resources into schools and training for teachers. The Ministry of Education (MoE) together with the GES were able to supply 60.000 computers. Furthermore, they provided a teacher training program, for teachers in all regions of Ghana, for ICT skills and digital literacy. Challenges during this project include the lack of electricity, poor internet access, insufficient number of computers, poor technical know-how and despite of the training, poor capabilities of teachers to use ICT for teaching and research [36]. It is unknown what the effects of this program has been.

- **I-Box and Student ID**

The i-box is introduced in 2016 as part of the Government of Ghana Secondary Education Improvement Project (SEIP). The i-box is an offline server which grants access to learning resources without the need internet connectivity and its associated cost. Furthermore, the box also has browsing options to find quality content without the need of internet. The box provides content in four formats, i.e. text, audio-visual, interactive and questions/answers [104]. The advantages of the i-box are that the schools only needs laptops, desktops, tablets or smartphones to access the content without the need of an expensive and most of the time unreliable internet connection. The challenges are still prevalent which includes the limited storage of learning materials on the i-box, lack of infrastructure (computer labs), difficulty of teaching other subjects, and the pressure of following the curriculum [105]. Awuni [104] found that 83.9% of 162 participants failed to integrate and use the iBox in teaching and learning as the iBox relies on internet connection and is difficult to use.

- **The Ghana Education Outcomes Project (GEOP)**

The Ghanaian government launched a new project in March 2023: The Ghana Education Outcomes Project (GEOP). This project is a 30 million dollar fund to get out-of-school children back into education and improve learning outcomes in primary schools. The goal is to get 70.000 out-of-school children back into school and enhance learning outcomes for 98.000 children over 600 primary school. The project works with a results-based financing mechanism, which means that schools will only receive the funding if they achieve certain results. Several issues have been identified with this project: the process is slow, the comparison with a control school (learning outcomes can be influenced by other interventions), the change of the start of the academic year from September to January can skew results, and possible poor-performing kids being dropped because of the results-based mechanism. In summary, while the project is a great new initiative, it comes with significant uncertainties and issues [106].

4.3.1.2 Non-Governmental initiatives

- **Maxim Nyansa**

The NGO Maxim Nyansa Foundation, established in 2016, aims to give underprivileged young Africans a change to be educated and equipped for the future with the help of information technologies. They believe in a bi-cultural approach where Europeans and Africans are working together on the basis of equality to reach each of their potential. Their programs include a Professional bootcamp for driven young Africans, a learning transformation program, a digital library, and ICT centres. A detailed description of their programs is given in Sub-section 3.4.1. Their trainings are given by African and Europeans experts in the field of ICT. They have taken ICT to over 102 schools and facilitated more than 57.000 students with ICT labs in Ghana. They are located in all over Western Africa and their goal is to give all the students a chance to receive quality education [35].

- **Africa ICT Right (AIR)**

Africa ICT Right (AIR) is an ICT-oriented NGO, established in 2007, aiming to bridge the digital divide by building a future where everyone can benefit, especially underprivileged countries and communities, from the advantages of the technological revolution with an evenly distributed amount of tools such as computers, internet and mobile phones. AIR uses Information and Communication Technology (ICT) tools to address critical national problems in Ghana related to education, agriculture, health, gender, and youth empowerment. They run the following educational programs that provide technological solutions and support to educational and health care facilities in underserved areas [107]:

- **ITeach:** ICT teacher training to equip them with skills to integrate ICTs in their lessons
- **Computer4Change:** is a laptop-donation program
- **Connecting the Unconnected:** This project builds community centres in rural areas and provides them with computers. These centres are digital information hubs where community members can share skills and help each other build and develop digital skills.
- **Girls In Tech:** This initiative educates girls the skills, ICTs, and enthusiasm necessary to pursue a career in technology.

- **Sustainable Economic Development (PSED)**

PSED is a development program commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ). This development program has the goal to enhance the conditions for utilizing digital transformation in employment and entrepreneurship, especially in rural areas. They are spreading digital skills, tools, and entrepreneurship through already existing decentralised Community ICT Centres (CICs) and innovation hubs, this is called their digital transformation center (DTC) approach [108]. The DTC facilitates the following initiatives [108]:

- **Access to digital technologies in rural areas:** In line with the Ghanaian government, the DTC strives to bridge the urban-rural divide by spreading digital services to rural and underprivileged communities, providing access to ICT tools and the internet.
- **Make-IT Africa:** This initiative focuses on Tech-Entrepreneurship. It supports an environment for young entrepreneurs in the digital sector.
- **#eSkills4Girls:** The #eSkills4Girls initiative empowers girls with the skills, ICTs, and enthusiasm needed to follow a career in technology, thereby bridging the gender digital divide.
- **FAIR Forward:** The FAIR Forward (Artificial Intelligence (AI) for All) initiative focuses on building new skills through the potential of AI.

4.3.1.3 Challenges and opportunities

Despite the successes achieved by these initiatives, the challenges are still prevalent and they have been identified by researchers. Several studies show difficulties in realizing the potential benefits of ICT for development (ICT4D) projects [101], [109], [110], [111].

Moreover, it has been argued that ICT4D research fails the poor [112]. According to Harris [112] and Davison [113] there are three main reasons why ICT4D research fails to serve the poor: (1) the researchers lack involvement in important policy positions needed to make a difference, as they tend to prioritize specialized qualitative studies making ICT4D research less accessible to a broader audience and especially the developing countries; (2) insufficient engagement between ICT4D researchers and end-users of their findings resulting in solutions that do not cover and solve real-world issues (a detailed description is provided in the next paragraph); and (3) few researchers actively contribute by engaging in policy positions or practical applications, needed to make a real impact on developing countries, because of their obsession with the publish-or-perish culture, which is the pressure to publish academic research to succeed in their academic career [114].

Although the good intentions of researchers, technology development projects seem to fail addressing the challenges faced by the poor resulting in unsuccessful projects [115], [116]. Davison [113] strengthens this perspective with "in order to make a better world, changes are needed in our research and practice".

Touray [19] identified the main ICT barriers leading to the failure of initiatives in developing countries, visible in Figure 5. Researchers found that the success or failure of ICT projects is determined by critical factors [117]. Touray [19] identified eight critical success factors (CSFs) crucial for the success of ICT projects in developing countries: political and leadership (PL), technical (TN), socio-cultural (SC), economical (EC), security and safety (SS), legal and regulatory (LR), infrastructural (IF), and educational & skills (ES). Figure 5 illustrates the identified barriers grouped into eight critical success factors, according to Touray et al. [19]. These critical success factors should all be present to ensure the success of an ICT project in a developing country. As elaborated in Sub-section 4.3.1.1, most of the governmental initiatives were either unsuccessful, or the outcomes remain unknown. The main factors contributing to the failures were political reasons; i.e., corruption, micromanaging (delegating responsibility without the relevant authority to execute it), and political instability [19].

Political & Leadership	Technical	Socio-Cultural	Economical	Security & Safety	Legal & Regulatory	Imfrastructural	Educational & Skills
corruption	obsolete technologies	lack of cultural knowledge or limitations	low income	perceived lack of privacy	lack of proper legal framework	lack of or inadequate fixed telephone lines	scarcity of technical personnel
lack of political will	inappropriate technologies	resistance to change	lack of investment	insecurity	poor regulation	lack of software and hardware	high illiteracy
unnecessary bureaucracy	complex technology	fear of technology	low returns on investment			lack of access	lack of ICT skills
high taxes	low Internet bandwidth	lack of relevant local content	high costs			inadequate or lack of electricity supply	lack of research and development
lack of regional initiatives	unreliable Internet connection	lack of maintenance culture	insufficient use or non-existing universal service fund			lack of Internet exchange points	
political instability	poor network reception	lack of language skills	limited sustainability of networks				
lack of proper planning or cordination			lack of incentives				
monopoly			high risk on investment				
invisible hands							
micromanaging							

Figure 5: barriers grouped into critical success factors [19].

Diniz [30] discovered the answer on the question why EDU4D project fail in the differences between designers' perceptions of the technology's functionalities and the actual needs of the users for the technology. Shortly, the designers' perceptions differ so significantly from the actual needs that this results in the failure of projects. Heeks [34] referred to this mismatch between designers' perception and users' experience as the design-reality gap. Cervantas et al. [118] concludes this by saying that the users' needs are "far more complex than what designers assume".
The following four approaches can be considered to narrow the gap between users' needs and designers' perceptions: the cognitive approach, the local setting approach, the contextualist approach, and the user agency approach. These approaches can be integrated individually or in combination [30]. The approaches and their detailed descriptions can be found in Table 6. Diniz [30] found that local adaptations to the context are crucial as contexts are unique and dynamic in their own specific situation. Consequently, local adjustments should be tailored to the context of use (context-oriented) rather than focusing on the technology itself (technology-oriented) [30], [119]. According to Van Reijswoud [120], ICT projects in developing countries tend to be more successful when tailored to the local context and by incorporating the appropriate technologies that meet the needs of the community. An effective method to map the needs of users and underprivileged communities is by conducting a "community needs assessment (CNA)" beforehand. The CNA should be tailored to the local context, and the outcomes are driven by the target group consisting of local users and communities. A crucial aspect of the CNA involves researchers to physically visit the site to investigate and delve into the true needs of both users and the community. The CNA provides a framework for identifying solutions to the challenges communities face, while preventing researchers from making assumptions [121], [122].
Users' adaptations are a key driver in determining the success of an ICT4D project [123]. The study considers the user agency approach with the focus on context-oriented actions as the most effective approach to understand failure and success in ICT4D projects because of the importance of user empowerment and the influence of the dynamic context in this approach [30].

Approach	Description
Cognitive	Users should employ a rational decision process to evaluate the use of a technology in a project, with emphasizing on the technology functionalities. Davis' [124] technology adoption model (TAM) forms the theoretical basis which uses perceived ease of use and perceived usefulness for predicting the usage in ICT4D projects.
Local setting	The focus is on understanding and optimizing the interaction between users and technology within a specific local context, taking into account the national culture, to design a user-friendly interface based on Human-Computer Interaction (HCI) principles. Those are the principles applicable to the design, build and evaluation of effective interfaces.
Contextualist	Develops and use concepts, models, and theories to explain (technological) contextual factors creating the differences between designers' perceptions and users' needs. Applies actor-network analysis and social construct of technology (SCOT) theory, which shows the existing differences in meaning for unique contexts, aiming to create case-specific factors for designers to consider.
User agency	Recognizes the influence of social, political, and organizational climates on technology development. Users are seen capable of making local adaptations to technologies to better fit the context. This approach acknowledges the ability of users in altering context to achieve project success.

Table 6: The four approaches by Diniz [30].

In summary, active engagement between ICT4D researchers and users in combination with active participation in policy positions, and a commitment of researchers to implement the findings of EDU4D research, there is a big opportunity to make a significant impact on education in developing countries. In addition, designers should prioritize the needs of users over their own perceptions. By considering the four approaches, i.e. the cognitive approach, the local setting approach, the contextualist approach, and the user agency approach, designers can narrow the gap between users' needs and designers' perceptions. An effective method, without researchers making their own assumptions, to map the needs of users and underprivileged communities is by conducting a "community needs assessment" beforehand. It is important to change the context of use (context-oriented) by following the needs of the users and not the technology itself (technology-oriented). These local adaptions from users are shown to be key to project success. In the design process of ICT projects, it is crucial to engage the main stakeholders and consider the local context. The designers and decision-makers should truly understand the community's needs and situation.

4.4 Evolution from distance learning to ubiquitous learning.

Distance learning (d-learning) is not a new form of education, d-learning already exists for more than a hundred years [125]. According to Keegan [126] the key characteristics of d-learning are: the physical separation of teacher and student in both time and distance, educational organizations provide content creation, planning and student support, use of technologies for teaching and it facilitates two-way communication (student-teacher and student-student communication).

With the emergence and rapid development of new technologies, such as computers and the internet, new forms of education appeared. E-education offers new methods for distance education by using new technologies to provide learning environments [125]. This relation of e-learning to d-learning is visible in Figure 6. E-learning (e-learning) has the potential to provide substantial amounts of students with access to education. E-education is becoming the universally accepted solution for the enormous shortage of trained and quality teachers that developing countries, such as Africa, suffer with [127].`

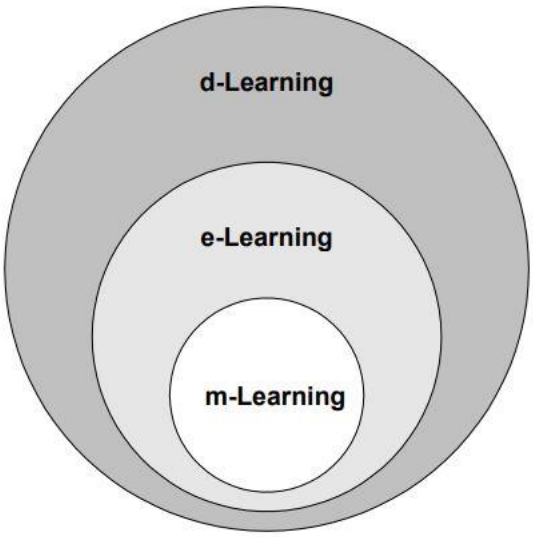


Figure 6: m-Learning in relation to e-Learning and d-Learning [125].

Since the introduction of mobile technologies, the development and adoption rate of mobile technologies are rapidly increasing all around the world. Mobile technologies include laptops, tablets, personal digital assistant (PDA), e-readers, cellular phones and smartphones. The difference between the cellular phones and smartphones are crucial, as only smartphones are

capable of using mobile technologies for e-learning. While cellular phones are basic devices mainly used for voice calls and SMS messaging, smartphones, on the other hand, are advanced devices capable of using interactive resources and the internet [125]. Especially, in developing countries, the adoption rates of smartphones are on an impressive rise [48]. These smartphones are important for the implementation of e-learning in education [125]. The number of smartphone subscriptions in Sub-Saharan Africa experienced a substantial increase from 19.12 million subscriptions in 2011 to 414.77 million in 2022, which is a remarkable growth of 2170% in just 11 years. The numbers of smartphone subscriptions in Sub-Saharan Africa are even expected to reach 689 million in 2028, as visible in Figure 7 [128].

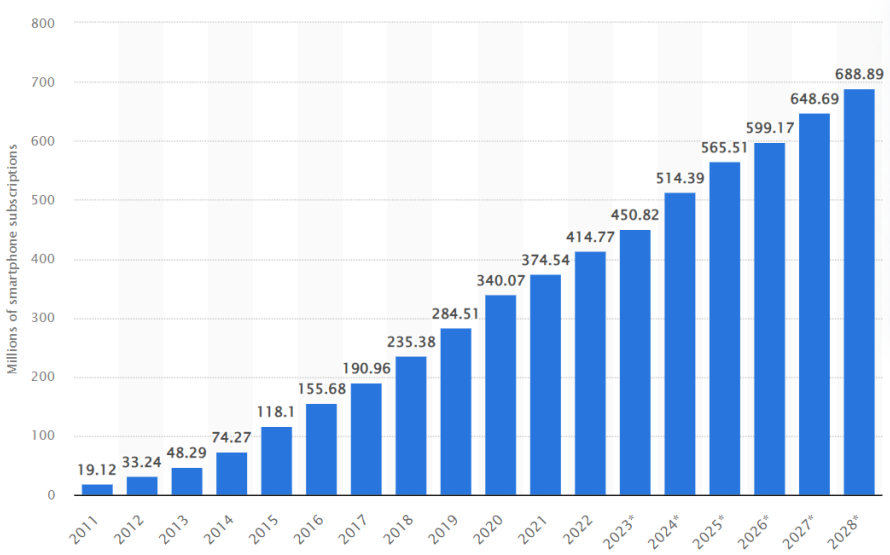


Figure 7: Number of smartphone subscriptions in Sub-Saharan Africa (2011 – 2028) [128].

Mobile technologies in combination with learning, called m-learning, is an extension of e-learning and have the power to make learning more widely available and accessible than existing e-learning environments, also visible in Figure 6 [26]. Quin [129] simply describes m-learning as: "e-learning through mobile computational devices". Mobile technologies, where the cell phone is the most prevalent, make it possible to provide learning opportunities for learners without educational infrastructure, which can be of great importance for rural areas such as most of the areas in Africa [26]. Bates [130] argues that it is very likely that m-learning will have a far greater impact on learning than e-learning. Criollo-C et al. [131] and Brown [26] describe the benefits of m-Learning as:

- Content and learning are available and accessible from anywhere at any time.
- M-Learning provides interactive and multimedia features that enhance student engagement.
- Provides flexibility for learning approaches, therefore students can decide their own learning path, and this leads to increased student motivation.
- Mobile technologies stimulate self-directed informal learning, which encourage more active participation [132].
- Many m-learning platforms tracks the learners' progress which provide the teacher with a better understanding of students' performance.
- Offline access to material, which is a benefit for learners in rural areas and areas that have limited internet connectivity.
- Mobile technologies promote collaboration and communication between students, teachers and student-teachers and this can promote learning [133], [134].
- Teachers are provided with a wide variety of content and assessment strategies [135], [136].

M-learning is the gateway to e-learning for learners in Africa as the wireless infrastructure and the penetration of mobile technologies give access to the world of e-education [40], [41]. As visible in Figure 8, about 68% of the Ghanaian population is accessing internet through the use of smartphones, compared to only 6.3% and 0.7% through laptops or tablets and desktop computers respectively [137]. M-learning, together with mobile devices, is gradually bringing e-education to rural communities. The influence of m-learning in the educational system, in both rural and urban areas, can have a significant impact on individuals and Africa as a continent [26].

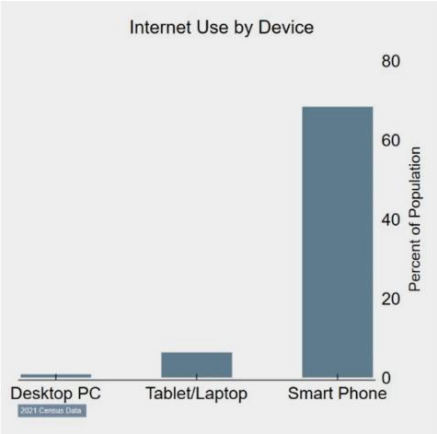


Figure 8: Smartphone uptake of internet access by Ghanaian population [137].

The most recent technological development in innovative learning approaches is defined as ubiquitous learning (u-learning). U-learning is the integration of m-learning into e-learning environments, providing a wide variety of digital information to students from anywhere at any time based on their personal needs and activities. U-learning has the potential to significantly transform the way information systems, such as digital libraries, make information resources accessible and available to users in developing countries [138]. Especially in West Africa, such as Ghana, U-learning can make a significant impact by using mobile phones for education, as the smartphone penetration with internet access in Ghana significantly increased to 68% in 2021, with the expectation of a further increase in the following years [137], [139], [EI.1]. U-learning is characterized by the utilization of technologies, enhancing interactive and effective learning experiences, with a focus on mobile learning [138]. U-learning technology features can enhances learning and digital libraries in the following aspects [140]: (1) Personalized learning; the goal of u-learning is to personalize the user experience by tailoring instructions and providing relevant personal content to the learner to improve effectiveness of the learning process. (2) Collaborative learning; u-learning facilitates collaboration between students without being physically together to enhance shared learning. (3) Mobile learning; u-learning technologies provide learning and accessibility to digital educational resources through mobile devices to facilitate learning from anywhere at any time, making learning for developing countries easier. (4) Interactive learning; u-learning technologies facilitates interactive learning through tools like virtual reality and augmented reality to enhance student engagement and improve their understanding. (5) Digital resources; u-learning technologies provide access to a wide range of digital resources enhancing information accessibility from anywhere at any time. (6) Real-time feedback; u-learning technologies can provide real-time feedback to users enhancing student engagement and progress engagement. (7) Blended learning or hybrid learning; u-learning technologies also allow blended learning, which is a combination of online and physical instruction [140].

4.5 Digital education vs traditional education

After the introduction of computers, the coronavirus pandemic at the end of 2019 posed one of the biggest and most important challenges of the global education system in the last century. 1.6 billion people in over 190 countries, covering all continents, were suffering from the pandemic and the closure of schools [141]. Suddenly, traditional face-to-face education had to rapidly adapt and change to e-education where the online environment ensured that education would be still available for all students [142], [143]. In developing countries, the transition from traditional face-to-face education to e-education was impossible due to the lack of the necessary equipment and the limited technological infrastructure required to provide online education. Especially the public schools in West African countries were affected greatly resulting in a complete interruption of students' learning process, as the technological infrastructure and equipment were non-existent. Some private schools, however, had the necessary technological resources to continue education and limit the learning disability [EI.1].

The pandemic was having a significant impact across multiple domains resulting in various implications, including lockdowns, social distancing measures, closure of educational buildings, government regulations, and a fundamental change in the delivery of education [142], [143]. Developed countries were fortunate with the implementation of e-education prior to the pandemic, which ensured the continuation of education online in developed countries. As students were forced to change from traditional education into full online learning, the impact of this transition was huge and felt challenging and difficult for all educational parties involved. Research must be conducted to reap the benefits and address the challenges of both educational systems for the implementation of e-education in developing countries [144]. Nevertheless, important aspects of technological innovation have to be taken into consideration, such as innovative and smart technologies, new teaching approaches, and students' experiences and perceptions to shape e-education in the future [145]. Table 7 provides an overview of the advantages as well as the disadvantages of both educational systems.

Areas	**Traditional education**	**E-education**
Accessibility/availability	Only accessible when scheduled	24/7 accessible from anywhere with an internet connection
Search and discovery	Time consuming by exploring books and others.	Fast and advanced search and discovery tools.
Cost of learning	High expenses due to physical infrastructure and resources required.	Low maintaining costs, only high starting expenses as a computer and internet is needed
Social interaction	High social interaction; face-to-face with teachers and students	Low social interaction, hard to communicate
Educational content	Limited, content offered by institute or books.	Wide range of content, such as multimedia resources, e-books, documents, papers
Scalability	Limited by content delivery, teachers, and physical resources	Unlimited regarding content and learners
Customization	Only teachers can customize.	Create customized courses and materials.
Learning environment	Physical classroom for face-to-face interaction.	Virtual environment
Flexibility	Limited; follows a schedule that students must adhere to	More flexibility as they can access education when they want
Assessment	In-person exams and assessments, more effective to measure knowledge	Online exams other remote assessment. Convenient but less effective.
Resources	Teacher and a classroom	Computer and internet connectivity

Table 7: Advantages and disadvantages of traditional education vs e-education [141], [144].

The results of Table 7 shows that both educational systems have clear advantages and disadvantages over the other. The findings identify practical suggestions that lead to a balance between traditional face-to-face education and digital education, which is called 'blended learning (BL)' or hybrid learning [144]. The perfect balance between face-to-face education and digital education will provide the students with an effective blended learning program. The most effective program can be created by consulting the best practices of educational systems [142], [146], [147].

4.6 Usability and knowledge building

4.6.1 Usability evaluation of digital libraries

According to Jeng's [148] usability model for digital educational libraries, illustrated in Figure 9, usability can be measured by considering effectiveness, efficiency, learnability, and satisfaction.

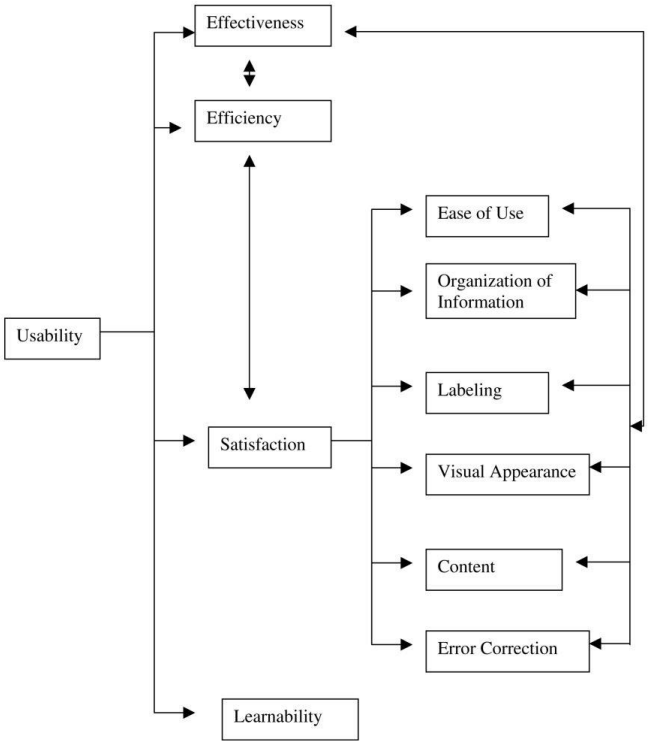


Figure 9: Usability evaluation model for digital libraries [148].

Following, the definition of the key measurements used to evaluate usability in digital libraries, according to Jeng [148]:

Effectiveness

Effectiveness refers to whether the information system achieves its intended goals effectively. Effectiveness is measured by whether a user's ability to complete tasks in relation to their intended goals, i.e. their success rate [148].

Efficiency

Efficiency refers to optimizing user productivity by minimizing the task completion time and the steps taken by the user [149]. Benbunan-Fich [150] suggests that task completion time is not suitable as the task completion time can be influenced by external factors, such as: connection speed and network traffic.

Satisfaction

User satisfaction refers to the users' experience, enjoyment and attitude when interacting with the digital library [151]. Jeng [148] highlighted that six key components have to be met to achieve user satisfaction: i.e., easy to use system, clear labelling, properly organized information, a good visual appearance, quality content, and error correction. These components are measures by Likert scales and questionnaires.

Learnability

Learnability refers to which extent users feel productive and quickly learn new functions when interacting with the system [151].

4.6.2 The focus should be on user-centric design

"The design of everyday objects is not always intuitive and at times it leaves the user frustrated and unable to complete a simple task" [152]. This also entails for information systems, such as digital libraries. The design of both information systems and everyday objects should prioritize the ease of use and user-friendliness. Any system designed for people should be easy to use, easy to learn and easy to remember [32]. The purpose of a library was to meet the needs of the community, and this principle hasn't changed for digital libraries. Digital libraries consist of several components, i.e. tools, and resources, that can either serve or fail the communities based on its usability. Digital libraries must serve a wide variety of unique users, consisting of a unique community with a wide range of information needs. These users can vary from information-seeking beginners to sophisticated users. Successful digital libraries require user studies, user pattern analysis and user evaluation. These components ensures a high usability standards in order to serve a broad audience [153]. Gould [32] recommends three different design principles:

- **Early focus on users**
  The design team should be user driven. Understanding the user is far more important the identifying or describing the user. Designers must really understand who the users are and what they want to achieve. Interviews should be taken before the system design.
- **Empirical measurement**
  In the development process potential users should assess prototypes by observing its performance and analyze user experience.
- **Iterative design**
  The design should be flexible and iterative as problems can arise in user testing. There must be a design cycle which can be executed as often as necessary, consisting of designing, testing and redesign.

Gould [32] found that these principles are often not implemented or applied as these principles seem too obvious. Even more, many designers lack the ability to fully understand the design principles, even when they are describing them. According to Gould [32], the lack of implementation is a result of the following believes: user diversity is underestimated (because of limited contact with their users), users do not know what they need, good design means getting it right the first time (there is a need to iterate and getting it right the first time is therefore not achievable in user interface design), scared of not meeting their time schedules and technology can solve every problem.

4.6.3 Knowledge economy and knowledge building

The term 'knowledge economy' was presented by Drucker [154]. Knowledge as a concept in economies has been questioned, however history shows that knowledge has been essential for all economies to produce goods, manage and exchange them. Some people see the Knowledge economy as the next phase of global economic development after the agricultural and industrial ages. International development and government describe knowledge as a central capacity builder that fuels education and innovation in a country. Education, particularly adaptable and analytical skills, is essential for a trained workforce, especially in the rapidly evolving knowledge world [155]. Literacy, including computer literacy, is seen as a key component of the knowledge economy. Aubert [156] describes the importance of knowledge as: *"Countries that fail to become part of this [information] revolution risk becoming even more marginalized than those left aside in the earlier industrial revolution"*. A country's knowledge economy is measures by the Knowledge Economy Index (KEI) and Knowledge Index (KI) [155]. Knowledge building, or knowledge creation, is an essential concept for achieving the knowledge economy. Knowledge building is an educational model defined as: "*the creation and advancement of knowledge which is of value for one's community*" [157], [158]. Knowledge building together with intentional learning creates a powerful tool to enhance the state of knowledge [157]. Knowledge building aims to push the boundaries of knowledge to achieve the highest level of understanding, expertise, and information in a given field or subject.

4.7 Digital educational libraries

4.7.1 The concept of a library and its role in education

The first library as well as the first university was created in Alexandria 2.000 years ago. Since the invention of the library, humanity has been using printed information sources mainly through libraries. Throughout the years, libraries have been improving from printed versions to electronic databases through CD-ROM's [159], [160]. However, the library always remained as a physical place consisting of physical elements. Later, Marchionini & Maurer [161] defined a library as *"an organized set of resources, which includes human services as well as the entire spectrum of media, such as: text, video, hypermedia"*. Libraries consist of physical elements and intellectual elements. Physical elements are elements such as space, equipment, and storage media. Intellectual elements can be elements like collection policies or people. The people, which are generally librarians, manage the elements present in the library as well as providing support for users to be able to address their information needs[159], [161].

A library serves three functions in learning: practical, cultural, and social/intellectual. Firstly, libraries serve a practical role as they facilitate the sharing of valuable information resources, such as: books, videos, software, databases, and tools. Secondly, they serve a cultural function by preserving and organizing both artifacts and ideas. Libraries make sure that previous and important literature is preserved and available for future learners. Thirdly, libraries provide a way for people and ideas to interact with one another to enrich themselves socially as well as intellectually. Libraries provide a physical place for teachers and learners to share different perspectives by meeting outside the walls of the classroom [159], [161].

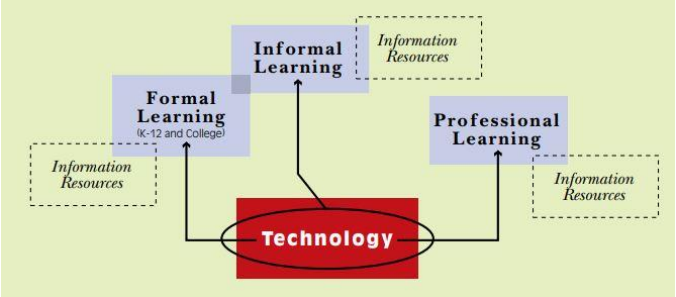


Figure 10: Library model for three types of learning [163].

Libraries support three areas of learning [161]. Figure 10 illustrates the interaction between specific types of learning and technology in libraries:

- **Formal learning** is structured and occurs in a planned setting which can be either physical or online. The function of libraries is important here to support the formal learning with specific content by using library services or materials.
- **Informal learning** is an unstructured environment where learning occurs outside of the classroom. Libraries provide the learners with a physical learning space and a wide range of information resources.
- **Professional learning** is an ongoing process to encourage knowledge building for teachers. Libraries provide them with information resources to be able to build new knowledge.

4.7.2 The concept of digital libraries and its impact on Africa

The innovative idea for using information technology to spread knowledge was already discussed by H.G. Wells [162] in 1938. Wells [162] wrote: *"The time is close at hand when any student, in any part of the world, will be able to sit with his projector in his own study at his or her own convenience to examine any book, any document, in an exact replica."*. The introduction of the computer ensured a revolutionary change in the process of information handling, i.e., generation, gathering, access and usage. Publishers began to publish information resources both printed and electronically. The electronic advancements came in the form of CD-ROMs, online public access catalogues and online databases [160]. The first digital library emerged in the early 1990s and evolved together with the web [163].

The web and the internet changed everything; within a time span of 10 years the web was able to make an incredible impact on all aspects of our life. One of the most important contributions of web technology has been the creation of information systems, such as digital libraries, which allows users to access digital information resources from virtually anywhere in the world [164]. Mamabolo and Durodolu [165] defines a digital library as *".. a technological resource for collecting information, storing in electronic format and making information available and accessible remotely through the use of internet and end-user interface."*. The definition shows that a digital library gathers a combination of activities, i.e., collections, services, and people, to serve the complete life cycle of information management instead of only being a digitized collection with the required tools [164].

Zirra et al. [166] highlights that digital libraries have the potential to bridge information gaps and the digital divide in African countries, as long as they are effectively implemented and utilized. Da Rosa et al. [167] further adding that this potential can only be reached with the availability of the internet connectivity and the necessary equipment, such as computers, and tablets. Digital resources, particularly the internet, play an essential role in utilizing digital libraries. To effectively address the digital divide and the knowledge gap between African countries, its regions, and the developed world, ensuring a reliable and accessible internet connection is essential [168], [RI.3].

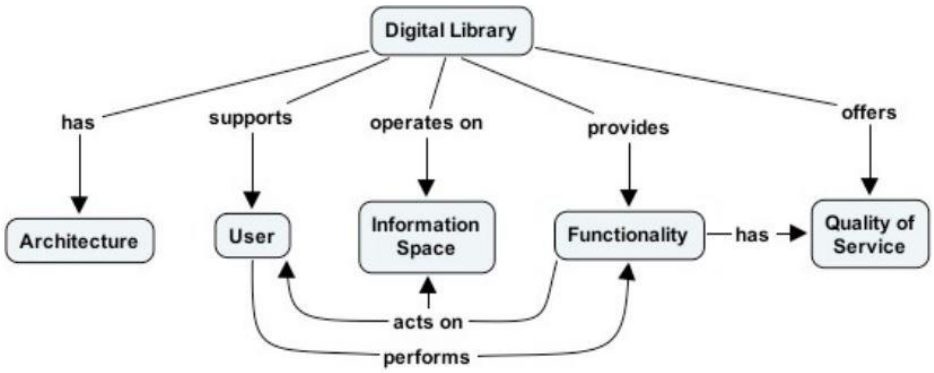


Figure 11: The main concepts of a digital library [169].

Candela et al. [169] identified five main concepts of a digital library: information space, user, functionality, quality of service, and architecture, as illustrated in Figure 11. Within this framework, users are interacting with the information space, which represents the content within the library. Besides interacting with the content, users also have a need for additional functionalities within the system. The requirements and functionalities identified for digital libraries are elaborated in Section 6.1. The concept 'quality of service' evaluates features, such as: security, availability, reliability, and performance with regards to the users' expectations. To support these functionalities, digital libraries require specific technological components and constraints, including hardware and software.

The internet and digital libraries facilitate the accessibility to a wide range of information sources and communication possibilities, independent of time and location [165]. However, internet accessibility and digital resource remain limited in most West African countries. Initiatives like the RuralCOMM, as implemented in Ghana, can potentially establish reliable and accessible internet connectivity in rural areas across West Africa, as the RuralCOMM initiative in Ghana has shown to be of great positive impact to rural areas in Ghana. The accessibility of a reliable internet connection in rural areas in developing countries is a significant step towards enabling education with digital libraries with accessibility from anywhere at any time.

A digital library can be employed using either the traditional approach or the cloud-based approach. In the traditional approach, the digital library is installed, maintained and hosted on local servers and infrastructure, which requires additional software and hardware. In contrast, the cloud-based approach refers to the digital library and its resources being delivered to its users over the internet instead of locally [170]. Currently, digital libraries in West African countries are installed on local servers or on a device and updated when the internet is available. Nevertheless, the traditional approach is still being utilized in developed countries [EI.1].

Moreover, digital libraries play an important role in fostering human rights by broadening individuals' understanding and knowledge of their rights, empowering communities by providing access to educational resources and actively engage community members, and contributing to sustainable development by limiting the reliance on physical resources, such as textbooks [171].

Mamabolo & Durodolu [165] identified several challenges with regards to the access of digital libraries in Africa. These challenges include censorship by the government which limits supportive content, lack of digital literacy among the majority of the population, unaffordable expensive devices, high telecommunication costs such as data and mobile calling, copyright threats, lack of awareness about the use of electronic equipment, electricity challenges, maintenance of digital resources, lack of government funding, and the lack of local language content. The advanced digital literacy necessary for online learning poses a problem for especially older and disabled people. These challenges, along with potential solutions, are further elaborated in Sub-section 4.6.3 and Section 5.

Nowadays, we can distribute knowledge to developments in technologies such as e-readers, mobile phones, or tablets. Building and managing digital libraries involves huge intellectual and financial resources, where the USA for example is spending 68 million US dollars on digital library research. You can say that instead of users going to the library for information, that digital libraries bring the information to users in real-time when they need it. The main idea is that there is no human intermediary needed in the information search and retrieval research. This means that the user interface and the search and retrieval mechanisms should be so simple that every member of the user community can use the facilities easily. Digital libraries overcome the barriers of geographical distance, language, and culture [159]. One of the greatest benefits of digital libraries is bringing together people with formal, informal, and professional learning as discussed in Sub-section 4.7.1. However, digital libraries have the most impact on advancing informal education as they are digital schools which offers formal information sources for specific skills and topics

chosen by the student [161]. The change of this structure is visible in Figure 12. In a true global digital library environment, virtually anyone should be able to access and use a digital library from anywhere in the world. It is often said that a library is not judged by its buildings, collection, or people but by its services. This is even truer for digital libraries since their overall objective is to provide improved information services [159].

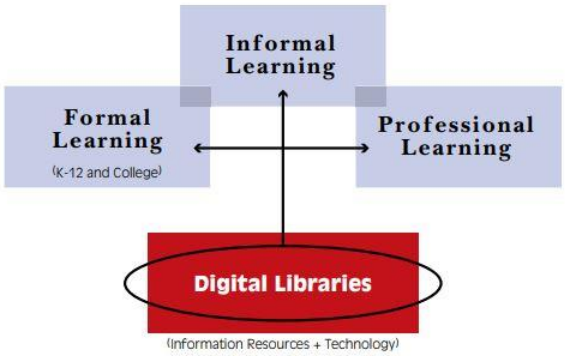


Figure 12: Library model for three types of learning [163].

4.7.3 Concepts and characteristics of digital educational libraries through UML class diagramming

Unified Modeling Language (UML) class diagramming is a visualization technique used in software engineering and system design to image the conceptual structure of a system, including the relationships between its components. The UML class diagram of digital educational libraries is visualized in Figure 13. The UML class diagram consists of the following components: classes, attributes, methods, and the relationships between classes within a system [172], [173]. The elements of the diagram are summarized in Appendix I. UML class diagramming is used to visualize the conceptual structure of digital educational libraries.

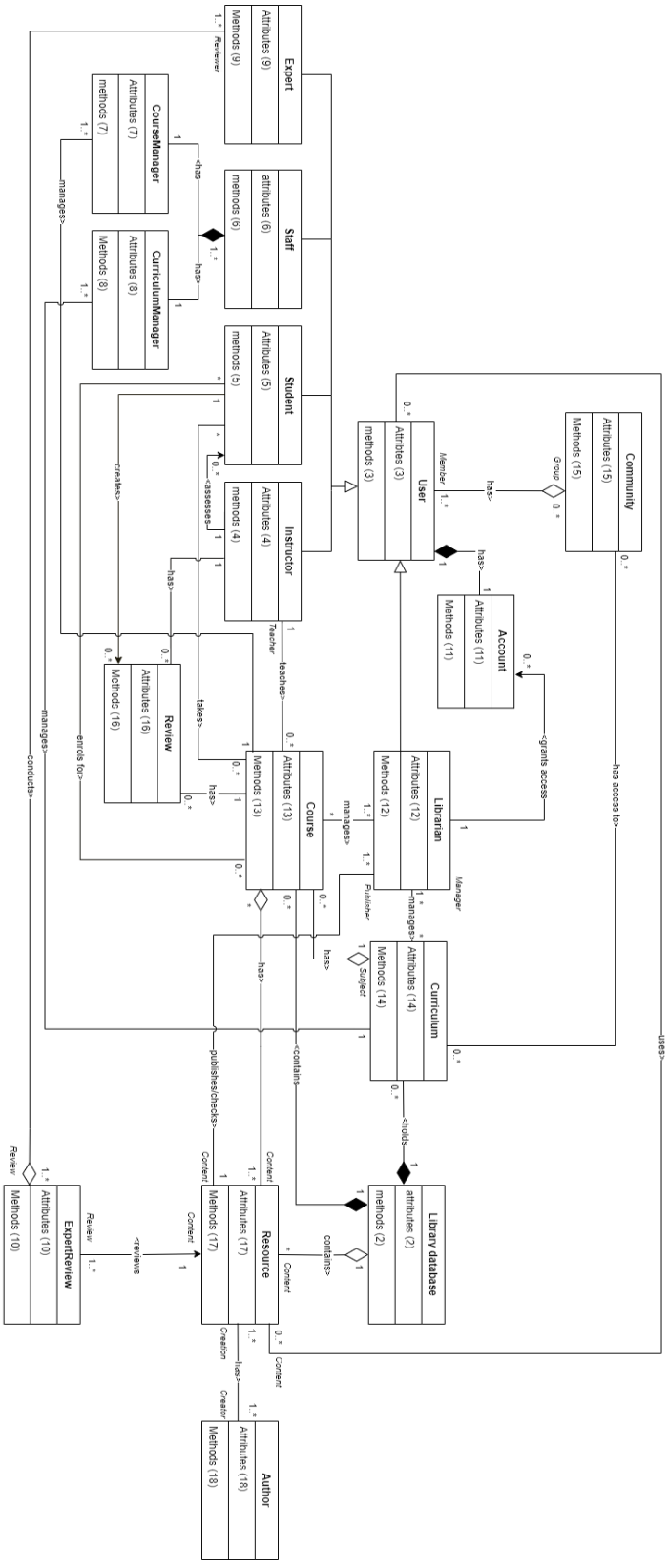


Figure 13: UML diagram - digital library.

As elaborated in Sub-section 4.7.2, a digital library is a collection of digital information resources accessible through the internet on a local server or in the cloud. The main component of the digital library is the Digital Library Management System (DLMS), which serves as the backbone of the digital library. The digital librarian is the admin of the digital library and holds the overview of the digital library management system (DLMS). The DLMS is the software platform responsible for the facilitation of creating, organizing, managing, and publishing of digital content within the digital library [169], [174]. As summarized in Sub-section 4.7.2, the DLMS can either be implemented through a local installation or a cloud-based solution, with the former remaining prevalent in the African context. Design principles for digital libraries in the African context can be found in Section 6.2. Additional design principles for the local implementation in African countries can be found in Section 6.3.

DLMS is essential for the technological infrastructure and tools necessary to efficiently deliver digital content to users. The implementation of a DLMS supports in reducing the cost of materials and storage [174].

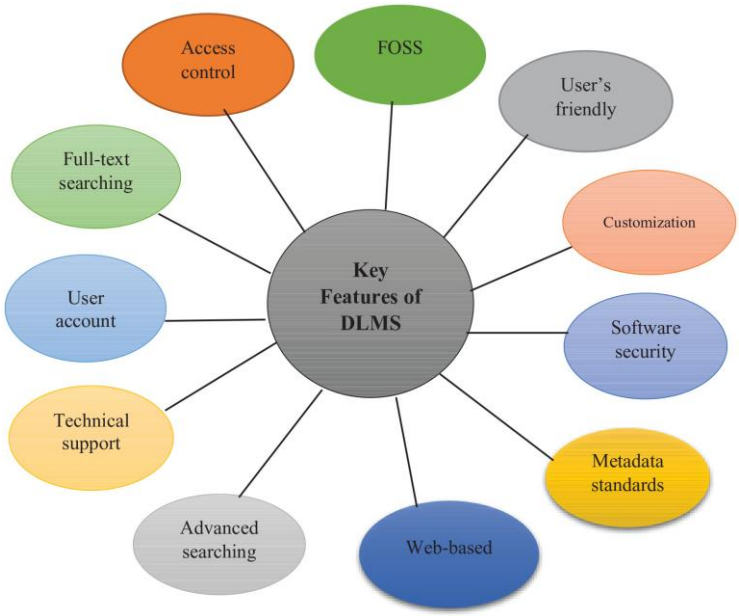


Figure 14: Key features of a DLMS [174].

Khan and Shahzad [174] identified the essential components of a DLMS, as visible in Figure 14. The most essential components were an easy installation of the digital library, metadata assignment, search and retrieval features, technical support, user account development, user-friendly interface, customization/ modification, web-based library, a backup of the digital resources, sharing resources to other digital devices, and mobile app accessibility. Especially customization and modification capabilities are found to be essential for a DLMS due to the rapidly changing technological innovations and changing user needs. Furthermore, the study highlights three essential factors that must be met for efficiently implementing a DLMS: IT-skilled personnel, sufficient IT equipment, and IT-training opportunities [174].

The DLMS typically consists of a content management system (CMS), user management system (UMS) and workflow management system (WFMS), as visible in Figure 15.

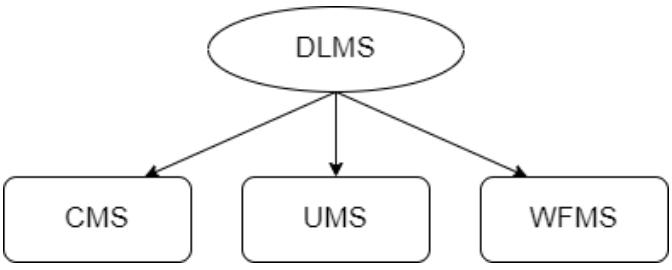


Figure 15: DLMS components.

First, the digital content management system (CMS). Yu [175] defines the CMS as: "*a process of collecting, organizing, and structuring informational resources of any type and format so that they can be saved, retrieved, published, updated and reused in any way desirable*". The CMS functions by the complex integration of technologies, databases, processes and quality control. Each of these elements must seamlessly integrate technically to ensure the successful implementation of a CMS. It supports librarians with categorizing content efficiently and facilitating a user-friendly search and retrieval process. Digital libraries either employ software-based or database-driven systems to manage the digital content, such as curricula, courses, and resources [175]. The CMS comprises of the following essential components: a library database, librarian, courses, curricula, librarian, course manager, curriculum manager [176].
The library database serves as a repository for all available educational resources. The database is structured in a hierarchical structure, starting with different curricula, followed by the courses corresponding to each curricula and finishing with the content associated with its relevant courses. The content includes PDFs, videos, images, EPUBs, e-books, and potentially other formats. Additionally, the curricula representing specific fields of expertise. The overview of the curricula and their quality is managed by the curriculum manager. Within each curricula, the corresponding courses are managed by a course manager, who is responsible for the provided content and its quality. The course manager is supervised by the curriculum manager. Courses can be taught by one or multiple instructors, each instructor is responsible for guiding the enrolled students within their course. Furthermore, students have the opportunity to provide feedback on courses and instructors to enhance course content and teaching methods [176].

Secondly, the user management system (UMS). The UMS facilitates the assignment of roles and group memberships to users, which are called communities. The UMS enables librarians to manage access levels, permissions and interactions within the digital library environment for different user roles (i.e., expert, librarian, student, staff, or instructor) [176]. The USM consists of users, communities, librarian, and an account. Users can manage their accounts through the UMS, including updating personal information, password management, and an overview of course enrollment. Furthermore, users can register for an account through the digital library environment. One of the essential components of the UMS are security measures to protect user data and privacy, generally consisting of authentication and authorization [177].

Lastly, the workflow management system (WFMS). The WFMS coordinates and automates the workflow processes, such as the assigning of tasks and responsibilities, with relevant stakeholders (i.e. librarians, authors, and reviewers) to manage the library resources from creation to publication. By integrating a Workflow Management System (WFMS) into the Digital Library Management System (DLMS), digital libraries can streamline the resource management process, maintain quality standards, and ensure that only high-quality resources are made available to users. The WFMS facilitates collaboration tools, communication, and the approval process between relevant workflow stakeholders, i.e. digital librarian, author(s), and experts [175]. The WFMS consists of resources, author(s), the digital librarian, and an expert review. The most important component of the WFMS is Quality Control, which determines whether a resource is of high-quality and whether it can be published in the digital library or needs additional adjustments by the author or authors. Another important component of the WFMS is Quality Control, when managing the digital resources of the digital library [175], [176].

Bentil et al. [178] suggests to incorporate the revised Techniques of Electronic Resource Management (TERMS) framework into digital libraries within the African context, in particular the Ghanaian context, to manage the electronic resource (ER) lifecycle and assess its quality. The TERMS framework consists of six stages: investigation of new content, acquisition of content, implementation, ongoing evaluation and access, annual review, and cancellation and replacement review, as visible in Figure 16. These stages of the TERMS framework comprise the full ER lifecycle process: i.e. selection, review, renewal, and cancellation of publications. However,

standardising of the ER workflow has shown to be a significant challenge compared to printed resources, as the workflow is seen as a complex iterative process with the need to be reviewed periodically for improvements. Based on their findings, the study recommends to increase involvement and collaboration with user communities for selection and evaluation input of digital resources, provided by the libraries meeting users' information needs.

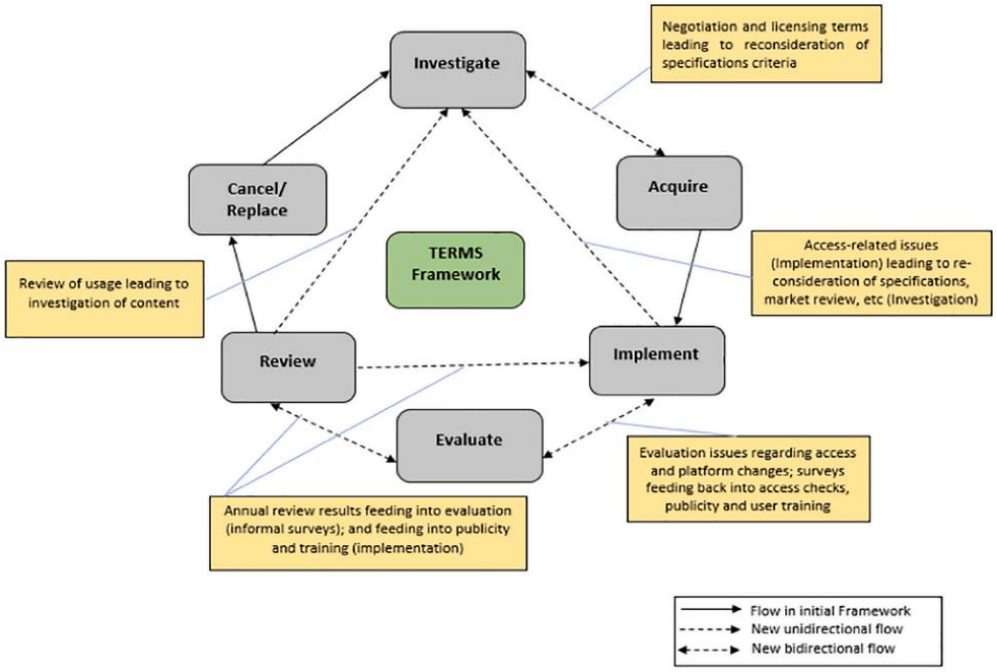


Figure 16: The revised TERMS framework by Bentil et al. [178].

Incorporating the TERMS framework into the WFMS ensures to maintain high-quality standards throughout the complete resource lifecycle [178]. The publication process of an ER is in particular important, as this process serves as the foundation for valuable and high-quality educational materials [176]. The process functions as follows [176]:

1. **Resource Submission**: Authors or content creators submit resources (e.g., documents or videos) to the digital library for publication. Before publication, two quality assessment steps must met, i.e. an expert review and a copyright & usability assessment.
2. **Review and Feedback**: Experts in the relevant field assess the quality of the submitted resource through an expert review based on predefined criteria. This review process is an iterative process including the initial review, expert evaluations, and discussions. The expert review provides feedback and recommendations for improvement. The experts can either approve or refuse the submission. When the resource is approved, the submission continues to step 4. When the content is refused, the submission continues to step 3.
3. **Revision and Resubmission**: Based on the feedback and recommendations provided by the expert review, authors may revise their resource. After the revision, authors can resubmit the resource and process returns to step 2.
4. **Copyright & usability assessment:** The digital librarian assesses the submission for copyright compliance and its usability for the available courses and curricula.
5. **Approval and Publication**: Once the resources is approved by the quality assessment steps, it is approved for publication and made accessible to the users by the digital librarian.

4.7.4 Digital libraries supporting e-learning.

The growth of e-learning in combination with new technological advancements, such as the internet, a new way of using traditional libraries is required. Digital libraries are one of the most promising inventions that allow people to access a wide variety of information and information sources, previously gathered in traditional libraries, from anywhere in the world at any given time [164], [RI.3]. The introduction of digital libraries supporting e-learning ensured both a learning environment and their corresponding network of resources. These are designed to meet the needs of learners and teachers and provide accessibility to a wide collection of materials for learning from anywhere in the world at any time [179].

According to Sharifabadi [164], digital libraries support e-learning in the following ways: enhance student performance, guarantee long-term availability of resources, user-friendly retrievable and discovery of resources by students, parents and teachers and enhance quantity, quality, and comprehensiveness of digital educational resources. The biggest challenge for digital libraries, however, is to support the goals of physical classroom education. Besides that, the role of librarians is becoming more important as they must become a key player in the learning process of students. Their role changes from information providers to educators, which requires a completely different set of skills compared to their previous role [161], [180].

4.7.5 Innovative technologies for digital educational libraries

The rapid developments in the world of emerging information and communication technologies (ICTs) has changed the way libraries provide services in learning to students and educators. The development of new digital library technologies to support education has been an important topic among researchers, particularly with the recent introduction into the Ghanaian educational framework [181], [EI.1], [EI.4]. Innovative IT technologies has been and continue to be the driving force of digital library development [170]. As the world becomes increasingly technology-based and more resources become digital, educators, students, and researchers are actively seeking for effective and efficient instructional strategies, assessment strategies, and learning paths to enhance the educational experience [182].

With the introduction of new technologies, a more accessible and engaging learning experience has been created. Emerging digital services enhance the learning process as people can learn at their own pace from anywhere at any time, which can significantly positively impact rural areas in developing countries [140]. The following digital services are examples of new technologies making important changes in education [140]: 1) Online learning platforms; provide high-quality learning materials and courses to anyone at any time with an internet connection, 2) Virtual classrooms; provide a collaborative environment between students and teachers from a different location, 3) Educational apps, like Duolingo and Quizlet; support students in providing interactive learning and enhancing their learning experience. 4) Gamification; provides interactive learning and increases student engagement and motivation, 5) Artificial intelligence (AI) is increasingly being used in education to personalize learning, provide feedback, and assess student performance [140]. The personalized learning design process should include user experience, demographics, and culture of the local communities to provide the best suited learning experience [EI.3]. AI tools can also provide additional help for teachers to support students [140].

Despite the significant rise of smartphone subscriptions and the mobile uptake of the population in West-Africa, as elaborated in Sub-section 4.4, the main challenge with implementing new technologies in education in developing countries is the fact that these may not be effective when students, teachers and parents lack technological knowledge and have limited digital literacy, or face limited access to mobile technologies as they are prohibited in schools [EI.1], [EI.4].

U-learning supports the integration of technology into learning environments to make it accessible from anytime and anywhere, as elaborated in Sub-section 4.4. The following sub-sections provide an overview of emerging technologies and their opportunities in the world of digital educational libraries.

4.7.5.1 Artificial Intelligence (AI) and Machine learning (ML)

Artificial Intelligence (AI) and machine learning (ML) are one of the most promising innovative technologies when it comes to revolutionizing education and digital libraries. AI refers to the engineering of intelligent machines that can think and act as humans, but without human interference. ML, on the other hand, is a subset of AI ensuring the utilization of self-learning algorithms trained on large datasets to perform the complex tasks of AI and make intelligent decisions [183]. These technologies have the potential to play a significant role in deprived communities as they enhance information systems (IS), provide tailored personalized learning environments for each student through adaptive learning systems and content recommendation, communicate with conversational AI chatbots (Sub-section 4.7.5.2), offer valuable feedback, enhance productivity, and provide interactive learning experience through gamification based on users' background, knowledge and skills (Sub-section 4.7.5.3) [140], [184], [EI.3], [EI.4]. The future of digital libraries seems bright with the implementation of AI and ML by revolutionizing search and retrieval methods, self-learning features, assessing content quality, anti-piracy measures, copyright compliance, analysis of users' search behavior, resource discovery, chatbots, and text and data processing [183], [185], [EI.1]. AI is seen as a disruptive yet transformative technology making significant positive changes to digital libraries with the potential of bridging the digital divide in developing countries, for example by creating educational content in local languages [186], [EI.3]. AI-powered tools can support educators and librarians to identify the struggles of students by assessing students' performance [140]. Librarians, in particular, can integrate AI for different purposes, including reference services, enhancing digital literacy skills, extensive monitoring and evaluation of students, and information search and retrieval processes. The implementation of these new technologies also requires librarians to possess advanced digital literacy and data skills to transform digital libraries into intelligent libraries [184].

Despite the potential of AI, its integration into digital libraries faces significant technological, social and economic challenges [184]. The main challenges when implementing AI into digital libraries are addressed below:

- **Data privacy:** AI systems are processing large amounts of data. As AI models require data to train the models, the potential threat of specific user data being misused, arises. Librarians need to anonymize their user data before it is used to train their AI models [184], [EI.3], [EI.4].
- **Intellectual freedom:** AI systems are storing personal information when people are engaging with the system, posing a threat to intellectual freedom [184].
- **Intelligence quality:** The quality of an AI system is determined by the quality of their datasets and the quality of the algorithms. The rapid technological advancements ensure the challenge to optimize algorithms to reach the highest intelligence quality [184].
- **Cost:** The cost of implementing AI and ML into digital libraries are significant. The cost is currently one of the major barriers for the implementation of AI and ML [184], [EI.4].
- **Linguistic styles:** Developing countries are often divided into several regions with different dialects and languages, making it challenging for developers to develop a generic conversation style.
- **Algorithmic bias & cultural nuances:** Algorithmic bias, or developer bias, refers to the potential threat of bias in AI models, as AI models are mostly trained on biased western datasets without taking into consideration the perspective, cultural nuances, and language of local communities when being trained or implemented in developing countries. To address this issue, future AI models can be trained on decentralized data while taking privacy, security, and anonymity into account [184], [EI.3], [EI.4].
- **Teacher, community, and student acceptance:** Ensuring that teachers, the community, and students understand and trust the role and potential advantages and challenges of AI in education. Without trust in new technologies from these stakeholders, there is no need in implementing a new technology [122], [EI.1], [EI.3].

According to Darlington [EI.3], the following future trends are emerging in the field of AI in combination with digital libraries and education: (1) Explainable AIs; As AI technologies improve and become more complex, explainable AI tools will support users to understand the decision-making process of AI models to enhance trust and transparency, (2) Training AI models on decentralized data; by training AI models on decentralized data, designers can address the issue of algorithmic bias and cultural differences, (3) AI-powered personalization for cybersecurity; By implementing AI-driven personalization in cybersecurity measures, security of AI can be enhanced by gathering individual user profiles and risk assessments.

4.7.5.2 Natural Language Interaction

Natural Language Interaction (NLI) is a combination of Artificial Intelligence (AI) and Natural Language Processing (NLP). NLI aims to deliver personalized and human-like interactions with computers through natural language [184]. NLI can either be chatbots or embodied conversational agents (ECAs). Chatbots are limited to text-based interactions and ECAs consist of a computer interface using a human-like body to move and interact with the user [187]. Conversational AI chatbots can answer questions and interact with the learner in their own local languages [EI.3]. Chatbots and ECAs offer a 24/7 available virtual librarian to digital libraries by providing an educational, informative, assistive and interactive service to users, which can enhance the efficiency and effectivity of the users' search and retrieval process in the digital library. NLI focuses on providing additional services to users and not on replacing human interaction [184].

4.7.5.3 Gamification

Gamification, as an innovative technology, incorporates game-like elements to transform students' learning experiences by making learning more interactive and enjoyable. Gamification has the potential to enhance user engagement, performance and motivation, especially in developing countries, by transforming users from only consumers to active participant in their own learning experience. Gamification elements may include leaderboards, levels, points, and challenges in the learning process. Gamification can be used in digital educational libraries for users to gain a deeper understanding of complex concepts compared to traditional education. However, the main challenge of gamification lies in designing a high-quality and engaging game. Nevertheless, the implementation of gamification can significantly enhance the learning experience [188]. Kamunya [189] proposed an adaptive gamification model for e-learning platforms, such as digital education libraries, by providing personalized game-like elements to students in their learning process. The adaptive gamification model further impacts education by achieving better learning outcomes through enhanced user engagement and motivation and at the same time facilitate enhanced knowledge building.

4.7.5.4 Virtual reality (VR) and augmented reality (AR)

As elaborated in Sub-section 4.4, interactive learning tools, such as: virtual reality (VR) and augmented reality (AR), can be used to enhance student engagement and enhance the understanding of learning concepts. VR refers to a complete user immersion into a fully simulated environment. A computer generates a simulated environment where users can interact in with equipment, such as headphones, sensor gloves, or controllers [184]. AR, on the other hand, supplements to the real world instead of fully replacing it, making it a 'mixed reality'. AR works together with headphones, digital devices (smart phones, tablets, laptops) to display digital objects into the physical world. VR and AR enhances the learning experience by offering an interactive learning environment together with collaboration possibilities and personal feedback. These technologies are relatively new, meaning that more opportunities still have to be explored [190]. In most developing countries, as well as West Africa and Ghana, VR and AR are new to the educational system. The implementation of AR and VR are far from a reality in developing countries, due to limited learning materials and equipment, limited funding, and the lack of parental support for using technology [191], [EI.1], [EI.4].

4.7.5.5 Mobile learning

Mobile technologies and mobile learning are becoming increasingly important in the world of education and digital libraries. Especially in developing countries, mobile technologies are on the rise and the primary technology for learning from anywhere at any time [26]. The benefits of m-learning for developing countries are summarized in Sub-section 4.4. Mobile technologies ensure easy accessibility to learning from anywhere at any time, providing students a simple way to transport their learning resources and use them at any time. The introduction of mobile learning significantly changes the learning experience of students by providing simple access to a wide variety of educational resources, impacting in particular rural areas and developing countries. Students can study at their own pace by allocating as much of their free time to studying by using their mobile device [181].

Additionally, Da Rosa et al. [167] highlights several challenges related to accessing digital libraries through mobile phones. Firstly, the study highlights the importance of user interaction design for mobile learning, as studies have shown users to be 50% less effective with limited screen space. Secondly, content requires to be adjusted to the small screen space, which poses limitations to the displayed content. Thirdly, mobile devices are limited to small keypads and with no pointing device, complicating user input. Lastly, mobile device often have limited processing power and memory, complicating the interaction with digital libraries. Particularly in developing countries, additional challenges arise, such as the unaffordability of expensive smartphone devices for the majority of the underprivileged individuals, and the poor technological quality of smartphone devices own by individuals.

4.7.5.6 Open Educational Resources (OER)

Open Educational Resources (OER) refer to freely accessible and openly licensed educational materials which can be accessed, shared, and improved by educators and students. These resources may include complete courses, programs, assessments, assignments, and digital resources, such as textbooks, videos or images. OER aims to provide access for everyone, including underprivileged children, to high-quality educational resources by allowing educational institutions to reach underprivileged communities with a low cost [192]. However, future research on OER must focus on designing the resources to ensure accessibility for the poor in developing countries, as these people are challenged with low-quality smartphones, poor internet connection, and limited access to equipment, such as computers and VR.

4.7.5.7 Cloud computing

Cloud computing is introduced in 2006 as a promising new innovative technology, often seen as the third revolution after the computer and the internet in IT. The basic goal of cloud computing is to manage, store, and process digital resources on remote servers through the internet, referred to as “the cloud”, serving users from anywhere in the world at any time, visible in Figure 17. With the introduction of digital libraries and the emergence of cloud computing, cloud computing became the predominant technology for shaping digital libraries [170], [193]. According to Chen [193] and Dankyira [EI.1], implementing a cloud-based system in digital libraries is essential during the construction and management of digital libraries to ensure universal accessibility for users to a wide variety of digital resources. Cloud computing offers significant advantages to digital libraries: reduced technological and maintenance costs, dynamic computing performance for handling usage peaks, elimination of server updates, low maintenance, implementation of innovative technologies, adaptability, high scalability, high reliability, collaboration features, high-quality security, accessible from anywhere, and extensive storage for digital resources [170], [193]. A cloud-based system facilitates automatic updates, making it easy to manage and to maintain the digital library. Storing the digital library data in the cloud also ensures advanced security. The cloud provides flexibility and efficiency, ensuring seamless integration of updates and new content whenever internet access is available. However, as Sub-section 4.7.2 summarizes, internet accessibility, and thus the cloud, is limited in West African countries. Nevertheless, Ghana is one of the leading countries in West Africa with enhanced internet connectivity due to the

introduction of RuralCOMM, as summarized in Sub-section 4.7.2. Proper internet connectivity is essential to implement cloud based systems into educational frameworks. Similar efforts to enhance internet connectivity should be taken in other ECOWAS countries. Currently, digital libraries are installed on local servers or on a device and updated when the internet is available [EI.1].

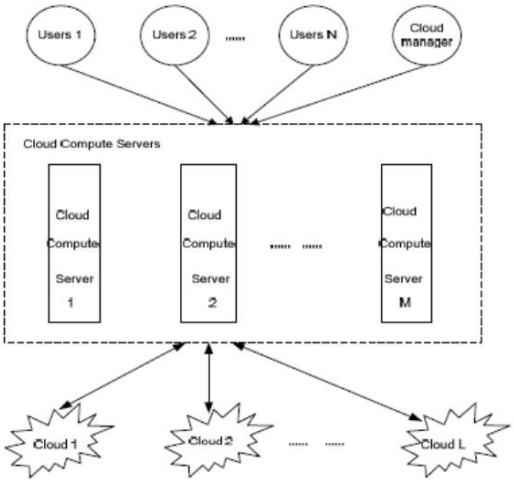


Figure 17: Cloud computing implementation [170].

4.7.5.8 Virtual classrooms

One of the key tools for e-learning nowadays is the virtual classroom (VC). The virtual classroom is an online learning environment to facilitate face-to-face communication, interaction, knowledge transmission, assessments, sharing of digital learning resources, and real-time collaboration between students and instructors without the need of being physically together in the same classroom. This technology facilitates education for students in remote areas without limitations, ensuring accessibility to education for everyone from anywhere. Remote areas in West Africa would benefit of this technology massively, as distance to education in rural areas can be quiet big and rural areas are not having the same facilities and resources as urban areas, as summarized in Sub-sections 5.2 and 5.3.3.1. To fully use the VC, students only require a computer/smartphone, an internet connection, and the necessary digital literacy to engage in virtual classrooms, which is at the same time a huge challenge in rural areas in developing countries [194]. Challenges arise in rural areas and on public schools in Ghana and West-Africa when it comes to these 'basic' resources, as elaborated in Sub-section 5.2. The RuralCOMM, as elaborated in Sub-section 4.7.2, is providing internet connectivity among both rural and urban areas, which is a game changer for VC use in education. The main challenges remains, however, the limited accessibility to resources and the internet, and the limited digital literacy of users utilizing technology-integrated education, especially in rural areas, as summarized in Sub-section 4.7.2 [EI.1].

5 Educational landscape in Ghana and West-Africa: A Rich Picture

The educational landscape plays a crucial role in shaping the future of younger generations, individual countries, and the world at large. Education is the foundation of societal development, economic growth, knowledge creation, and technological development. Therefore, this section serves as the problem context for formulating the design requirements and principles in Sub-section 6.1 and 6.2. This section explores the educational landscape of Ghana, providing a lens into the broader context of West-Africa. Beyond the exploration of facts and figures by researchers, the educational landscape will also be explored through insights of experts in the field of education in Ghana and West-Africa. Rich picture modelling, elaborated on in Sub-section 5.4, is employed to gain a comprehensive and holistic understanding of the multifaceted, complex dimensions of the educational landscape in Ghana. This visual representation provides a simplistic view of the cultural, economic, and geographical factors that influence the educational system, which also is in line with the Human-rights based approach (HRBA) to education in Sub-section 5.3. This Section primarily focuses on Ghana, as Ghana is one of the leading African countries in educational development. Additionally, the educational landscape in Ghana is multifaceted; from private to public schools to the rural-urban divide, and from government regulations to community involvement. By discussing these different elements, we aim to give in-depth insights into the complex dynamics defining the Ghanaian education. Firstly, the main contributors to these dynamics are discussed, which encompass the distinctions between public and private schools and the rural-urban divide. Understanding both contributors is essential as they significantly impact the diverse educational landscape in both Ghana and across most West African countries. Subsequently, our developed EDUlandscape framework is elaborated, which integrates the four-fold (4-As) dimensions, i.e. availability, accessibility, acceptability and adoptability, of the Human Rights-Based Approach (HRBA) with key influencing factors for each dimension. This framework ensures a comprehensive overview of the educational landscape in Ghana and West Africa. In the subsequent Sub-sections, we explore each key factor that influence each dimension to provide in-depth insights into the educational landscape in Ghana and other West African countries.

Expanding beyond Ghana, the scope of this Section extends to the broader context of West Africa. The Economic Community of West African States (ECOWAS) is the main provider of the educational system in all West African countries; e.g. the curriculum. Additionally, the similarities and differences between Ghana and other ECOWAS countries is investigated.

By exploring the educational landscape in Ghana and West-Africa, our intention is not only to provide a description of the current landscape, but also to contribute insights that can drive positive change. Before delving into the design and requirements of digital educational libraries, it is essential to have a thorough understanding of the challenges and opportunities within the multifaceted educational landscape of the regions where these libraries will be implemented. Section 5 provides this contextual understanding by exploring the complex interplay of factors shaping the educational system in Ghana and West-Africa. Understanding these dynamics is essential for designing digital libraries, i.e. the design requirements and principles, that effectively engage with all relevant stakeholders. Section 5 serves as the foundation for understanding the requirements, concepts, and design principles for digital educational libraries by implementing the Human-rights based approach (HRBA). By thoroughly understanding the situation that Ghana and West-Africa face, our aim is to enhance learning outcomes and empower young Africans to create a better future.

5.1 Private and public schools

The government of Ghana serves as the main provider of education with 72% of the students enrolled in government (public) schools and 28% enrolled in private schools. In urban areas, the enrolment of private school (41%) tends to be lower than the enrolment for public schools (59%). In rural areas, 86% of the students are enrolled in public schools and 14% in private schools, which is significantly different compared to the enrolment rates in the urban areas. The difference between these schools are most likely because of the limited financial resources parents in the rural areas have. Peri-urban area enrolment rates are showing an interesting change, as the estimated private school enrolment rates (66%) are clearly higher than the estimated public school rates (33%) [195].

In the context of Ghana's educational landscape, the dynamics between private and public schools are shaped by several factors that influence the school choice by the parents for their children's education. Factors like the school name, infrastructure and parental resources are determining factors that play a role in the choice for a school. Schools with reputable names are associated with better facilities and quality personnel, both teaching and support. Parents are more attracted to, and prefer private schools due to their superior infrastructure, resources, and personalized environment in both urban and rural areas, such as computers and internet. However, parents have to possess the financial resources to afford private school education [EI.1].

Public schools remain crucial in providing education to a significant part of the population, as the majority of the population is not able to afford private schooling. However, there are cases in rural areas where low-cost private schools are located with access for underprivileged children. This is often a result of governmental challenges with regards to meeting the high demand for education caused by rapid population growth, which leads to a prioritization of public schools resources to areas with greater demand and leaving the rural areas behind. Public school outnumber private schools in terms of numbers due to government policies and school fees. Even with the large number of public schools available in Ghana, class sizes can reach up to 60 children for one teacher, making it difficult for teachers to work with students personally.

Nevertheless, private schools are in high demand and they have to reject students based on their reached capacity. The lack of government financial support for private schools ensure that schools have to raise their school fees to cover the costs of education, which is the main reason that the school fees on private schools are significantly higher than on public schools. The costs of education are elaborated in Sub-section 5.3.1.4. Private schools are significantly more expensive than public schools. Despite the financial challenges, private schools have higher performance from the primary to junior high levels [EI.1].

However, as students continue education to the senior high level, the political influence becomes more prevalent ensuring a more dominant role for public schools. Private schools struggle in senior high school levels due to the lack of substantial financial funding, where public schools are still enjoying free senior high school policies. In contrast, public schools are preferred by parents in high school levels due to the good reputation of experienced teachers and perceived higher quality of education [EI.1]. The next sub-sections will provide an elaborated overview of the factors influencing this choice .

In summary, the choice between private and public schools in Ghana comes down to a complex interplay of factors, such as parental resources, government support, perceived education quality, the level of education and the schools' infrastructure.

5.2 Rural and urban areas

Urban and rural areas in Ghana are both having their own unique characteristics, as outlined in Table 8. This Sub-section provides a detailed overview of these different characteristics.

Characteristic	*Urban*	*Rural*
Population density	High	Low
Economic activities	Diverse and dynamic economy	Agriculture
Infrastructure	Developed (roads, buildings, electricity, proper internet, etc.)	Underdeveloped (poor roads, no public transport, limited electricity, etc.)
Educational resources	Advanced (IT labs, internet, computers, library, etc.)	Limited (no computers and no/irrelevant books)
Cultural diversity	Diverse due to urban migration	Local culture
Educational institutions	Broad	Limited
Cost of living	High	Low
Income level	High	Low
Perc. Living under the poverty line of 1$	10.6%	37.9%

Table 8: characteristics for rural and urban areas.

Figure 18 shows the division of urban areas, characterized by high population density mainly in the south, and rural areas, characterized by low population density mainly in the north, in Ghana. The most highly populated area is Accra and had a population of 5.5 million in 2021, accounting for 17.7% of the total population of Ghana and reside in only 1.4% of the total area in Ghana. The majority of Ghana encompasses rural area with a low population density.

Urban areas are known for a high population density with a wide variety of economic activities, exemplary areas are Accra or Kumasi. The urban areas are characterized by their well-developed infrastructure with quality roads, electricity across the area, modern facilities, broad range of resources (mobile phones, computers, internet, etc.), and a wide variety of educational opportunities and institutions [EI.1]. These characteristics collectively result in only 10.6% of the urban population living under the poverty line of 1 dollar. The cultural diversity in the urban areas are diverse due to urban migration, as these migrated individuals from rural areas are seeking for a better future without poverty in urban areas. Rural-urban migration is on the rise due to several push and pull factors (i.e. positive and negative aspects of an area), such as better perceived life quality and economic opportunities. The complex interplay of factors for rural-urban migration is visible in figure 19. The rise of rural-urban migration ensures that peri-rural and rural areas slowly turn into urban areas. The increased population, that comes with this increase of rural-urban migration, results in overcrowded urban areas and environmental degradation due to the pressure on natural resources such as water and land. Consequently, talented young Africans are leaving to urban areas, leaving behind vulnerable elderly and children. This pattern contributes to a limited economic growth and limited social wellbeing in rural areas [196]. The implementation of new innovative technologies from ICT4D in urban areas contribute to more advanced development in Ghana, providing new job opportunities for young Africans [91].

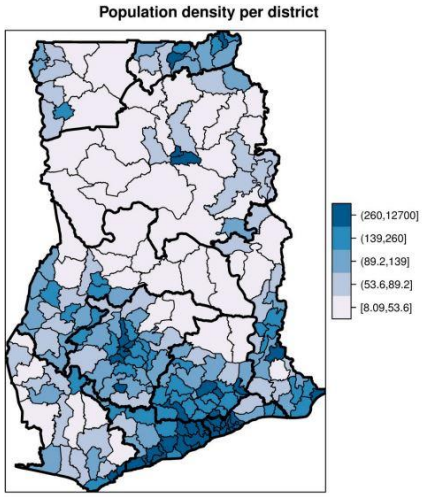


Figure 18: Population density map Ghana [197].

In contrast, rural areas in Ghana are showing a completely different image. These rural areas are characterized by lower population density, mainly engaging in agricultural activities, low income levels, high percentage of poverty, limited resources (lack of computers and books), limited and poor infrastructure, and limited amount of educational institutions. Teachers are also hesitant to go to rural areas due to the lack of proper infrastructure and support, resulting in a shortage of qualified teachers in rural areas. The limited infrastructure is visible because of the poor constructed roads, poorly maintained buildings, limited amount of electricity, and no transportation options [EI.1]. The economy is predominantly focused on agriculture with most of the population engaged in farming, fishing, and selling their harvest. The percentage of the rural population living under the poverty line of 1 dollar is significantly higher compared to urban areas with 37.9%. These rural families are mostly depending on the support from relatives working in urban areas [196]. The low income level and limited parental support due to high poverty rates, also impact the educational opportunities of the young Africans in these areas. Due to the high poverty rates and low enrolment rates in rural areas, the government introduced different policies for education to encourage underprivileged children to go to school [198].

The educational landscape further increases the gap between rural and urban areas. Urban areas are showing a wide variety of educational institutions offering diverse programs in a close distance. In rural areas, however, the educational resources and institutions are limited, meaning long travel distances for most of the community [EI.1].

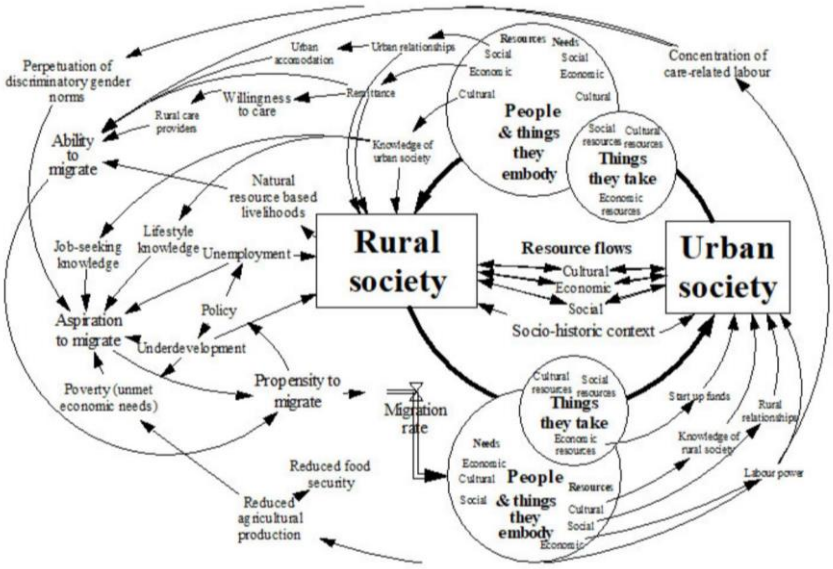


Figure 19: The complex interplay of factors contributing to rural-urban migration [196].

5.3 Educational dimensions and influencing factors

In 1948, the United Nations (UN) developed the Human-rights based approach (HRBA) to education. This framework stands on the fundamental principle that every individual, regardless of their race, geographical location, or socio-economic background, is entitled to have the right to education with a reasonable standard [199]. Availability and accessibility are closely related, as they both address the fundamental goal of ensuring that education is accessible to all individuals, without discrimination. Tomasevski [200] introduced the four-fold (4-As) schema of the rights-based approach to education, which include the dimensions: availability, accessibility, acceptability and adoptability, visible in Figure 20. The 4A's are summarized below from the user's point of view [200]:

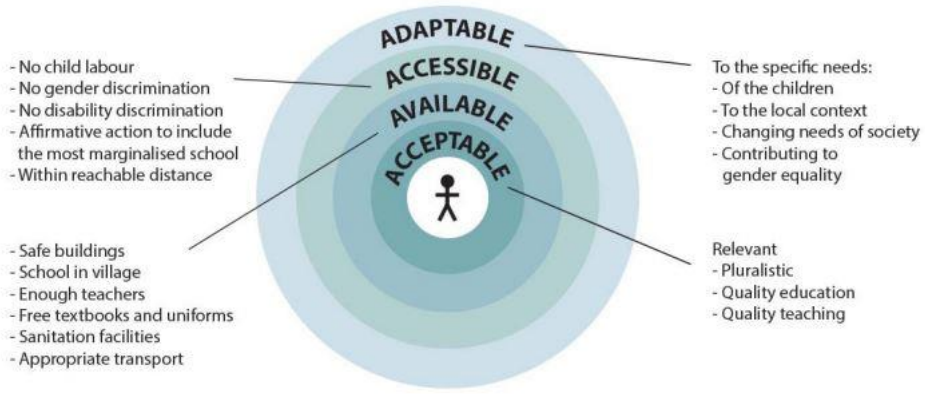


Figure 20: The 4-A scheme. Education Rights Circle Diagram [169].

-- **Acceptability** – refers to ensuring that the education system, the content, and the learning environment are acceptable for all individuals without discriminating.

-- **Availability** – education must be freely available for everyone. Availability focuses on establishing the institutions, infrastructure and resources essential to provide quality education to everyone.

-- **Accessibility** – All governments should ensure that education is accessible for every child without discriminating. Discrimination can be on multiple aspects, such as: gender, socio-economic status, or race. The focus should be on including marginalized individuals.

-- **Adaptability** – refers to whether education is able to evolve with the changing needs of society and therewith can improve the desired impact of education.

In order to explore the multifaceted dimensions of education in Ghana, we established the EDUlandscape framework which encompasses the factors influencing the 4A's dimensions. Table 9 provides the key factors with their corresponding dimensions. The detailed insights of the factors and their dimensions are elaborated in the subsequent sub-sections.

Dimensions	***Factors***	
Accessibility	- Access to education	- Policies
	- Gender disparities	- Community and family support
	- Funding	- Distance to education
	- Cost of education	
Acceptability	- Quality of education	- Teacher quality
	- Curriculum	- Medium of instruction
Availability	- Learning resources and utilities	- Grading & assessment
	- Internet accessibility	
Adaptability	- Adapting to the need for technology	- Influence of COVID-19

Table 9: the EDUlandscape framework: the four dimensions with corresponding factors.

The following subsections will discuss detailed insights into each factor influencing the dimensions of the EDUlandscape framework in Ghana and the ECOWAS region. Each subsection delves into a specific dimension and its corresponding factors, providing an in-depth exploration of the current educational situation, opportunities, and challenges related to education in the Ghanaian and broader ECOWAS context.

5.3.1 Accessibility: Access & affordability

5.3.1.1 Access to education

The access to education is a simpler answer than you might expect. It mainly comes down to government policy, elaborated in Sub-section 5.3.1.5 The Free and Compulsory Universal Basic Education (FCUBE) ensures that the children are obliged to go to school, this includes primary and junior high school (JHS) levels. Poverty remains a problem in Ghana as education is supposed to be free but in reality is very expensive for underprivileged communities. In rural areas, the distance from home to school can be far, but the access to education is available. Even though children are living several miles away from school and transportation is limited to walking, children are still required to go to school. Since 2017, there is a new policy that ensures free senior high school (SHS) education, which ensures that SHS is more accessible by all children, especially in rural areas. Access to tertiary education is more difficult as financial constraints exist. In contrast, the access to education in other countries in the ECOWAS region is significantly restricted compared to Ghana due to the lack of supportive government policies similar to those implemented in Ghana, as summarized in Sub-section 5.3.1.5, resulting in many out-of-school children without any form of education [EI.1].

5.3.1.2 Gender disparities

Advocacy for gender equality in education is significant in Ghana. The government introduced policies to ensure free and compulsory education for everyone, without discriminating on gender. The first of such policies is the Free and Compulsory Universal Basic Education (FCUBE), ensuring that every child can go to school for free. The government also introduced the Girls' Education Unit (GEU) under the FCUBE program, which objective is to increase enrolment, retention rates and achievement of girls. A more detailed description of these laws can be found in Sub-section 5.3.1.5. Before the implementation of these laws, women were predominantly engaged in traditional roles, such as raising children, cooking, and cleaning. At that time, men were the educated ones and working to earn the money for the household. The introduction of these policies made sure that education was compulsory for every child, including women. The importance of education for women was growing and together with the new policies, positive change were made to enrolment rates. Despite the improvement of enrolment rates, women still face additional challenges to enhance their participation and access to quality education in higher education levels. However, these challenges are more cultural issues as the advocacy is that every child must go to school [EI.1]. Consequently, the government introduced the Girls' Education Unit (GEU), operating under the FCUBE program, aiming to increase girls' enrolment, retention, and academic achievements [201].

Studies [202], [203] found that female enrolment levels worsen as education levels increase, therewith contributing to the gender gap. Additionally, common factors, such as teenage pregnancy, early marriage, poverty, culture, and the lack of role models for women, contribute to the decreasing enrolment rates. As elaborated in Sub-section 5.3.1.1, poverty remains a problem in Ghana as education is supposed to be free but in reality is very expensive for underprivileged communities. Especially in combination with the cultural belief that education for girls is not as important as for the boys, access for girls in poor families can be difficult. These challenges have to be addressed to enhance educational opportunities for women in Ghana.

Nowadays, women are being encouraged to go to school to receive the kind of education they deserve. Various non-governmental initiatives, such as the #eSkills4Girls and GirlsInTech initiatives elaborated in Sub-section 4.3.1.2, strive to ensure that women are also having the opportunities to thrive for a better future [EI.1].

5.3.1.3 Funding

In Ghana, education is funded from mainly five different sources: government funding, internally generated funding (IGF) by educational institutions, local communities, students/families and private funding (including non-governmental organizations (NGOs), private companies and foreign direct investment (FDI)). The Ghanaian government is the main financier of education in Ghana. However, the financial support from the Ghanaian government for education falls short in various aspects. Firstly, the education budget in 2023 increased with 21.5% in nominal terms to 24,772 million Ghanaian cedi's (GHS), however due to the high price inflation, the real budget decreased with 6.1%. This decreasing trend has been there since 2018 and will most likely continue in the following years, as visible in Figure 21. Since 2018 the nominal budget of the ministry of education (MoE) increased by 120%, however the price inflation came up by 170%, resulting in the real education budget for 2023 being 18% lower than in 2018 [3].

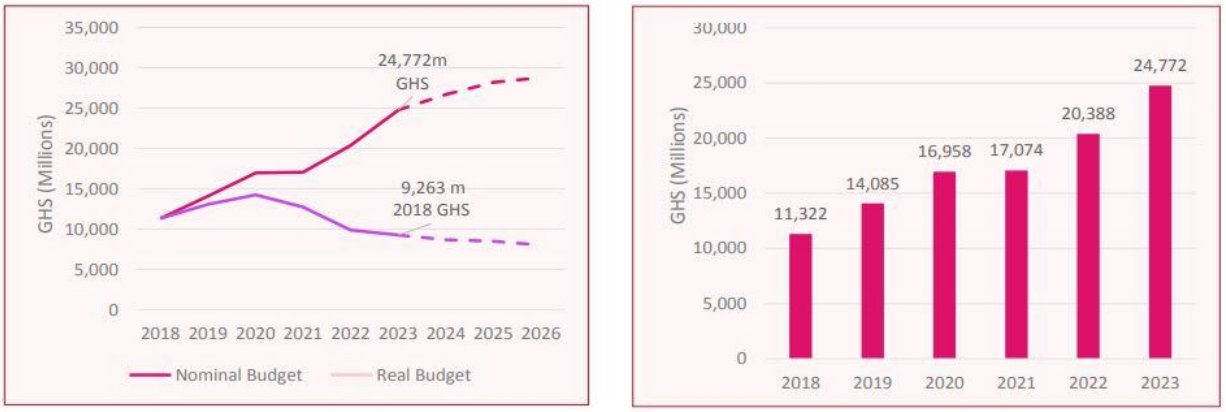


Figure 21: Education budget since 2018 [3].

Secondly, the total education budget as a share of the total government spending has decreased since 2019 and is below the UNESCO benchmark of 15% to 20% and also below their own goal of 23%, visible in Figure 22b. In 2023, the share of education spending was only 10.9% and this is predicted to continue declining to 8.6% of total government spending in 2026, which is by far of the UNESCO target. The primary reasons for the decline of government educational spending are the challenges related to budget allocation and execution and a shift in government spending priorities away from capital investment and goods/services (i.e., facilities and resources) towards salaries and other non-education expenditures [3].

Thirdly, the share of education spending in terms of the GDP has declined from 4.3% in 2020 to 3.1% in 2023, failing to meet the UNESCO target of 4% to 6%. The prediction is that the share will continue declining to 2.3% of GDP in 2026, which is by far of the UNESCO target, visible in Figure 22a [3].

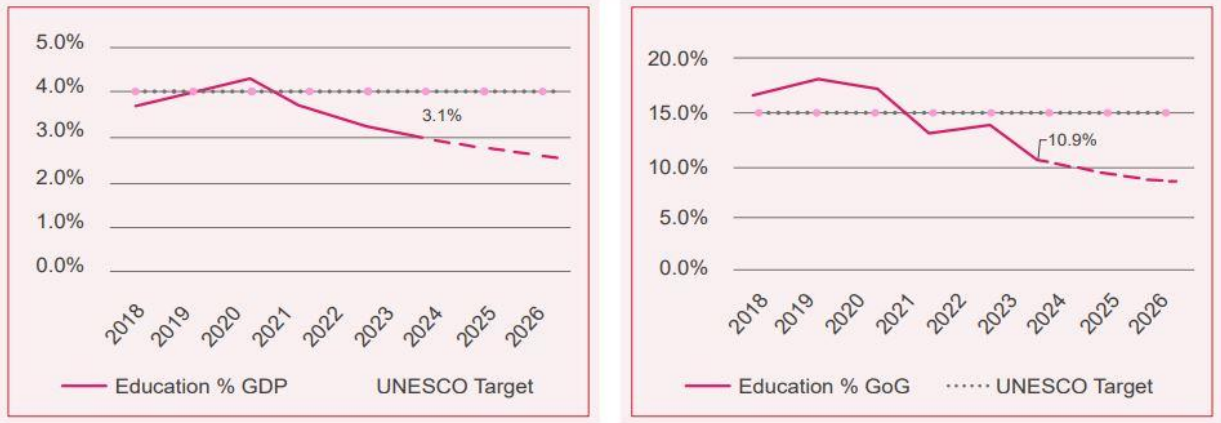


Figure 22: (a): Education Budget % of GDP (left), (b): Education Share of Total government Budget (right), both compared to a low UNESCO target [3].

Lastly, the percentage of the ministry of education (MoE) budget allocated to basic education has declined from 39.2% in 2019 to 20% in 2023. Basic education is accessed by the broadest part of the population and therefore a crucial area for investment by the MoE, given its foundational stage for young Africans [3].

The insufficient government funding capacity has led to the implementation of a cost-sharing system, leading to the exploration of alternative funding sources. The cost-sharing system is currently financed by internally generated funds (IGFs), local communities, students/families and private funding (including non-governmental organizations (NGOs), private companies and foreign direct investment (FDI), making the educational system vulnerable for variations in external funding or government spending [204]. The allocation of funds to schools are based on the type of school (private or public) and the number of enrolled students. Consequently, schools may enroll more students than they accommodate, resulting in overcrowded classrooms. The allocation of government spending to schools varies significantly, and is significantly lower than the approved budget for education, because of poor record management and payroll verification of teachers, leading to corruption and unorganized spending of funds [205]. Most institutions rely for a minimum of 10% of their total budget funding from IGFs. The most common activities for IGF are: commercial activities, such as supermarkets (for food) and local transportation, workshops, patents and industry partnerships. The implementation of the cost-sharing system has also led to an increasing growth of non-governmental/private schools, which supports the system in providing funding and resources. The remaining financial gap is financed by the students themselves, their families, local communities and NGOs who provide support with their best efforts [204].

5.3.1.4 Cost of education

The cost of education in Ghana can vary significantly based on several factors, including the level of education (basic, junior high school (JHS) and senior high school (SHS)), the type of institution (public or private), and the area (rural or urban). The average household in Ghana spends 459GH₵ (35€) per household member attending school per year. Across income levels, households spend over a third of their income on education.

Firstly, as explained, education in Ghana is divided between government (public) schools and private schools. These institutions both have their own resources and expenditures. On average, private schools are 54% more expensive than government (public) schools and both have additional costly fees. These fees, tuition and additional fees, are higher for private schools compared to public schools as the government only provides subsidies to public schools. The cost of education for different public schools vary significantly, based on the tuition fees and additional fees due to the cost-sharing system. However, these fees are still prevalent in public schools. Public education in lower and higher education in Ghana is supposed to be ‘free’ with the Ghanaian policies (Sub-section 5.3.1.5). In practice, due to the lack of funding and the implementation of the cost-sharing system, parents and students are obliged to pay several additional costs to cover their education, which can pose significant challenges for parents and students, especially in rural areas [206]. In urban areas, parents love to contribute as long as schools deliver proper equipment. However, in rural areas, financial means are tight and therefore parents may not be willing to pay all the additional fees [EI.1].

Private schools, on the other hand, have higher tuition fees than public schools. The difference in tuition fees for private schools are quite high. The average in Table 10 represents a very simple private school. Private schools with a big name and good infrastructure can go up to 30.000 GH₵ [EI.1]. For the tuition fees and additional fees, private schools can charge up to whatever they think is appropriate. The most commonly cited extra fees for both government and private schools are: meals, uniforms, transportation, textbooks, exam fees, mandatory extra classes, and parent teacher association contributions [206]. As discussed earlier, averages and numbers in Africa are hard to obtain as these are hardly up-to-date. The most up-to-date information is from 2015 [195],

so we recommend to check the latest sources for the most up-to-date information whenever available.

Secondly, there is also a significant disparity of educational costs and spending between rural and urban areas. Education spending in rural areas accounts for 15% in urban households and 11% in rural areas of the total spending of households [195].

Ghanaian area type	**Average annual expenditure on education**
Urban: Accra	1024 GH¢
Urban: other areas	521 GH¢
Rural: coastal area	291 GH¢
Rural: Savannah	120 GH¢

Table 10: Average annual expenditure (GH¢) on education per area in Ghana [195].

Additionally, the location of the area is also a determinant of the average annual expenditure on education. The average annual education spending per household significantly differs between different urban areas, respectively Accra (1024 GH¢) and other (521 GH¢), and different rural areas, savannah (291 GH¢) and coastal areas (120 GH¢), visible in Table 10 [195].

Lastly, the level of education is also a determinant of the cost of education. As visible in Table 11, both the tuition fees and additional fees increase with the level of the education, with basic education being the lowest and senior high school being the highest [195].

Cost category (per household)	**Average annual costs in GH¢**
Tuition costs	
- *Public schools*	56 GH¢
- *Private schools*	315 GH¢
Other costs than tuition	
- *Public schools*	737 GH¢
- *Private schools*	903 GH¢
Total cost per year	
- *Public schools*	793 GH¢
- *Private schools*	1218 GH¢

Table 11: Average annual costs (GH¢) per school category [198].

5.3.1.5 Policies

Education in Ghana is 100% influenced by the government. In fact, education is one of the major topics in the elections and part of every political party's manifesto, which highlights the importance of education in Ghana. The government plays a central role in every aspect of education to educate young Ghanaians. The following policies are of great importance to education in Ghana [198]:

- **Free Compulsory Universal Basic Education (FCUBE)**

The Free Compulsory Universal Basic Education (FCUBE) ensures that it is mandatory for every child in Ghana to attend school free of charge. This policy exclusively applies to the public schools in Ghana. Parents are obliged to take their children to school and legal actions can be taken if parents' fail to take their children to school. The policy also deals with poverty, as the FCUBE ensures free education for everyone from the primary level to junior high school (JHS) levels. This policy both increased the school enrolment rates and bridged the gender gap. However, the policy

is constrained by a lack of resources which means that educational institutions had to introduce the cost-sharing system.

- **Free Senior High School (SHS) policy**

The Free Senior High School (SHS) policy was introduced in 2017 to serve disadvantaged children in mainly rural areas to remove the financial constraints to continue their education. The policy ensured that many young Ghanaians continued with SHS, who would have ended their education after JHS otherwise. Results are showing a 32.2% increase of the enrolment rates in SHS after the implementation of this policy.

- **School feeding program**

The Ghana School Feeding Program (GSFP) operates started in 2005 to encourage children to attend school (increase enrolment and retention rates) and reduce poverty across Ghana. The requirement is that at least 80% of the food for the program is purchased from local farmers, which ensures additional income for poor households and consequently contributing to reducing poverty. The program provides one hot meal per day during the school term targeting primary public school children. The GSFP is a successful program serving 2.6 million children by providing poor and disadvantaged children with the possibility to follow education without any financial constraints [207].

- **Complementary education**

Complementary Education is a policy to bridge the gap of geographically disadvantaged people (rural or northern people) to ensure education for everyone. This policy strives to help the people that didn't advantage from the introduction of the FCUBE. The program offers literacy and numeracy education in the native language for out-of-school children taught by volunteers in the local area.

5.3.1.6 Community and family support

The level of community and family support varies significantly, particularly between urban and rural areas as well as private and public schools. In both urban and rural areas, parents are positive about the changed being made in education and the prospects for their children.
In urban areas, there is a significant and positive parental involvement for private and public schools with the goal to enhance their children's education. The parents and communities in urban areas are contributing financially and actively engage in school activities, e.g. teachers meetings, parent-teacher associations (PTAs), volunteering, or cooking. The Parent-Teacher Associations (PTAs) advocate the interest for students, teachers and the community. The active engagement also applies to private schools in peri-urban or rural areas, as the families of children on private schools often have greater financial resources [EI.1].

Support levels	*Urban areas*	*Rural areas*
Private schools	High	Semi-high
Public schools	Semi-high	Low

Table 12: financial parental support levels in education.

However, in rural areas, the dynamics of financial contributions is significantly different because of the limited financial resources of parents and communities, particularly on public schools, as visible in Table 12. The economic challenges of rural parents and communities make it more difficult to support their children's education. In some instances, families need the support of their children outside of school hours because of the financial constraints and not because of unwillingness. Moreover, rural families face additional challenges which limit the support level, such as limited transportation options and greater distances between their house and the school.

Lastly, the government has removed the parent-teacher associations, which is used to bring parents together to support financially, because of the free education in public schools. As the government promises free education, the institutions are hesitant to ask parents for financial contributions [EI.1].

Non-financial parental engagement encompasses active engagement in school activities, such as volunteering or attending teacher meetings, or providing practical support to children's learning at home [208]. While many schools in Ghana and the broader West Africa involve parents in these school-based activities, Harris et al. [208] found that these activities have minimal impact on the learning process and achievement of children. Active engagement and practical support in the learning process at home is shown to significantly enhance students' learning and achievement. Practical parental engagement is not bound to financial resources, the area, or the type of school, as every parent has the responsibility to contribute to their children's learning process [208].

In summary, the level of financial support is closely related to the resources available. The financial situation of urban areas and communities are generally better compared to rural areas, leading to a different level of support. Parents can, however, make a significant difference in the children's learning process by actively engage in practically supporting their children.

5.3.1.7 Distance to education

Urban areas are privileged with a wide variety of schools situated nearby, which significantly limits the distance that children have to travel to their school. Additionally, children in rural areas have the availability of different transportation options, including public transport like TroTros, school buses, motorbikes, services like uber or parents can bring them by car. TroTros are minivans that serve as cheap public transportation for locals, mainly in urban areas [EI.1].

In the rural areas, there may be differences in terms of the distance between where people live and the school. The results of our survey, as discussed in Sub-section 6.3.5, show that in rural areas, distances can range from 500 meters to 8 kilometers, with 89.5% of the respondents travelling by foot. The majority of the children live 3 to 7 kilometers away from their school, which is a significant distance to cover by foot. Travelling by foot for such a long distance poses significant potential dangers, including exposure to insects, encounters with wild animals, the danger of fast-driving cars, and the threat of abduction or sexual assault, particularly in remote areas. In countries like Sierra Leone, for example, girls who are walking through the forest by foot are in danger of being abducted or raped during their journey without any support nearby. Despite the potential dangers, children have no other option than to walk daily to school and back home to access education [EI.1].

5.3.2 Acceptability: Educational quality

5.3.2.1 Quality of education

The education system of Ghana is considered as one of the most effective and advanced in West Africa. The quality of education is influenced by a combination of factors, which can be both challenges and positive developments.

The main factors influencing the quality of the Ghanaian education system are financial resources, by both the parent and the educational institution, and the quality of teachers. Financial constraints pose significant challenges for educational institutions to acquire the essential resources and materials necessary for effective teaching. The financial resources of parents determine whether their children attend private or public schools. As private school fees can be expensive, not every parents is able to afford private education. Public schools, on the other hand, are suffering from a lack of financial and educational resources, leading to a lower quality of education. The advantages and challenges for private and public schools are elaborated in Sub-

section 5.1. Lastly, teachers are the main provider of education to children, meaning that the quality and qualification of teachers is incredibly important for the level of schooling, as elaborated in Sub-section 5.3.2.3. The combination of financial limitations and the quality of teachers contribute to the variations in education across different regions and schools [EI.1].

Other important factors that influence the quality of education are government policies, community support, external support, and educational resources. Government policies ensure that educational institutions have the necessary resources to facilitate quality education, as these resources provide teachers with tools for effective schooling. However, insufficient funding from the government is leading to the shortage of necessary resources. Community support is also important for the quality of education, as the community often provide additional educational resources to ensure that children receive the quality of education they need. Moreover, external support, i.e. NGOs and development partners (DPs), contribute to educational development by supporting government initiatives and addressing gaps within the system. These efforts make significant impact in overcoming educational challenges and the aim to improve the quality of education, e.g. with the supply and funding of computers and books [EI.1].

The quality of education in Ghana is a complex combination of factors, and addressing the challenges collectively contribute to enhancing the overall education landscape. The quality of education in Ghana has been poor, but due to positive developments the Ghanaian education system improved. The government recognizes education as an important political topic, indicating a shared goal to actively engage in curriculum reforms and policies to improve the quality of education. Technological advancements and infrastructure improvements in recent years contributed to the evolvement of the Ghanaian system, contributing to an effective and advanced educational landscape. Ghana, nowadays, serves as the technological gateway to Africa [EI.1].

5.3.2.2 Curriculum

As elaborated in Sub-section 5.3.1.5, the government prioritizes education in their political agenda, which is a positive development in the goal to improve the quality of education in Ghana. The curriculum in Ghana is identical with the curriculum of the Economic Community of West African States (ECOWAS). The curriculum has undergone several significant reforms, with the latest reform shifting to a more practical and technology-integrated approach. The West African Examinations Council (WAEC) provides the standardized exams across West Africa to assess and evaluate students' performance. The WAEC is operating independently from government bodies, and provides the exam results to the national governments for, for example, policymakers and the Nacca for curriculum development. The WAEC ensures that the exams assess the understanding of the student with regards to the curriculum and their ability to apply the necessary knowledge [EI.1].

Another significant change in the new reform is the introduction of teachers' licensure exams, which is seen as positive development to improve the quality of education. A more detailed explanation on the licensure exam is given in Sub-section 5.3.2.3.

The latest curriculum reform was about 2 years ago with the goal to stimulate the integration of technology in every aspect, from implementing AI technologies to the use of devices in classrooms. The teachers had to follow an intensive training program to equip themselves with the knowledge and skills necessary to adapt to the new curriculum. With the new reforms, the curriculum now incorporates a specific syllabus for Information and Communication Technology (ICT). The intention with the new reforms of the curriculum is to change from a theoretical approach to a practical approach by integrating technology into education. However, the reality is that there is a significant lack of resources and infrastructure to implement the new reforms [EI.1].

5.3.2.3 Teacher quality

The quality of teachers in Ghana play a significant role in determining the overall quality of education, as elaborated in Sub-section 5.3.2.1. Several measures are taken to ensure the quality of education in both private and public schools, including the licensure exam and qualifications criteria [EI.1].

The introduction of the teachers' licensure exam in the new reform is an important step in ensuring quality education for Ghanaian schools. The licensure exam, mandatory for both qualified and non-qualified teachers, ensures that all teachers meet a minimum level of teacher quality. Without passing the exam, a teacher is not allowed to engage in education. Before the reforms, educational institutions faced challenges regarding the quality of education caused by high unemployment rates. Many individuals started as a teacher because they were unable to find alternative employment, ensuring a lack of motivation and passion for teaching. This challenge posed a significant risk to the overall quality of education, especially in rural areas. The lack of proper infrastructure and support also results in a shortage of qualified teachers in rural areas. Consequently, if people found alternative employment later on, they tended to leave teaching [EI.1].

In government schools, additional criteria such as training college or a university degree in education are a requirement for teacher qualifications. However, relying only on teachers with these formal qualification may results in limited teacher availability for certain subjects. In contrast, private schools have the flexibility to hire teachers with a formal educational qualification or teachers with at least a senior high-school qualification. These teachers are closely monitored by secret supervisors to maintain a high quality standard. Non-qualified teachers mainly consist of individuals who are unable to find alternative job employment and therefore take teaching as the last option. In West Africa, teaching is perceived as an unpopular profession with low salaries. Consequently, private schools are often perceived as having a higher quality than public schools, although this perception does not necessarily reflect the reality. Nevertheless, most private schools outperform the public schools due to better resources and infrastructure [EI.1].

5.3.2.4 Medium of instruction

The primary language in West-Africa is either Frech (francophone zone) or English (anglophone zone). The language is key in both communication and education. Certainly, in some areas and instances, particularly in rural areas, students may face challenges with the language of instruction, which can result in the use of local language to understand the content more effectively. Factors can also be quality of teachers, language proficiency, and communication skill [EI.1]. According to Varghese and Nagaraj [209], comprehensive reading and student performance are negatively influenced by the fact that children are taught in another language, i.e. English or French, other than their mother tongue, i.e. their tribal language. Despite English or French being the national languages in West Africa, concerns persist regarding the quality of English language instruction. The quality, and subsequently learning outcomes, are negatively impacted by challenges, such as: large class sizes, non-qualified teachers, and irrelevant revisions of the curriculum. These challenges contribute to the underdevelopment of tribal communities in social, economic, and educational aspects.

5.3.3 Availability: Resources & infrastructure

5.3.3.1 Learning resources and utilities

Learning materials, including textbooks and syllabi, are provided to support the learning process. The available learning resources in Ghana vary across different regions and educational institutions. Recent reforms introduced the use of technology in the learning process. Resources, such as technology and the internet, significantly impact students' perceptions and understanding of the concepts taught in school. Mobile phones cannot be used for effective schooling, as mobile

phones are prohibited in education in Ghana. However, universal access to computers, internet and other technologies remains far away, due to a lack of resources and infrastructure. As a result, the use of traditional textbooks remain prevalent. Unfortunately, the traditional textbooks are either insufficient or irrelevant to the subjects taught in both urban and rural areas [EI.1].

Computers and internet can significantly impact the learning process due to the wide variety of content and access to digital textbooks. However, challenges arise due to limited access to computers, with the main challenge being to build the infrastructure needed to utilize technologies, such as the internet. While the internet may be available, the unavailability of actual equipment will affect the use of technology for teaching and learning purposes. The resources are crucial for providing technology-integrated education. However, the Urban areas tend to have a higher accessibility to resources, resulting in a higher impact of technological and practical education compared to rural areas. Especially in rural areas and on public schools, schools are dealing with high student numbers, the effectivity of technologies is low. These schools either have no access to technologies or students face challenges with receiving limited time and resources on using technologies per student. External support is providing additional resources to educational institutions, but the current level of support remains insufficient [EI.1].

5.3.3.2 Access to internet

Ghana is advanced in using technologies, including the internet, compared to other ECOWAS countries. Access to the internet is relatively widespread across Ghana, facilitated by initiatives such as the RuralCOMM. RuralCOMM ensures that both urban and rural areas are connected to fiber and 5G technology. The telecom companies are able to use the RuralCOMM to spread their internet network across a wider range, including rural areas. The main challenge is to build the infrastructure to utilize these technologies [EI.1]. Figure 23 shows that internet availability across Ghana significantly increased from 8% in 2010 to 69% in 2021. However, the figure also shows the existing rural-urban gap that has widened over the years. In urban areas, the internet availability increased from 13% to 80% compared to 2% to 54% in rural areas. Nevertheless, a positive aspect is that rural areas are increasingly being connected to the world of internet and supporting technologies [137]. In contrast, most other countries across the ECOWAS region, like Burkina Faso, Gambia, and Nigeria, are facing challenges to widespread internet accessibility, such as limited accessibility, only 3G without fiber, and poor internet quality. Similar efforts should be taken in other ECOWAS countries to enhance internet connectivity [EI.1].

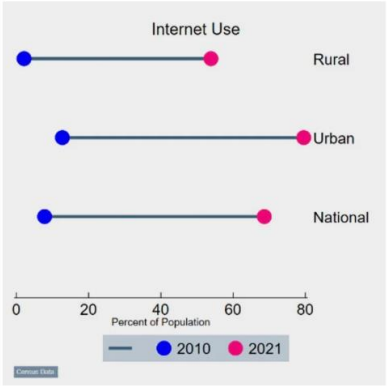


Figure 23: Internet access across Ghana [141].

5.3.3.3 Grading & assessment

The Ghanaian education system has made significant changes with the introduction of the new curriculum in grading and assessment methods. Traditional assessment methods are turning into practical assessment, resulting in a different grading system. The integration of technologies is also shaping these new practical assessments. The new grading system ensured the removal of the conventional ranking system with positions based on the students' performance in class. The focus is now on the individual performance on subject instead of their ranking in class, which aims to prevent students from feeling inferior [210].

5.3.4 Adaptability: Technology-integrated education

5.3.4.1 Adapting to the need for technology

The adaptation to the growing need for technology has become an incredibly important part in different aspects of society bringing both opportunities and challenges. Technology is able to influence individuals, businesses, communication, and education by efficiency, connectivity, and innovation. Innovative technologies, including AI, OER, and digital libraries, are introduced into the school system, particularly into private schools as they have the sufficient technological resources compared to public schools. The integration of technology in developing countries often serves as a catalyst for socio-economic development. Not only the students can significantly learn from technology, but also parents and the community, which was also identified in the responses during the case study interview in Sub-section 6.3.5 [EI.1].

Technology has significantly changed people's daily life through the use of mobile phones and other digital devices increasing connectivity and efficiency of people across Ghana. In the context of education, technology-integrated learning became prevalent with the new reforms of the ECOWAS curriculum. The traditional theoretical approach has been shifting towards more practically-oriented education. Traditional classrooms in combination with technological resources, such as computers and digital libraries, are becoming the new way of educating [EI.1].

The integration of technology into education brought a significant positive impact to student outcomes. The adoption of technology is gradually increasing, with in particular private schools incorporating digital tools and technologies. The practical technology-integrated education enhances students' perception and their understanding. Nevertheless, challenges, such as a lack of resources, internet, and infrastructure in both rural and urban areas, are still a major factor hindering the full potential of new technologies, this was also identified in the case study interview in Sub-section 6.3.5 [EI.1], [EI.4]..

5.3.4.2 Pandemic impact

The COVID-19 pandemic made a significant impact on all aspects of society, particularly in the context of education. The impact on students varied significantly between private and public schools. The public schools were affected greatly by the pandemic due to the limited technological infrastructure. Students in public schools were obliged to stay at home because of safety measures, resulting in a lack of effective learning opportunities and at the same time stopping their learning progress. However, private schools were able to continue their education due to the availability of the necessary technological resources. The integration of technologies in private schools facilitated communication and learning. Some private schools were already equipped with the necessary technological resources and others managed to supply their private school during the pandemic with technologies. Consequently, the pandemic emphasized the essential role of technology in education, with the need to reform the curriculum and the Ghanaian education system with a focus on technology-integrated education [EI.1], [EI.6], [EI.7], [EI.8].

5.4 The rich picture of the Ghanaian educational landscape

Rich picture modeling is a flexible visualization technique used in systems thinking and business analysis to visualize complex situations, systems or processes. It is an easy-to-conceive diagramming method that aims to gain a better understanding of the operational processes and structures in a system by providing a comprehensive and intuitive overview. Rich pictures are known for their powerfulness and simplicity [211], [212], [213]. Most rich pictures are developed with minimal prompts and constraints to ensure and encourage the free-form and flexibility of rich picture modeling. This flexibility and minimum amount of constraints encourage creativity and expression resulting in varied outcomes with diverse interpretations [213]. Bell [211] emphasize the value of multiple interpretations of rich pictures as it can "lead to the maximum depth of understanding". This is important as the goal of rich pictures is to build a shared understanding for all involved stakeholders of the relevant context, relationships and dynamics [212].

While rich pictures do not provide direct input for formal modeling approaches, it excels in providing a broad and rich description of potential issues within a system, thereby enriching

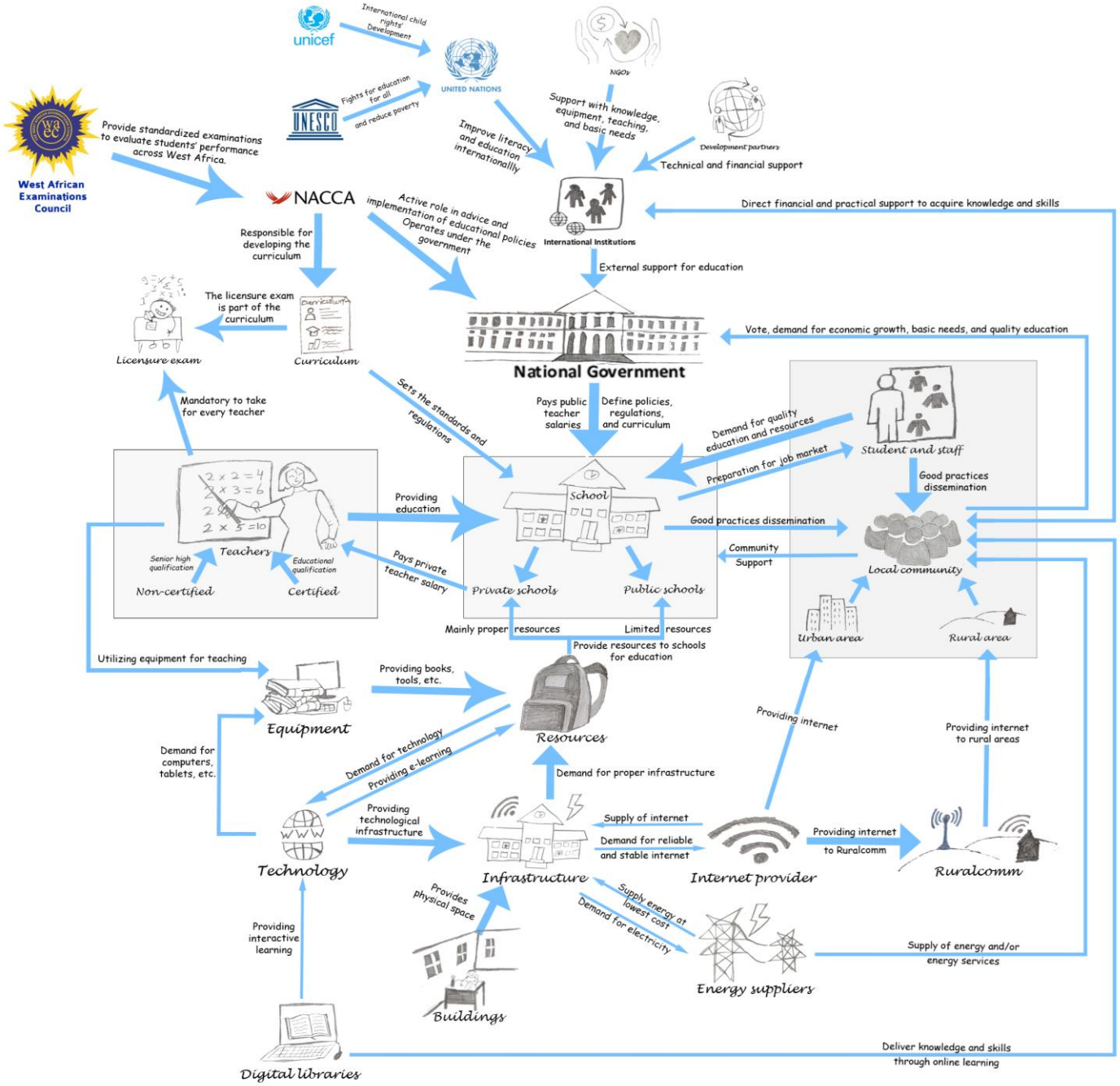


Figure 24: Rich picture of the Ghanaian educational landscape.

problem-solving attempts. This technique can be especially useful in situations in which participants are illiterate or where language barriers are present [213]. Rich pictures are generally constructed by performing a semi-structured interview with a stakeholder and they can be drawn by either the involved stakeholders or the modeler [212]. The best working conditions for the rich picture is within a small group (two to six people) while encouraging creativity during the visual representation of the complex socio-technical system [214].

The rich picture illustrating the educational landscape in the Ghanaian context has been collectively developed by the primary researcher together with two essential stakeholders: Stanley K. Dankyira, CEO of Maxim Nyansa, a parent and also an ICT teacher, and Kofi Asante, an experienced digital librarian [EI.1.2]. Dankyira's multifaced experience in the educational field, encompassing most stakeholders including an ICT teacher, parent, student, and organizational leader on Maxim Nyansa and its digital library project, provides a comprehensive overview on the educational system in Ghana and the broader West African context. Complementing this perspective, Asante is an experienced digital librarian in the educational sector, contributing insights for the rich picture from the digital librarian perspective. This collaborative effort provides the rich picture with an in-depth analysis of the complex interplay of factors, while representing a diverse combination of stakeholders, of education and digital libraries in the Ghanaian context.

The rich picture represents a comprehensive overview of the multifaceted educational landscape in Ghana, as visualized in Figure 24. The rich picture illustrates the relationships between the stakeholders, institutions, and dynamics within the system, based on the insights gained from the factors influencing the EDUlandschape framework and the group discussion regarding the rich picture drawing [EI.1.2].

The connections between the EDUlandscape framework and the elements in the rich picture are visualized in Figure 25. The influence of the different elements and stakeholders on the EDUlandscape framework are summarized below.

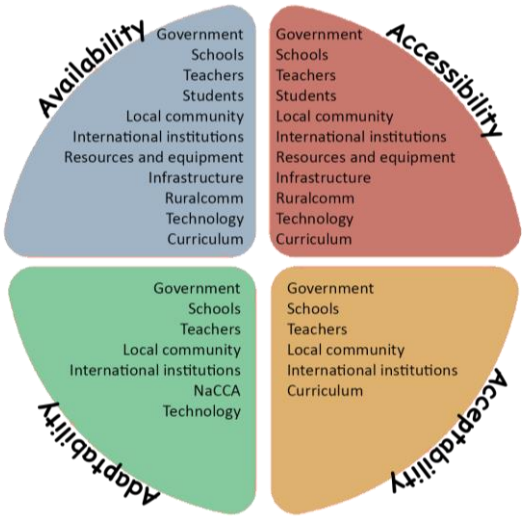


Figure 25: Stakeholder influence in shaping the EDUlandscape framework.

Key features of the educational landscape in Ghana are illustrated in the rich picture according to their significance in the system. The main contributors to the educational landscape in Ghana are the government, the schools, the teachers, emerging technologies, and the rural-urban divide. The government of Ghana is the central player in the educational system, as they are responsible for the policies, regulations, resource allocation, infrastructure, funding allocation, initiatives, and the curriculum development to ensure universal access to education for all individuals, regardless of their gender, socio-economic situation or background. Public school teachers' salaries are also funded by the government, while private school teachers are paid by their private institution instead of the government. On a national level, the hierarchical structure of Ghana's education system is led by the Ministry of Education (MoE), serving as the main authority of the educational

framework by distributing educational budget, allocation of resources, and policymaker (Sub-sections 5.1, 5.3.1.1, 5.3.1.3, 5.3.1.5 & 5.3.2.1) [EI.1.2].

Subsequent to the MoE, the Ghana Education Service (GES) serves as an important government body for implementing the policies and the framework facilitated by the MoE. The GES is for example responsible for the implementation of the new licensure exam. The GES is, for example, responsible for the implementation of the curriculum. One important component of the current curriculum is the licensure exam, which is mandatory for all teachers, both certified and non-certified, across all levels of education. The licensure exam is the qualification to become an educator in Ghana, ensuring a high-quality standard for educators in Ghana (Sub-section 5.3.2.2) [EI.1.2].

The GES is followed by the District Education Directorate (DED), which operates at regional and local levels. The DED ensures the implementation of the national policies and regulations in the rural and local context. Additionally, the DED addresses other rural or urban specific challenges and needs [EI.1.2].

The National Council for Curriculum Assessment (NaCCA) is an important government body responsible for adapting the curriculum to the changing societal needs, technological developments, and educational best practices. The changing technological and societal needs enhance the adaptability of the system. The NaCCA operates under the MoE, taking the responsibility over the development of the national curriculum and learning methods for both private and public education in Ghana. The curriculum determines the content, the standards, and teaching methods provided by the school with the goal to facilitate a diverse, universal and inclusive learning environment. The diverse, universal and inclusive learning environment enhances the accessibility and availability of the Ghanaian educational landscape by providing education for a broader audience. The West African Examinations Council (WAC) provides and conducts the standardized exams across West Africa to assess and evaluate student performance. The WAEC shares the exam results with the national government for evaluation by, for example, policymakers and the NaCCA (Sub-section 5.3.2.2) [EI.1.2].

Schools are the second main determinant of the educational landscape by providing the necessary learning environment, consisting of the infrastructure (i.e. building, internet, and electricity) and resources (i.e. equipment and learning materials). The rich picture illustrates the importance of educational resources and infrastructure, including sufficient equipment (such as books, computers, etc.), and buildings respectively (Sub-section 5.3.3.1). Ghanaian schools are subdivided in public (governmental) and private schools, bringing additional challenges and opportunities to students' learning experience. Due to the Ghanaian government policies, public schools ensure accessibility for every child, without exception (Sub-section 5.3.1.5). In contrast, the access to private schools is limited and only available for economically advantaged people due to their expensive tuition fees and additional costs. However, there are cases in rural areas where inexpensive private schools are located with access for underprivileged children. This situation occurs in areas where the government has challenges in meeting the demand for education due to rapid population growth and a prioritization of public schools in other areas. Private schools, however, have to pay the private school teachers themselves, which brings additional challenges in rural areas. Additionally, the type of school significantly influences the availability and accessibility of resources and infrastructure. Private schools are known for their high-quality resources and infrastructure, while public schools often suffer from limited infrastructure and resources. Sub-section 5.1 provides a comprehensive overview of the differences and similarities between public and private schools. Both public and private schools have to adhere to the curriculum provided by the government, including the need for qualification through the mandatory licensure exam for all teachers (Sub-sections 5.3.2.2 & 5.3.2.3) [EI.1.2].

An essential element of any school is the teacher, facilitating students' learning by providing the relevant learning materials and utilization of effective teaching methods. The availability of

qualified teachers is essential for providing quality education. Public schools are required to have certified trained teachers through the successful completion of training college, a bachelors in education, or another educational qualification from a university. In contrast, private schools are flexible as they can either employ both certified and non-certified teachers to ensure the availability of teachers for every subject. Private schools themselves are responsible for providing quality teachers, which is mostly evaluated by secret supervisors. Non-certified teachers are individuals who have completed their senior high-school or undergraduate at a university. This is due to the fact that teaching in West African countries is seen as an unpopular profession with low salaries. Many individuals view teaching as the last option when other job opportunities are unavailable. However, both certified and non-certified teachers have to successfully pass the licensure exam (Sub-section 5.3.2.3). All of these elements are influencing the landscape with regards to the accessibility, availability, acceptability, and adaptability [EI.1.2].

The integration of technology, including digital libraries, and the focus on practically-oriented education has become the leading aspect of the new reforms in the curriculum. However, the emerging technologies and their implementation brings additional challenges with regards to the availability and accessibility of reliable and stable internet connection and electricity to run the equipment. Schools are expected to provide ICT lessons to their student, however, the budget for equipment is limited and insufficient (Sub-section 5.3.4.1) [EI.1.2]. Technologies also provide new ways of accessing digital educational resources, for example through digital libraries (Sub-section 4.7.5 and 5.3.4.1) [EI.1.2]. The impressive rise of smartphone subscriptions in Ghana shows the potential of accessing education through the internet by enabling learning with relevant educational resources from anywhere at any time. Nevertheless, the accessibility of these innovative technologies are dependent on the accessibility to a reliable and stable internet connection and the availability of electricity (Sub-section 4.4) [EI.1.2]. Initiatives, such as the Ruralcomm, aim to bridge the digital divide by providing internet connectivity to rural areas to address the needs and challenges within rural communities and enable them to also benefit from these technologies (Sub-section 5.3.3.2) [EI.1.2].

Aside of the government, the schools and the teachers, the rural-urban divide is the last main determinant contributing to the educational landscape in Ghana and other West African countries. The rural and urban context encompass socio-economic factors and educational challenges, impacting the quality of education. The rural-urban divide brings additional challenges and opportunities, affecting the availability, accessibility, acceptability and adaptability (Sub-section 5.2). Within this framework, community engagement plays an essential role, consisting of families, students, teachers and other stakeholders like the elders of the community, in supporting both financially and practically to provide education for all individuals within local communities. Financial and practical support to students and educational institutions may include the gathering of necessary equipment, providing practical support for students, engaging in voluntary work such as cooking for the feeding programs, or providing financial support. Parent-Teacher Associations (PTAs) also have a significantly influence in the support and decision-making process for educational institutions in both rural and urban areas (Sub-section 5.3.1.6) [EI.1.2]. The local community can enhance accessibility, availability, and acceptability.

Moreover, the rich picture highlights the importance of external support, ranging from the non-governmental organizations (NGOs) to international development partners and the United Nations (UN), such as UNESCO and UNICEF. These organizations are either supporting through the government or directly to the community. These international institutions support developing countries by providing expertise, technical support, funding, and knowledge building initiatives to leverage the best practices from international education and promote education for every child without discrimination. External support enhances the inclusion of underprivileged individuals, thus enhancing acceptability, and availability and accessibility of resources and infrastructure (Sub-section 5.3.1.3) [EI.1.2].

6 Design of digital educational libraries in a West African context.

This chapter elaborates on the treatment design of digital educational libraries in a West African context. The process of formulating design principles consists of the following five steps: Requirements Engineering by employing User Stories, validating design requirements, formulating design principles, developing enhanced local design principles with regards to the local implementation of digital educational libraries, and validating design principles. First, the design requirements are formulated, which are based on literature review, the concepts and characteristics of a digital library, the educational landscape and the rich picture, and expert, user, and researcher interviews. Requirements Engineering (RE) has shown to be an essential process for software system and information system development [215]. Secondly, the requirements are validated through relevant scientific literature, and the case study results. Thirdly, the design principles are formulated which are based on the identified requirements and User Stories. Fourthly, enhanced local design principles are elaborated through developing the CNTA. Lastly, the design principles are validated through relevant scientific literature and expert interviews.

6.1 Requirements Engineering (RE) by integrating the Abstraction-oriented Frames framework

The foundation for successful software and information system development lies in fully understanding and effectively communicating the requirements responsible for its functionality, usability, and adaptability, while focusing on user needs and technological limitations [216]. As visualized in Figure 26, Requirements Engineering (RE) consists of the following three process: Requirements Elicitation, Analysis, and Specification [217].

After assessing different RE techniques, we chose to employ User Stories as our documentation technique. The elicitation of the Requirements (RQs) through User Stories is discussed in Sub-section 6.1.1.4. User stories are known to be easy to understand for people without notation or modeling skills, simple, promote collaboration, and widespread adoption in agile software development. User stories are a short description of a requirement by conveying the 'who', 'what', 'how', and 'when' of the requirements document [218]. According to Cohn [219], User stories should be adopted in the structure: As a [stakeholder], I want to [goal], so that [benefit]. The engineering of the requirements serve as the basis for the formulation of design principles in Sub-section 6.2.

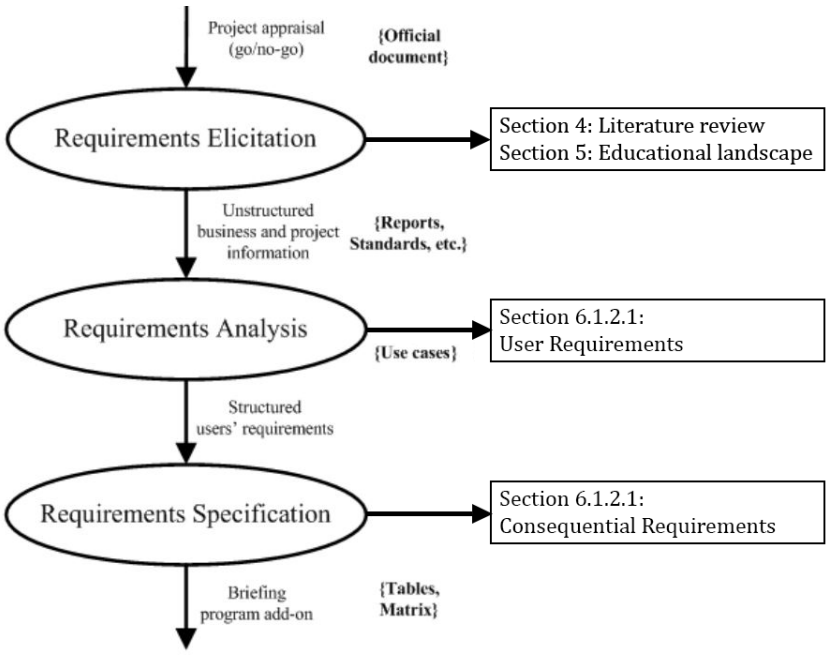


Figure 26: The three step process of Requirements Engineering [217].

Bastani [216] proposed to integrate the Abstraction-oriented Frames (AoF) framework into the RE process to support the identification, analysis, and documenting of requirements for software development projects, particularly in the context of complex and evolving information systems such as digital educational libraries. The framework integrates three conceptual approaches, i.e. the Integrated Triple Sequence Model, Use Case Instrumentality, and Abstraction-Oriented Elicitation and Classification, for requirement analysis and system design by translating user problems into system requirements. Figure 27 visualizes an overview of the relation between the AoF framework, the step in the Requirement Elicitation process, and its section [216].

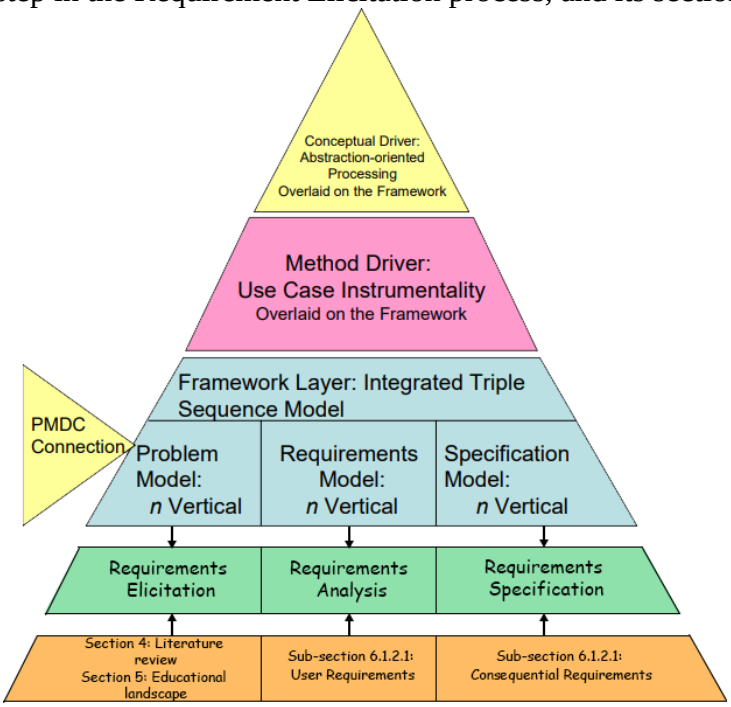


Figure 27: An overview of the Abstraction-oriented Frames framework in combination with the Requirements Engineering process [216].

First, the Integrated Triple Sequence Model (ITSM) functions as the foundational framework layer, consisting of the problem, the requirements, and specification model. It aims to highlight the importance of an extensive problem investigation and the organization of requirements based on user choices and desired system functionalities. It enables multiple iterations for evolving societal and/or technological needs [216]. Traceability and mapping are two essential components, ensuring that every requirement is traceable and mapped to a higher abstraction level within the Requirements model [216].

The Requirements Elicitation process refers to the in-depth understanding of the real-world problems faced by potential system users, which have been addressed in Sections 4 and 5 of this research. This corresponds to the "*understanding the domain context*" activity of the Requirements Elicitation process and the Problem Model in the AoF framework. Through Pre-Problem-Model Discovery and Categorization Method (PMDC), the identified problem model elements from the real-world problems of relevant stakeholders are systematically organized and classified. The framework starts with a high-abstraction level in the problem model and gradually changes to a low-abstraction level in the specification model [216].

Building upon the problem model, the requirements model serves as a user requirements analysis of the system with the desired functionalities. Sub-section 6.1.2.2 summarizes the user requirements of a digital educational library in a West African context [216].

Lastly, the specification model refers to the design decisions formulated from the identified user requirements. These decisions, known as Consequential Requirements, serve as the guideline for

the implementation phase of the information system, which is elaborated in Sub-section 6.1.3.2 [216].

Secondly, Use Case Instrumentality in the AoF framework refers to the employment of use cases to identify, in particular, functional requirements. Use cases help to understand the user-system interactions and desired functionalities of a software system, while being emerged in the local context. The focus of use cases is only on the systems' functionalities without looking at how it will be implemented, which is the task of the specification model. Additionally, use cases may also validate the developers' design decisions of the software system. We conducted three different use cases in Ghana for the local digital library project, as summarized in Sub-section 3.4.2.

Lastly, the Abstraction-oriented Elicitation and Classification approach translates user input obtained from interviews into actionable system elements for system design through, focusing on organizing requirements based on the problem context and user needs, while taking into account technological and architectural constraints.

By incorporating the AoF framework into the RE process, we can effectively identify, analyse and document requirements for various stakeholders with the aim to fully understand and address users' needs and system constraints for digital educational libraries in a West African context [216]. The AoF framework is especially useful for organizing the requirements during the Requirements Analysis and Requirements specification step.

Furthermore, two key aspects of the AoF framework involve flexibility and adaptability through iterative development cycles. These aspects ensure the support for evolving user needs and emerging technologies. Through iterative development, the framework ensures an incremental enhancement of the software system during the development phases [216].

In the subsequent sections, we dive into the steps of the RE process and integrate the AoF framework for a comprehensive understanding of user needs and system constraints.

6.1.1 Requirements Elicitation

Requirements Elicitation involves several activities with relevant stakeholders to provide a strong foundation for the formulation of the requirements. The process consists of the following activities: understanding the domain context, identify the sources for the requirements, identify the relevant stakeholder, and eliciting requirements [217]. The gathered requirements are the starting point of the subsequent Requirements Analysis step. The Requirements Elicitation process is elaborated in the following sub-sections.

6.1.1.1 Understanding the domain context

The Requirements Elicitation process starts with gaining an in-depth understanding of the 'real-world' context where the software system will operate. This step, equal to the problem model in the AoF framework, is essential for formulating design requirements [220]. The domain context refers to understanding the educational landscape, particularly in West Africa and Ghana, by utilizing qualitative research methods, such as case studies, to explore the real stakeholder needs for the system [220]. By understanding the context of the educational landscape, researchers can tailor the design requirements to meet user needs and utilize the appropriate technologies for the local context. The current educational environment needs to be thoroughly explored, which includes political, organizational, and social aspects of the system. Additional constraints influencing the process should also be identified for a comprehensive requirements document [215].

The activity "*Understanding the domain context*" of the Requirements Elicitation process has already been addressed in Sub-section 1.1, the literature review (Section 4), the EDUlandscape framework (Section 5), and the corresponding Rich Picture. These sections investigated the domain context, including its opportunities and challenges, with regards to education and the implementation of technology.

6.1.1.2 Sources for requirements

In every software development project, requirements can be identified from various sources and formats [221]. Stakeholders and experts serve as the main source for requirements elicitation. while existing systems, such as digital libraries which have a proven track record, can also provide valuable insights for tailoring the system to a specific context [215]. Additional to the sources, the identified requirements are also partially validated through literature search. For this research, the following sources, identified by Zowghi [215], are utilized to identify the requirements to address the problem context:

Interviews (Intv)

Interviews are the most used technique to effectively elicit in software development [69]. Interviews are conducted to understand user needs and relationships with other stakeholders, a detailed description of the conducted interviews is provided in Sub-section 3.3. Nevertheless, the effectiveness and quality of the gathered information during the interview depends significantly on the quality of the interaction and the skill of the interviewer [222]. The interviews are divided into user interviews (Uintv), expert interviews (Eintv), and researcher interviews (Rintv).

Domain Analysis (DA)

The exploration of existing and related documentation of a software and information system is an effective technique to gather requirements, understand the domain context, and identify the concepts and components of the digital library system. This source is especially effective when it enhances existing software and information systems, as seen in the case of digital libraries with having years of development [215]. Useful documentation include design documents, current system processes and technological instruction manuals. This source refers to the identified elements in the "understanding of the domain context", as discussed in Sub-section 6.1.1.1. This source is mostly combined with observation of the existing digital library system and conducting stakeholder interviews [215]. The DA has been applied in Sub-section 1.1, the literature review (Section 4), the EDUlandscape framework (Section 5).

Introspection (Ispec)

Introspection aims to develop requirements based on the analyst's understanding of the needs and desires of users and other stakeholders from the system. This technique is mainly used as a starting point for eliciting requirements. In cases where the users have little or no experience with the system, the analyst should also incorporate other sources for eliciting requirements [215]. The Ispec technique is applied through conducting case study research within the local context, by immersing into the real-world problem context.

Group Work Brainstorming (GWB)

Group Work is a common technique for eliciting requirements and effective as it involves direct stakeholder involvement. During Group Work, stakeholders can collaborate and brainstorm to discuss solutions for the existing problem context with regards to the implementation of the development project [215]. The GWB technique is applied through the Community Meetings from the CNTA, elaborated in Sub-section 6.3.4, and the brainstorm group session [EI.1.2].

Observation (Obs)

Observation is another common technique for eliciting requirements. By observing the current situation and the implementation of the project, the researcher can fully understand the tasks being performed when using the information system. This technique is often combined with other requirement elicitation techniques [215]. The Obs technique is applied through conducting case study research within the local context, by immersing into the real-world problem context.

6.1.1.3 Stakeholder Identification (SI)

Stakeholder Identification (SI) refers to the process of selecting the relevant stakeholders who represent the entire population. This process is essential for the design process and therefore the selection process should be selected carefully [223]. Glinz and Wieringa [224] defines stakeholders as: *".. individuals or groups with varying needs and desires who play a role in eliciting and validating system requirements".* The stakeholders are identified through the case study research. Each stakeholder provides a unique perspective to the development and implementation of a digital library in a West African context. Wieringa [57] describes stakeholders as the starting point for requirements identification in the treatment design. We have categorized stakeholders into three different groups: Educational system (EDUsystem) stakeholders, User stakeholders, and Content administration stakeholders. EDUsystem stakeholders are essential for the educational system, but are not directly involved in the digital library system. They are elaborated in hierarchical order and visualized as essential stakeholders in the educational system in the rich picture, visualized in Sub-section 5.4. User stakeholders are the end-users of the digital educational library in the local West African context. Content administration stakeholders are responsible for delivering, managing, and publishing content. The relevant stakeholders corresponding to each category is summarized in Appendix C.

6.1.1.4 Elicitation of requirements

In this section, the identified requirements are elicited. The elicited requirements (RQs) are organized and structured to the relevant stakeholders, i.e. teachers, users in general, students, community members (CMs), Digital librarian (DL), Expert, authors, by utilizing user stories. The tool to assure requirements quality is User Stories [218]. Therefore, we implement User Stories in our RE process. The User Stories (US), together with their relevant stakeholders, are elaborated in Appendix D. In addition, Appendix F presents the identified requirements with their corresponding sources. These sources are abbreviated, as elaborated in Sub-section 6.1.1.2. Additionally, this appendix includes cross-referencing of relevant papers, serving as self-validation instead of a source to elicit requirements, as discussed in Sub-section 6.5.1. Lastly, Appendix E elaborates on the final elicitation of requirements, providing clarity through their definitions and without duplication.

6.1.2 Requirements Analysis and Specification

Requirement analysis is an essential component of the development process with the elicited requirements as its starting point [216]. The aim of requirement analysis is to conceptualize the system's goals and provide guidance in the necessary functionality from the perceptions of the user. The Requirements Specification together with the Requirements analysis is categorized and documented through the AoF Framework, elaborated in Sub-section 6.1.2.1.

6.1.2.1 Requirement categorization according to the AoF framework

As summarized in Sub-section 6.1, the requirement model provides the desired solutions for the identified problems. A requirement can be identified through a mixture of methods, as elaborated in Sub-section 6.1.1.2. A requirements document, which is the outcome of the Specification model, should essentially clarify four categories of conceptual system elements: 'who', 'what', 'how', and 'when'. In this research, we will identify requirements based on the problem investigation, user and stakeholder interviews, and relevant papers on digital library requirements. The requirement and specification model is divided in two conceptual levels: *Choice Requirements* (often referred to as 'User Requirements') and *Consequential Requirements* respectively [216].

The first conceptual level are the Choice Requirements, from now on referred to as 'User Requirements' (URQs), related to the requirements model, representing the users' needs, choices, and personal experiences with regards to their specific problem context. The User Requirements describe the specific user desires with regards to the system by providing solutions to address their challenges and achieve their intended goals, as identified in the problem model [216]. Sub-sections

4.3.1.3 and 4.6.2 discuss the importance of aligning design decisions with users' perspectives, i.e. user-centric design, which has been identified as the main reason of EDU4D project failure.

The second conceptual level are the Consequential Requirements (CRQs), related to the specification model, refers to the logical, mathematical, and technical requirements necessary as a result of the identified URQs. These requirements are the result of users' choices, meaning that system stakeholders have to implement these requirement regardless of the designers' perception (Sub-section 4.3.1.3).

Both URQs and CRQs consist of functional and non-functional requirements. Functional requirements refer to functionalities that developers must implement to fulfil the users' needs and desired behavior of the system. Use cases, including user and stakeholder interviews, can be utilized to identify the functional requirements of the system. However, not all requirements can be identified by functional requirements, this is where non-functional requirements come in. The non-functional requirements are referring to constraints and specification for the operation of the software system that does not relate to functionality, which includes features such as reliability, scalability, performance, usability, legal issues, security, and platform constraints [216].

The categorization of requirements into URQs and CRQs, together with their further categorization into functional and non-functional requirements, provide a comprehensive framework for understanding the needs and constraints to support the development of digital educational libraries. This framework can be found in Table 13.

Additionally, Appendix G provides the relation between the identified requirements and their overarching dimensions with regards to the digital library system and the EDUlandscape framework, elaborated in Section 5, in West Africa and Ghana. These dimensions are categorized in the 4As, as explained in Sub-section 5.3, and the key dimensions central in the main research question, i.e. Usability and Knowledge Building.

Requirements (R)	*Functional*	*Non-functional*
User Requirements	R3, R4, R5, R6, R7, R8, R11, R12, R12+, R13, R15, R16, R17, R19, R22, R28, R33	R1, R2, R5, R7, R9, R10, R13
Consequential Requirements	R3, R14, R18, R21, R23, R25, R26, R28, R30, R35, R36	R5, R9, R10, R18, R20, R24, R25, R27, R29, R31, R32, R34

Table 13: Overview of digital educational library requirements.

Lastly, the last step in the RE process refers to Requirements Specification. Requirements Specification aims to prioritize the requirements for the development of the information system. Candela et al. [169] identified a comprehensive list and ranked them based on their importance to users, as visible in Figure 28. As 'search and retrieval' is the main functionality in the digital library, it is as expected that search functionality and performance are the most important to users.

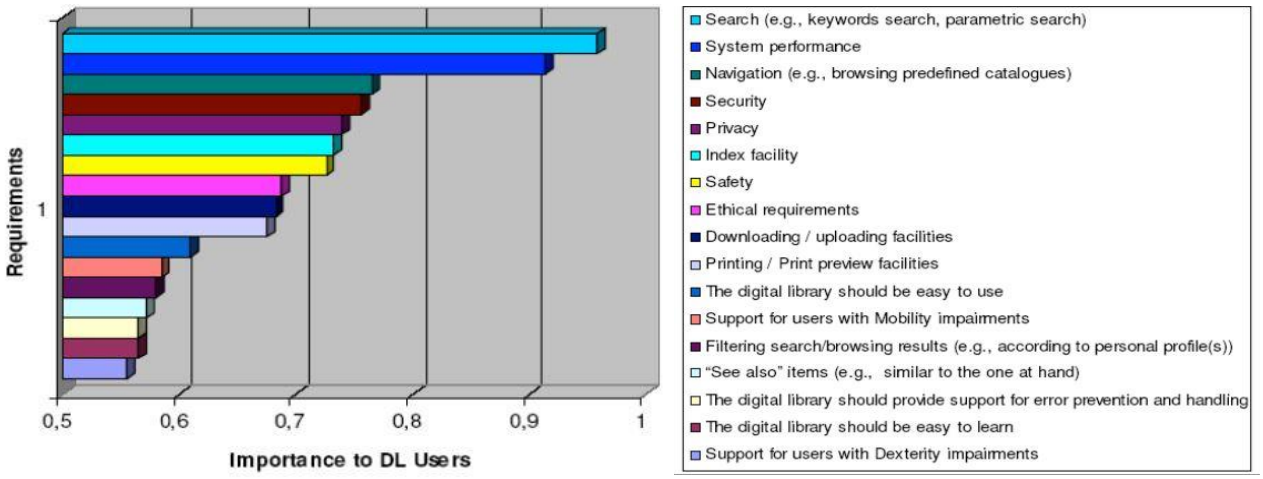


Figure 28: Ranking of most important requirements to users [169].

6.2 Design principles for digital educational libraries

In the previous sections of the design process, a total of 53 User Stories (US) were derived from five different sources, as discussed in Sub-sections 6.1.1.2 and 6.1.1.4. Subsequently, These 55 US are disseminated in Appendix D, including their corresponding stakeholders. Subsequently, the 55 US were formulated into 36 RQs. Based on these findings, the Design Principles (DPs) are constructed in this section serving as the foundation of digital educational libraries in a West African context, both in the rural and urban context.

For the construction of the DPs, we followed the design principle structure and framework of Gregor et al. [88], as discussed in Sub-section 4.1. The relation between the DPs and our main research goals, i.e. usability and knowledge building, are elaborated in Appendix H.2. These DPs aim to design a digital educational library in a West African context that is user-friendly, inclusive, secure, and continually improving based on changing user needs and technological advancements. The DPs are ordered based on their prioritization in the design process, indicating the importance of each principle during the subsequent development phase. This prioritization is based on the challenges with limited internet connectivity and varying device usage in West Africa with both low-end and high-end devices.

Figure 29 provides an overview of the constructed design principles throughout this research' process, starting with the User Stories. The elaboration of the DPs in combination with the framework of Gregor et al. [88] is provided in Appendix H.1, while they are further elaborated below in-depth.

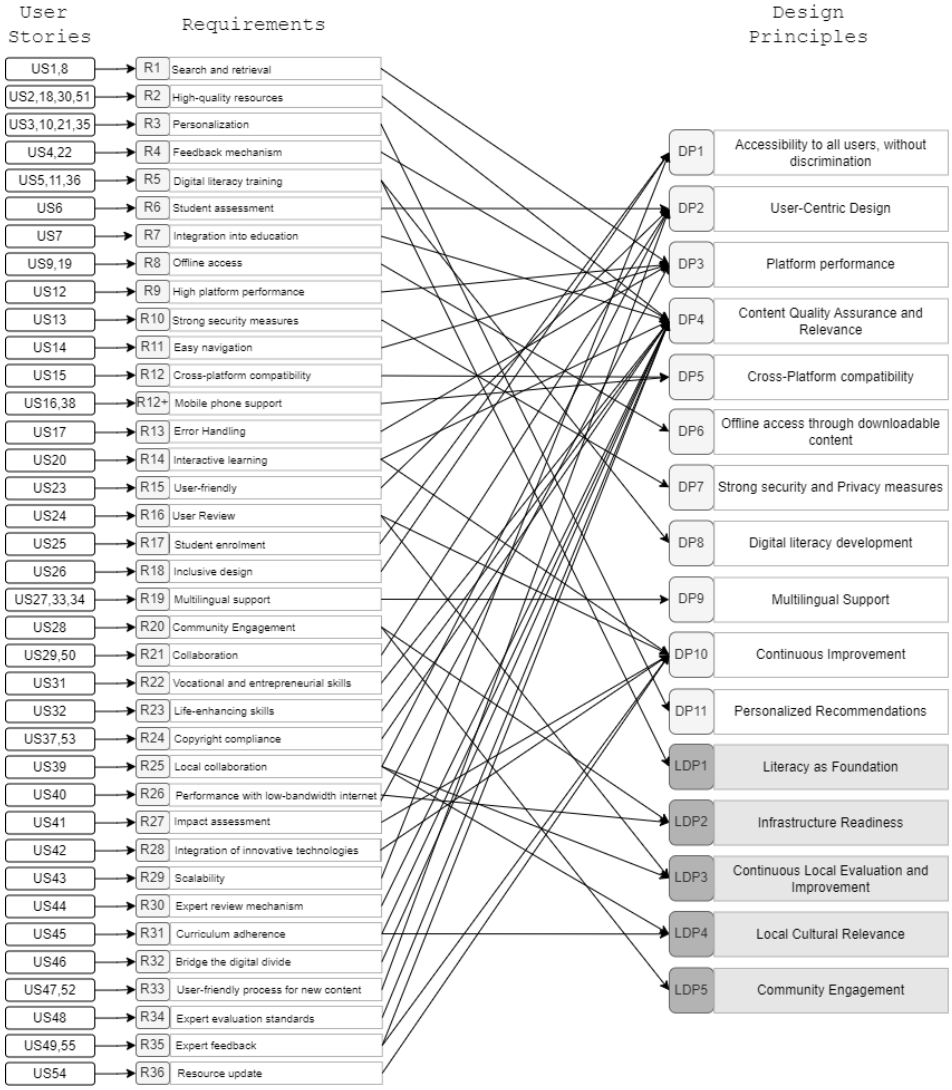


Figure 29: The process of designing design principles for digital educational libraries in a West African context.

Design Principle 1 (**DP1**) focuses on the importance of *Accessibility* and *Inclusivity* during the design process. **DP1** states that the platform should be designed to be accessible to all users, regardless of their abilities, gender, digital literacy, socio-economic situation or background. It should also be accessible for individuals with a disability, by implementing features such as: text-to-speech, keyboard navigation, and adjustable font sizes. An important aspect in the African context is the ability of the system to provide support and an easy-to-understand user interface for individuals with low digital literacy levels and diverse learning levels. This DP also includes scalability of the platform to provide access to all of these users, without discrimination.

Additionally, **DP2** focuses on ensuring a *User-Centric Design*. The developers should be user driven and have to ensure a comprehensive understanding of the users' needs and their desired functionalities during the design and development process, which is essential for the successful implementation of the design principles and functionalities. The designers should conduct user research, measure empirically by analysing the performance and user experience, and feedback sessions by iterating and enhancing the design accordingly based on user feedback and changing user needs, as discussed in Sub-section 4.6.2. User-Centric design also refers to the user-friendliness of the platform by ensuring a intuitive and easy-to-navigate user interface to enhance the experience for all users, without discrimination, which strengthens the foundation of **DP1**. User-friendly design includes easy navigation, simple search functionalities, well-categorized content and clear instructions for accessing and downloading content.

Furthermore, **DP3** states that developers should provide *platform performance* in all contexts, including areas with low-bandwidth internet connectivity, to ensure that individuals in all areas in West Africa can fully participate in education. The platform performance should ensure an optimal user experience for everyone while using the digital library. An optimal user experience includes fast loading times, reliability, proper error handling, and responsive user interfaces.

In **DP4**, we propose the implementation of mechanisms to ensure high-quality standards and relevance for educational resources, which can be in various formats, such as video, text, audio, i.e. *Content Quality Assurance and Relevance*. Firstly, the content must adhere to the curriculum guidelines specific to the local context to ensure content alignment with the national government and learning goals. Secondly, the developers should implement an Expert Review mechanism to assess the quality of newly submitted resources through clear criteria, by experts in the content domain, as discussed in Sub-section 6.2. Whenever the content does not meet the quality standards, the authors are required to enhance their resource. Thirdly, the designers should implement user feedback and reviews to teachers and courses to enhance the quality and relevance of the provided resources. Fourthly, the content must comply with copyright regulations to prevent unauthorized use. This issue can be addressed through OER, as discussed in Sub-section 4.7.5.6. Fifthly, gamification should be implemented to enhance student engagement and facilitate active learning, as discussed in Section 4.7.5.3. Lastly, the digital library should include teacher-support materials, such as guides and professional development, and life-enhancing content relevant to community members' needs to enhance their quality of life. Life-enhancing content can include skill development (e.g. farming best practices), entrepreneurship, and health.

DP5 refers to *Cross-Platform Compatibility*. Cross-platform compatibility ensure the compatibility of the digital library with various devices and platforms to facilitate access from anywhere at any time, including both low-end and high-end devices. This means that regardless of a user accessing the digital educational library from a basic smartphone, tablet, laptop or computer, the platform should be fully functional and accessible. By enabling both low-end and high-end devices, the digital library can reach a wider audience with diverse technological capabilities, as discussed in **DP1**. As discussed in Sub-section 4.4, smartphones in West Africa are on a rise and in possession of a significant part of the population. Therefore, digital educational libraries in a West African context should prioritize compatibility on smartphone devices to ensure responsive interfaces by adapting to different screen sizes and specifications. As distances to education are big and internet connectivity is limited in most West African areas, the compatibility to smartphones is essential to provide access to digital educational libraries.

In addition to providing cross-platform compatibility, digital libraries should also ensure offline accessibility to provide access to individuals in areas with limited internet connectivity. **DP6** states that *offline accessibility* is essential for integrating digital libraries in a West African context. Users in these regions require the ability to download content for offline access, which enables them to utilize resources without a continuous internet connection. It is essential to update these resources whenever an internet connection is available to ensure relevance and accuracy.

As accounts and digital libraries itself bring user data, the developers should ensure a secure environment to protect the data and ensure privacy. **DP7** states the importance of *strong Security and Privacy measures*. The developers should include data security and privacy measures, such as encryption of sensitive user information, to comply with data protection regulations.

DP8 indicates *Digital literacy development* as essential for students in a West African context. The platform and external organizations should provide comprehensive digital literacy training to the users, both teachers and students, with different levels of digital skill levels. Users in developing countries often lack the necessary digital skills to effectively and efficiently utilize all aspects of the digital library and its content. The digital literacy training can be in the form of tutorials and interactive learning to develop the essential digital skills.

DP9 proposes to implement *Multilingual Support* in the digital library design to facilitate access to educational content in local languages. The platform should provide support for the most popular languages in Africa, which are English, Frech, and Arabic. Additionally, the platform should provide support for native languages to facilitate access to educational content in their local language. Multilingual support enhances students' comprehension of the taught concepts and enhance student engagement. The content, interface, and navigation should be accessible by individuals in their local language. English or French literacy levels for young students and older people in West Africa are sometimes lacking, therefore concepts can be better understood through their local language. By providing multiple languages in the platform, the platform can be accessed by a broader audience, especially in rural areas.

DP10 states the importance of *Continuous Improvement*. This principle refers to the ongoing process of reviewing, providing feedback, and updating resources to ensure the continuous relevance and effectiveness of the content within the platform. The developers should actively seek for user- and stakeholder feedback to ensure iterative design improvements. Moreover, the administrators should regularly review and update content to align them with the curriculum and changing user needs. Additionally, the developers should stay up-to-date with cutting-edge educational technologies to ensure continuous enhancement of the platform's functionalities. Sub-section 4.7.5 provides an overview of potential innovative technologies that can enhance and change the functioning of the digital library in the future. The platform should be flexible and adaptable to changing user needs and technological advancements to actively address challenges and opportunities. These technologies have shown and will show to be of significant importance for the functioning of digital educational libraries in various contexts, including the West African context.

Lastly, **DP11** indicates that the system should provide *personalized recommendation* for resources and courses based on their learning goals and previous interactions with the system. The implementation of innovative technologies, such as AI, can enhance and facilitate the personalization process. The provision of personalized recommendations enhances user engagement and motivation by providing them with relevant content and courses.

6.3 Enhanced design principles for a local digital library

In addition to the constructed design principles for digital libraries in a West African context, we also propose local design principles (LDPs) for the physical implementation of a digital library within local communities in Western Africa, which are visible in Figure 28. The elaboration of the DPs in combination with the framework of Gregor et al. [88] are provided in Appendix H.1, while they are further elaborated below in-depth.

Local Design Principle 1 (**LDP1**) states that *Literacy* is the *Foundation* for engaging with digital library content. Basic reading, writing, and literacy skills are essential for users to navigate and understand the content. As users are mainly students from lower level school, it is essential that the students contain the necessary literacy level to engage in the platform. Without these fundamental literacy skills, users may face challenges with accessing and utilizing the platform.

LDP2 discusses the essential role of the *Infrastructure* for the local implementation of digital educational libraries in West Africa. The rural and urban schools or ICT centres must possess the necessary physical and technological infrastructure before implementing such technological initiatives. The physical infrastructure consists of buildings, facilities, and the measures to protect the equipment. This also includes the set-up of an ICT lab or community library. On the other hand, the technological infrastructure refers to the hardware, software, and network elements necessary to support the operation of the digital library. The hardware and software refers to the availability of the necessary equipment to implement technology-integrated education, such as computers, servers, and laptops. Furthermore, the community is essential in providing support for acquiring and maintaining these resources, this is further discussed in **LDP5**. Additionally, a reliable internet connection within the ICT center is essential for accessing, storing, and managing digital content. Lastly, the community, users, and the school should protect the infrastructure, especially with the high temperatures, humidity, and robbery.

Continuing with **LDP3**, which refers to the importance of *Continuous Local Evaluation and Improvement* of the local digital library to ensure its relevance and acceptance within the local context. Local contexts can vary significantly due to scholar, cultural, and personal backgrounds. Continuous iterations are necessary to tailor the digital library to the specific local community's needs. By engaging local community members, such as educators, leaders, and experts, the content can be tailored to ensure relevance to the local context. The local implementation of the platform also requires piloting the digital library design in various schools and environments, including rural and urban areas. Piloting and testing helps in identifying accessibility challenges for all users, in combination with **DP1**, to ensure the tailoring of the design to the local context. The engagement of local community members also leads to **LDP4**.

In **LDP4**, we propose the principle for ensuring *Local Cultural Relevance*. The digital library's content should be tailored to the local culture and the educational needs of the local community. By involving local institutions, educators, and experts, the content can be customized to the local user needs and thereby preserve cultural traditions and history.

Lastly, **LDP5** highlights *Community Engagement* as an essential component for the successful implementation of digital libraries in a West African context. Community Engagement refers to the provision of financial and practical support of families and the local community to children's education and its institutions, as discussed in Sub-section 5.3.1.6. Community Engagement enhances the collaboration and engagement within the community and with local teachers and schools. The aim is to engage community members to provide the necessary infrastructure and equipment, such as computers and tablets, to provide technology-oriented education, as implemented in the new curriculum reforms. The need of community support through the facilitation of the necessary infrastructure and equipment is especially essential for public schools. Additionally, local experts, such as teachers, can enhance the relevance and effectiveness of educational resources. To assess the *Community's Engagement* and specific local context, we developed the Community Needs Tech Assessment (CNTA), as discussed below.

6.3.1 Community Engagement

As elaborated in Section 5.3, acceptability plays an essential role in the successful implementation of digital libraries in a local West African context. Acceptability is one of the 4As of the HRBA framework, showing the significance of the acceptability dimension in the design of digital educational libraries in this context. It is essential for any technological initiative, both in the educational domain as in other domains, that the communities embrace the implementation of these initiatives and that these initiatives are tailored to their local context, as elaborated in DP9. Tailored technologies have the potential to enhance the opportunities in rural areas, such as: education, the financial situation, economic activities, and access to basic resources. In essence, a local digital library refers to the local implementation of the digital library through smartphones, computers, or tablets, with the goal to be accessible by both students and community members to enhance their knowledge and skills, as summarized in Sub-section 3.4.1.

Rural areas and developing countries are suffering from several challenges with regards to the implementation of technologies, such as limited accessibility to technology, limited resources and inadequate infrastructure, including a lack of electricity, and an unreliable and unstable internet connectivity. To effectively tailor technological solutions to meet the community needs in the local context, we developed the Community Needs Tech Assessment (CNTA). The CNTA is categorized under LDP5. Our CNTA is based on the Community Needs Assessment (CNA) framework [121], [122] and tailored to the local African context by enhancing the KPIs developed by Smulders [59]. Research shows that local ICT projects in developing countries tend to be more successful when they align with the local context and the corresponding appropriate technologies. The CNTA is a comprehensive framework aimed at understanding the technological and local needs of local West African communities, particularly in the context of implementing digital educational libraries, ICT labs, or similar technological initiatives. Besides using the CNTA as a tool for interventions, the CNTA itself already acts as an intervention for a local community due to the active participation in identifying problems and possible solutions. This framework is designed to gather valuable insights from various community stakeholders within the community concerning the problem context, the requirements, and its cultural needs.

6.3.2 The goals of the CNTA

The goals of the Community Needs Tech Assessment (CNTA) are elaborated below:

- Gain in-depth insights into the unique dynamics present within the local community to effectively solve the challenges within their community.
- Provide a platform for community members to express their experiences and perspectives with regards to the challenges and opportunities within the local community.
- Identify hidden strengths and weaknesses for future growth.
- Provide the foundation for the design and the implementation of development projects, including technological and practical initiatives.
- Enhance trust, collaboration and community engagement to successfully implement development projects.

6.3.3 Stakeholder Engagement

In order to serve the entire population, all stakeholders should be engaged in the educational and technological development within the community through utilizing the CNTA. The relevant stakeholders of a digital library are identified in Sub-section 6.1.1.3. These stakeholders are assigned to the different assessments of the CNTA, which is summarized in Sub-section 6.3.4.

The CNTA consists of five assessments, each assessment is designed to gather specific insights of various stakeholders, a detailed description can be found in Sub-section 6.3.4. For the Interviews, the Community Meeting, and the Focus Group we will use a random sampling technique. However, it can be challenging to remain with random sampling in rural areas due to the limited engagement of community members in rural areas. Therefore, the decision can be made

to use non-random sampling. We found that community members tend to be more engaged when they receive a financial or other form of compensation for their participation.

For the Quick Scan and Asset Inventory, we will use non-random sampling as these have to be conducted specifically with the Educational Head and the ICT teacher of the school to assess the existing resources.

6.3.4 The Community Needs Tech Assessment (CNTA)

The Community Needs Tech Assessment (CNTA) is an enhanced integrated approach based on enhancing the Community Needs Assessment (CNA) developed by Waters [122] and Rotary International [121], the Quick Scan by Maxim Nyansa [72], and the KPIs developed by Smulders [59]. The CNTA assessments can be accessed through the Yoda portal as explained in Sub-section 3.4.1.2.The CNTA utilizes Google Forms to provide central data storage through Google Drive and a comprehensive data analysis of the conducted assessments. All components of the CNTA can be found in Appendix J. Our CNTA consists of the following six different assessments:

Community Meeting

A Community Meeting is the first assessment conducted to understand the real needs of a specific local community. The community meeting is an organized group discussion with the community members of a local community where the technology will be implemented. The meeting provides a platform for stakeholders to gather, share opinions, discuss challenges, and collaborate on decisions that may impact the community, including social, technological and economic issues [121], [122]. The relevant stakeholders in the community meeting consist of national government representatives, the community leader (also called the Chief or Chief Executive), Educational Head, Elders in the community, (ICT) teachers, a digital librarian, parents, and students. The Community Meeting only consists of qualitative questions to ensure flexibility in the discussed topics and to gain a full understanding of the dynamics and the needs within a specific local community. These qualitative questions are formulated in collaboration with Rotary International [RI.5] and its protocol can be found in Appendix B.

A facilitator is required to guide the discussion and ensure relevant outcomes. The advice is to also include a respected community member, who is fluent in the official national language, typically English or French, and the local language, to guide the meeting together with the facilitator, especially when cultural or language barriers exist. This local individual can then serve as a translator, ensuring that all participants can fully express their true feelings and experience without a language barrier. This also brings additional challenges, as the translator must fully understand and convey the feelings expressed by the participants.

The challenge is to create an open environment for all stakeholders, because of the existing hierarchical structure and influence dynamics, therefore we decided to divide the stakeholders into three groups:

Group 1: National government representatives, community leader, and the digital librarian.

Group 2: Educational Head, Elders in the community, other community members, and the digital librarian.

Group 3: (ICT) teachers, parents, students, digital librarian.

We found that financial or other forms of compensation helps to increase community member engagement by appreciating the stakeholders' time and effort.

Quick Scan

The Quick Scan is a concise assessment with the goal to verify whether the school meets the essential basic requirements necessary for local technology implementation. A school has to successfully complete all checklist items to proceed with the following assessments. In the situation where the school does not meet the Quick Scan requirements, the school must first enhance their local environment before it can proceed with further assessments [72], [EI.1]. The Quick Scan is conducted with the Educational Head of the school.

Asset Inventory

The Asset Inventory is an extensive and comprehensive assessment to identify and assess the available technological and practical resources for a school [121], [122]. These resources include facilities, ICT infrastructure, availability of electricity and internet connectivity, as well as the availability of skilled teachers with the required knowledge for technology implementation. The Asset Inventory is conducted with the Educational Head of the school. We also incorporated an automatic report generator to provide a comprehensive overview of the available resources, infrastructure, and knowledge. The comprehensive asset inventory protocol, in combination with the findings of Smulders [59], Rotary International [RI.5], and the Quick Scan [72], are elaborated in Appendix J.2.

Interview-Survey

The Interview-Survey is a one-on-one personal conversation between an interviewer and the interviewee, with the goal to gain an in-depth understanding of the perspectives and experiences of local community members [121], [122]. The interviewees consist of the end-users of the technological intervention, consisting of local teachers and students. The Interview-Survey questions differ between students and teachers. This approach integrates the strengths of both quantitative and qualitative interviews and surveys to enable a comprehensive data analysis. As elaborated in Sub-section 6.3.3, the interviewees are, when possible, selected randomly and anonymously.

Based on our case-study research, we found that the Interview-Survey assessment is the most effective for illiterate individuals, as we encountered challenges with limited received responses. The Interview-Surveys were conducted on-site at the school to ensure accessibility and minimize the challenges for the interviewees.

The questions are divided into quantitative and qualitative questions. The quantitative questions, including multiple-choice and rating scales, are developed based on the KPIs of Smulders [59], [RI.3], with adaptations made tailored to the local context through collaboration with Dankyira [EI.1] and Asante [EI.1.2]. These questions or protocols, in combination with the KPI criteria, are elaborated in Appendix J.1. The quantitative and qualitative questions, including open-ended questions, are developed in collaboration with Rotary International [RI.5], by utilizing their expertise in local development projects and Community Needs Assessments (CNAs).

Focus Group

The Focus Group is a structured group discussion with selected stakeholders or community members to determine the needs of the community on specific topics or ideas, such as the local implementation of a digital library. The goal is to allow participants to share their perspective and experience on the topics. The focus group is guided by a facilitator and involves six to 12 participants [121], [122]. However, in our case-study research, the Focus Group was not conducted as the use cases had not reached this stage of development yet.

Community Mapping

Community Mapping is another assessment method utilized in the Community Needs Assessment (CNA) by Waters [122]. However, we decided to exclude this assessment from our CNTA due to the comprehensive Rich Picture elaborated and visualized in Sub-section 5.4.

6.3.5 CNTA data analysis

This section presents the data analysis for the results of the case study research through utilizing our developed CNTA. It is important to note that the data analysis is part of the case study research and does not intend to draw conclusions with regards to the research questions, as the collected data is insufficient to find significant results. Nevertheless, the conducted interviews present interesting results with regards to support and validate the identified requirements in the local West African context for education and digitization. The results of the conducted interviews can be found in Appendix J. The visualizations are developed through utilizing the data analysis functionalities integrated within Google Forms.

6.3.5.1 Community Meeting

As discussed in Sub-section 6.3.3, flexibility and relevance are important aspects of the Community Meeting. Due to the limitations with regards to conducting the Community Meeting, as discussed in Sub-section 8.1.2, only one complete Community Meeting could be conducted by the researchers, specifically within the community of Case C. The Community Meeting of Case A was conducted by the staff members of Maxim Nyansa due to limitations, as discussed in Section 8.1.

The Community Meeting consists of a qualitative analysis to ensure flexibility in discussing relevant topics and to gain a comprehensive understanding of the local context. The qualitative questions are focused on aspects of the local community context. The findings from Case C's Community Meeting are discussed below. Subsequently, the findings from Case A's Community Meeting is discussed.

Firstly, the spreading of information within the community and potential improvements were explored. In Case C, the traditional verbal communication methods are used to communicate new information to the local community members. The Chief starts with communication the new information to its sub-Chiefs, who then utilize the elders in the community to spread the information to local community members. As there is no reliable internet connection and 95% of the rural community is poor and therefore does not possess a phone, the information cannot be spread digitally but only through mouth-to-mouth communication. However, with the emerging digital technologies, information spreading is shifting towards digital communication.

Secondly, the needs to enhance children's learning journey were discussed. The suggested improvements include additional access to food, additional educational resources, supervision by parents, implementation of new policies, enhanced educational tools, and enhanced literacy skills.

Thirdly, findings indicate that farming is the dominant skill within the community. Community members highlighted the importance of children learning to assist and enhance farming practices, thereby generating income and cover basic needs. Despite the poor living conditions, community members are mainly occupied with providing family's basic needs mainly through farming, leading to the limited support of their children's education. However, they also recognize the importance of parental support in enhancing children's learning for children. Furthermore, the parents also recognize that these emerging technologies may ensure that children can teach digital skills to parents and enhance their agricultural knowledge.

Lastly, community members view the introduction of digital devices in their community as impactful and valuable for knowledge gaining and communication. However, community members are concerned about the potential negative impacts of technology on children. Nevertheless, they estimate that digital libraries could significantly reduce poverty by 80% within their community.

The Community Meeting in Case A also revealed several interesting findings about the rural community of Adanwomase. First, the rural community of Adanwomase consists of four public schools and one private school. Secondly, children in this rural community are not allowed to work during school hours to enhance children's learning, only when returning from school or in the weekends. Thirdly, most community members are working in Kente weaving, selling of Kente, and farming, with weaving being the dominant skill. Lastly, despite the living conditions in

Adanwomase being below standard, the community members can afford basic needs, such as food, clothing and shelter, with an average income of 25 Ghanaian Cedis or 2 dollars per day.

Additionally, each school is supported by a Parent-Teacher Association (PTA), with the chairpersons together forming a collective PTA. Moreover, the set-up of a digital library and a computer lab, vacation classes, teacher/nurses training centres, and funds to support students upon completion of junior and senior high schools were identified as initiatives to enhance the situation of children within the community. The introduction of ICT, a digital library, and internet access would significantly enhance the learning journey and literacy levels of the children and is embraced by the community. Furthermore, children are enjoying ICT, hair dressing, weaving, sewing, music, and football. The community and the children would also benefit from additional ICT training to use digital devices effectively. Additionally, the parents are also willing to allow access to mobile phones for educational purposes.

The meeting also revealed that the class sizes are above average and the need for encouragement of sporting activities, as the schools are lacking sports equipment. Concerns were also raised about the rising drug addiction within the community. Lastly, they indicate that tourism could serve as an important future source of income for the community.

6.3.5.2 Asset Inventory

The Asset Inventory aims to assess the technological infrastructure, practical resources, and knowledge within a school. This assessment was conducted for all schools involved in the case study research: Case A and C are both located in rural areas but in different regions, while Case B is located in an urban area, as discussed in Sub-section 3.4.1.1. Schools B and C are already further in the digital transformation process of Maxim Nyansa and possess a computer lab and a trained digital librarian. This stage is before the implementation of a digital educational library. In contrast, School A is in the pre-stage of a computer lab and does not possess any technological resources. The results of the Asset Inventory are visualized through bar charts in Figure 30 and Figure 31. These figures are elaborated below.

The results of the Asset Inventory assessment present interesting findings with regards to the rural-urban divide, as discussed in Sub-section 5.2. Firstly, School B is performing higher on the General School National Final Exams, where School B has a 100% passing percentage compared to 85% in School A. Secondly, the number of teachers is higher in the urban area (school B) compared to the rural area (School A and C), with 26 compared to 9 and 20 teachers, respectively. Notably, among the total teaching staff, there is only one ICT teacher in place at every school. Furthermore, School B is the only school with 2 non-teaching staff members, whereas the other schools are all part of the teaching staff.

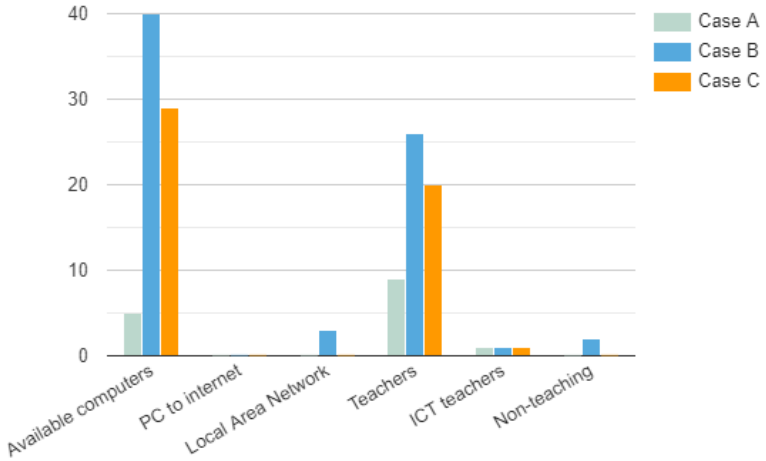


Figure 30: Asset Inventory Results part 1.

The assessment also highlights the resource divide between urban and rural schools. School B and School C have benefitted from the deployment of Maxim Nyansa's IT lab by the provision of the necessary equipment, with 40 and 29 available computers, respectively, compared to only five

in School A. Notably, none of these computers are connected to the internet. Despite Schools B and C being part of the same transformation program and School C having a higher student enrolment, rural areas are still lagging behind in terms of available computers, leading to a lower computer-student ratio in rural areas. Additionally, the five computers for school A are only available for teaching staff and not for the students, which further limits the access to technological education for students.

With 40 computers, School B can accommodate 200 active users out of a total of 455 students, while School C can accommodate 312 active users out of 658 students. This means that only less than half of the students receive effective ICT education, even with Maxim Nyansa's intervention. These numbers indicate the significant need for additional support with regards to technological equipment and infrastructure to ensure access for all students to technology-oriented education, aligning with R31. In rural schools without the Maxim Nyansa's intervention, there are no computer available for the students at all.

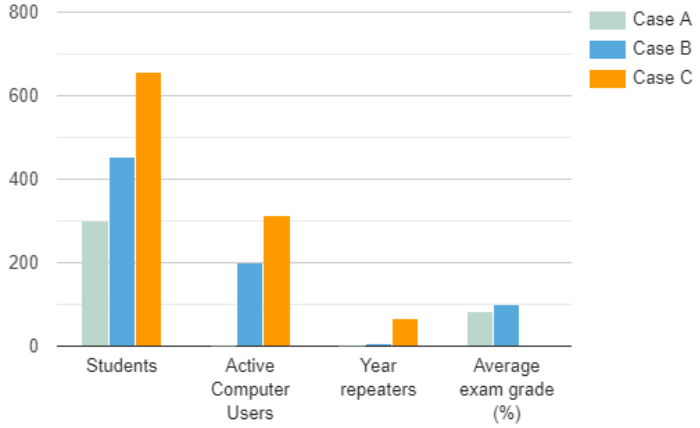


Figure 31: Asset Inventory results part 2.

Furthermore, all schools are equipped with the necessary infrastructure, including electricity, air-conditioning, internet connectivity, and the necessary security measures to implement a local digital library. However, Printers and projectors are missing in all three schools. Lastly, the rural schools of Case A and C are supported with the necessary equipment and accessories through their local community engagement, which aligning with R20. According to School B, which is in the urban area, they are lacking the engagement from the local community.

6.3.5.3 Interview-Surveys

Teacher data

The teacher data presents interesting results with regards to the requirements identified in Sub-section 6.1. This section provides an overview of the Teacher Survey results of the three cases combined through the visualisation and elaboration of the quantitative and qualitative data. By cross-referencing the results with the corresponding identified requirements (R), we can connect the needs of the stakeholders, which are involved in the case study research, and the requirements identified in this research. This cross-referencing is visible in Appendix F.

Notably, the education level of the teachers can potentially show interesting differences between public and private schools. However, since the case study research was only performed on public schools with educational qualified teachers, this visualisation is not relevant in this context.

The first visualisation is based on the digital literacy levels of the teachers. Figure 32a shows that the majority of the teachers score and perceive themselves as average or insufficient when it comes to digital literacy. Additionally, the participants provided lower digital literacy scores, indicating that they self-assess their digital literacy levels as lower than their literacy levels, when comparing Figure 32a with Figure 32b. These findings show that there is a need for digital literacy training, aligning with R5, for teachers. Furthermore, the results have shown that 96.7% of the teachers have used a computer beforehand and 79.3% has access to a personal computer or laptop.

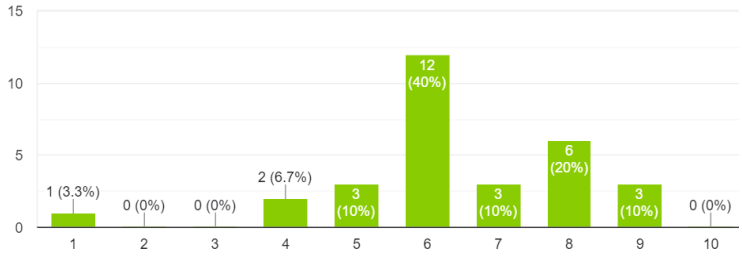


Figure 32a: Digital literacy results per teacher.

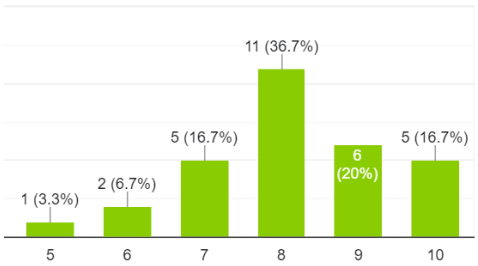


Figure 32b: Literacy results per teacher.

Additionally, the survey results showed that 96.7% of the teachers prioritized the provision of electricity, computers and an ICT lab over renovating washroom and bathroom facilities, showing the need for local stakeholders to implement IT within these communities.

Another interesting finding referred to the information need of teachers. The results show that 66.7% of the respondents are in need of academic research to enhance their teaching and self-learning, while 30% are interested in accessing the news. This finding is also supported in survey results with regards to internet usage, as visualized in Figure 33. The results shows that 76.6% of the teachers would utilize the internet for academic purposes, including learning, teaching and conducting research, as well as for general information search and retrieval, and communication purposes.

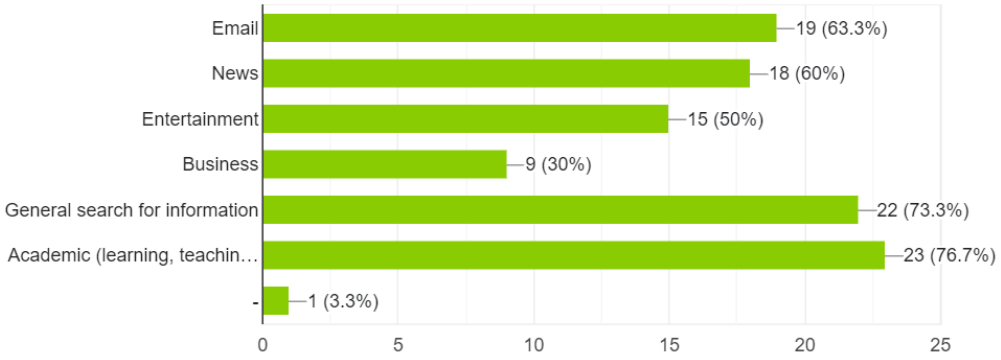


Figure 33: Results of potential internet usage by teachers.

In addition, the qualitative questions ‘what could be done to make your job better, easier, and more enjoyable?’ and ‘What could be done to make the school better for students?’ provided the following interesting outcomes. These outcomes were posed by multiple teachers and therefore were seen as valuable. Firstly, the teachers stated the importance of enhancing ICT facilities, increasing the amount of computers, and providing equipment for teaching, to provide students with more resources and facilitate practical-oriented education, aligning with R31. A teacher added the importance of a reliable infrastructure, such as electricity and the internet. Moreover, the teachers also highlighted the lack of fans, furniture and poor drainage systems to protect the books and computers.

Furthermore, the teachers expressed the need of teaching and learning resources, either through more textbooks or online learning resources, to enhance student learning and provide teacher with the necessary subject knowledge. Many teachers also stated the importance of regular professional development and ICT training to enhance their digital skills and knowledge, aligning with R5.

Lastly, the teachers highlighted that there are too many children in one class to provide effective learning. They provided possible solutions, such as additional teachers and the provision of additional classrooms. One teacher even suggested to “build another public school in the area to decongest the school”.

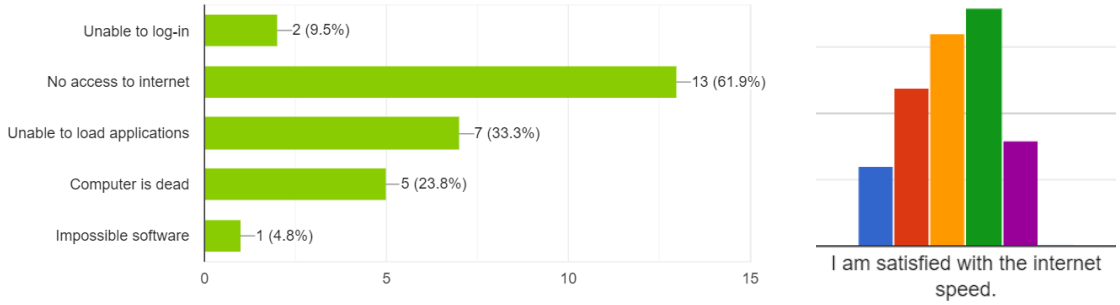


Figure 34: a) Most occurring computer failure. B) Satisfaction with internet speed.

Another interesting finding refers to the fact that 96.7% of the teachers possess a smartphone, showing the need of mobile compatibility for digital libraries, as discussed in R12 and R12+.

The respondents who have access to a computer at their school, provided the most common computer failures, visible in Figure 34a. No access to the internet is the biggest issue with 61.9% of the reported failures. Furthermore, when the internet is available, the teachers are not satisfied with the internet speed, as visible in Figure 34b. Additionally, the specifications and quality of the available computers are lacking, with 33.3% of the responses being unable to load applications and 23.8% indicating that the computer is broken. Figure 34b and 35 are visualizations from obtaining data through Likert scales, where the dark blue bar indicates “strongly agree” and the purple bar indicating “strongly disagree”.

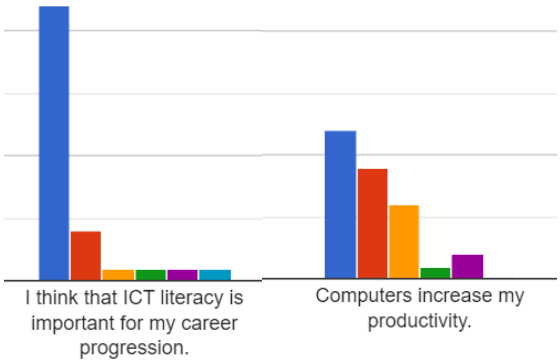


Figure 35: Importance of ICT for teachers (Strongly agree to Strongly disagree)

Furthermore, qualitative insights address the potential positive impact of the IT lab on teachers' personal lives and their students. The positive effect on teachers themselves consists of the support for effective teaching, the opportunity to learn new skills, enhance their digital literacy skills, conducting research before teaching, and enhancing communication and connectivity with other educators and students (R21). Figure 35 also shows that teachers consider digital literacy as essential for their career progression and also enhances their productivity. Furthermore, the teachers all strongly agree with the fact that ICT, such as computers, smartphones and the internet, is of added value for personal development and education.

The positive impact on students consists of enabling students to do their assignments (R6), learning by practice and hand-on experience, understanding of the concepts being taught, moving at the same pace as the rest of the world (R32), enhancing learning outcomes and their digital literacy, gaining more recent knowledge (R32), interacting with educational tools (R14), and getting access to a wide variety of resources (R2).

Additionally, teachers believe that integrating ICT into teaching and learning can support families in helping their children to learn effectively, can utilize effective assessment strategies, and support children in their learning.

Lastly, we asked the qualitative question about desired changes in the school. The responses provided some areas for improvement, including poor drainage system leading to floodings in the schools, lack of bathroom facilities, providing the necessary equipment to integrate technologies, provide personal computers for teachers, and increase the number of computers in relation to the number of students. For example, Case B is a cluster of four schools with more than two thousand learners. 40 computers are significantly insufficient to provide all students with ICT classes and this also leads to early computer breakdown. One important aspect is that most students have families that do not show interest and support in what the kids do at school, i.e. a lack of community and family support, which aligns with R20. As a result, they lack resources that helps them to learn, e.g., books, textbooks, laptops, etc.

Student data

The student data also presents interesting results with regards to the requirements identified in Sub-section 6.1. However, it is essential to note that the data of Case C is lost as discussed in Sub-section 8.1.3, influencing the outcomes of the student data. The respondents are between 12 and 15 years old. The results are obtained from the three case studies combined.

Firstly, Figure 36b shows that 89.5% of the respondents is travelling by foot to school. The Survey results from students in Cases A and B, visualized in Figure 36a, presents the differences in terms of distance between the school and where the students live. The data shows that distances range from 500 metres to 8 kilometres, with the majority living between 3 to 7 kilometres away from school. This poses a significant challenge for the students travelling on foot. Notably, the lost data from Case C is not taken into account. As Case C is located in a rural area and the only public school in the whole area, these results would most likely reflect longer distances between the school and the students' home, with more students travelling on foot because of poverty, indicating the need to access educational resources from home, aligning with R8.

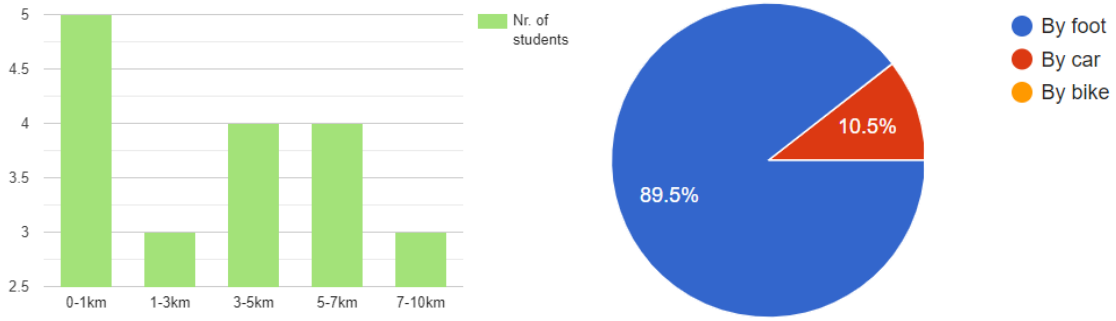


Figure 36: Distance between school and students' home (a) with mode of transportation (b).

Figure 37 visualizes a quantitative analysis of the available facilities, complemented by a qualitative explanations provided from students' responses. According to the students, the only facilities present in each school are tables and chairs. However, due to the large class sizes, these are mostly inadequate and in a poor condition, meaning that the students have to share their table in pairs. The state of these resources ensure students to bring their own tables and chairs from home to be more comfortable.

Moreover, none of the schools have proper washrooms facilities and only five out of the 19 respondents believe that the schools have proper bathroom facilities with the notion that they are often not clean and poorly maintained. Notably, Case A does not have any bathroom facilities at all. Additionally, only 12 of the respondents indicate that they have access to a proper playground for activities, such as soccer, volleyball or basketball.

Furthermore, 16 out of 19 students indicate that presence of a library including books within their schools. However, the amount of textbooks is very limited, mostly irrelevant, and in a poor condition, which hinders students' learning experiences. Additionally, the data shows that books are the main source of information for students, these limitations are posing challenges for students' learning.

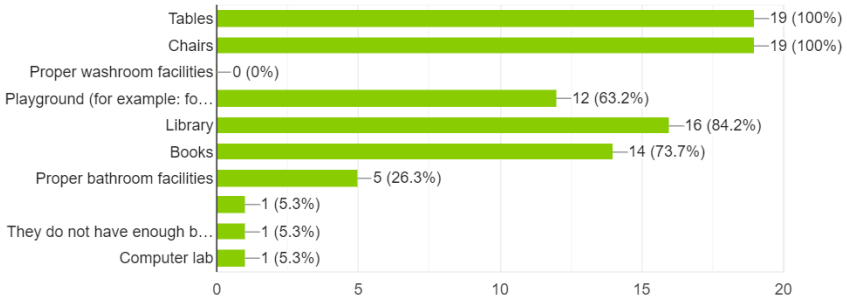


Figure 37: Available facilities according to the students.

Furthermore, the results indicate that students self-assess their digital literacy at an average grade of 5, with five students rating themselves the lowest grade of 1. This digital literacy grade is lower than their self-assessed literacy grade, which they rate at 8.4 on average, showing the need of digital literacy training for students, aligning with R5.

Moreover, the data indicates that only 52.6% of the students have used the internet before, while 68.4% have used a computer before. However, access to a personal computer or laptop is limited, with only 30.8% of the students reported to possess a personal computer or laptop. The true percentage of students possessing a personal mobile phone is expected to be significantly lower, especially in rural areas. However, if parental mobile phone access is taken into account by the students, this percentage may be more accurate. Unfortunately, this distinction was not specified in the question. Additionally, the data analysis in Figure 38 shows that the students would mainly utilize the internet for academic learning (70%) and the general search for information (50%).

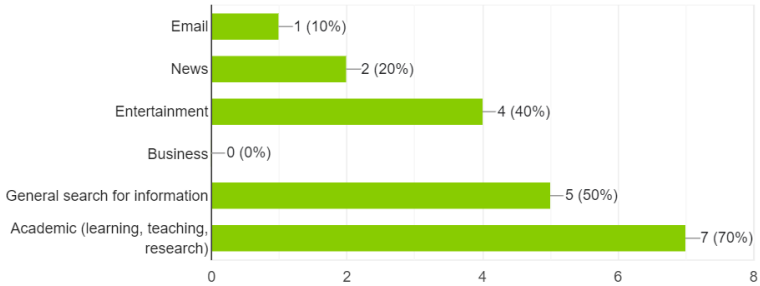


Figure 38: Potential internet usage for students.

Similar to the observations in teacher data, the student data in Figure 39 shows that the most common computer failure is the lack of access to the internet, followed by the inability to load applications and broken computers. Therefore, the digital library should be fully accessible offline by downloading the content to a local server or device to ensure accessibility when there is a lack of internet connectivity, aligning with R8, or ensuring digital library performance when there is low-bandwidth connectivity, aligning with R26.

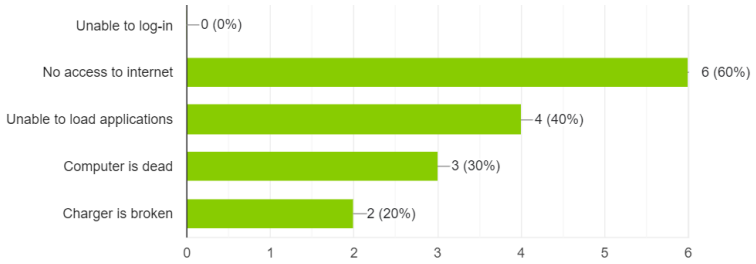


Figure 39: Most common computer failure.

Furthermore, results show that 57.9% of the students have used a smartphone or tablet before, while 47.4% of the 19 respondents have access to a personal device, showing the need for mobile compatibility, aligning with R12 and R12+. As only half of the students can access the digital library within the school premises, as discussed in Sub-section 6.3.5.2, ensuring access from home becomes essential, which aligns with R29. The respondents indicate that they want to use a smartphone for the internet. However, the lack of an internet connection is a challenge. Initiatives, such as the Ruralcomm, are aiming to provide access to the internet for all regions. However, the accessibility is still limited, especially in other West African countries.

Furthermore, qualitative insights address the potential positive impact of the IT lab on students' personal lives and their peers. The positive effect on students themselves include the ability to practice and enhance the skills taught by their teachers (R7), better understanding of complex concepts, broadening IT and general knowledge, enhance digital literacy including typing skills, guiding the students to be more creative, and ensure collaboration between students (R21).

Figure 40 visualizes the obtained data from Likert scales through a bar chart, where the dark blue bar indicates "strongly agree" and the purple bar indicates "strongly disagree". The students indicate that the education they receive is too easy. However, they are satisfied with the level of ICT knowledge of their teachers, which is essential to form the foundation for enhanced digital literacy.

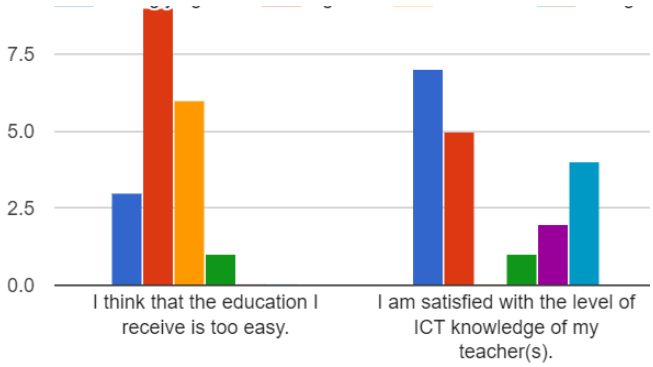


Figure 40: Satisfaction with students' education.

Moreover, the students highlighted Artificial Intelligence (AI) and computer understanding as the most valuable aspects of their IT course. The fact that these students learn AI at this age, this is showing promising potential for their future. They would enhance the course by providing additional resources, such as video (R2), and share their knowledge with their peers (R21).

Additionally, data was obtained about the financial situation of the students' families. Figure 41 shows that most of the students' families have sufficient income to cover basic survival needs.

However, five out of 19 students' families, which corresponds to a staggering 26% of the students, come from families with insufficient financial resources to cover the costs of basic survival, healthcare, and education. Notably, all five students are from the rural area, which represents 56% of rural students, showing the problematic financial conditions prevalent in rural communities. Notably, the lost data of Case C is not taken into account, but would most likely have reflected the same outcomes, as this school is located in the upper north of Ghana. Due to the poor financial situation of their families, students are required to work on farms or as sellers on the market. These additional activities have to be performed, besides their schoolwork, to cover family costs and their own educational costs. For these students, Community Engagement is essential to follow education, aligning with R20. Financial family Engagement is more challenging because of the financial situation. However, they can support their children with practical, non-financial, support.

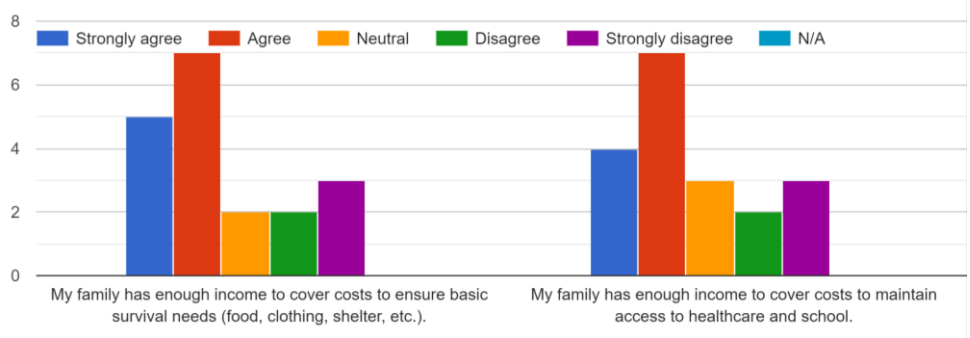


Figure 41: The financial situation of students' families.

Lastly, the qualitative analysis of students' responses with regards to improvements on their school. They provided the following challenges: some of the classes are poorly ventilated and therefore need additional fans, there is a lack of windows and doors, enhanced bathroom and toilet facilities, availability of sufficient learning resources, providing an IT lab, and poor drainage system during rainfall as the classrooms are flooding.

6.4 Validation of design requirements and principles

Wieringa [57] discusses the importance of validation before the implementation of a system. Wieringa [57] describes the validation process as the process of investigating the results of the interaction between a prototype of a system and a model which represents the problem context.

This chapter focuses on the validation of the design principles, discussed in Sub-section 6.5.2. The validation validates the identified design constructed design principles in Sub-sections 6.2 and 6.3. As design principles are of a higher abstraction level than the design requirements, our validation process involves the validation of the essential design requirements for digital libraries in the specific context of West Africa. This approach ensures a comprehensive understanding of the developed design principles and therewith ensures the validity within the West African context.

As proposed by Wieringa [57], we conducted four expert interviews [EI.2, EI.4.2, RI.1, RI.2.2], with experts in the domain of digital libraries and the West African context, to validate our developed design principles. The validation by local experts is essential to ensure the adaptability of the system in every local West African context.

Furthermore, we also conducted self-validation by cross-referencing the developed design requirements and design principles with relevant literature in the domain of digital libraries and the implementation in a local context. First, the self-validation of the design requirements is discussed through investigating the relevant scientific literature in the domain of digital library requirements and the local context. Secondly, the self-validation of the design principles is discussed through investigating the relevant scientific literature in the domain of digital library design principles. Lastly, the validation through expert interviews is elaborated to validate our developed design principles.

6.4.1 Requirement validation

This section provides a self-validation of the developed design requirements. The self-validation is conducted by cross-referencing our developed design requirements with relevant scientific literature in the domain of digital libraries and one paper in the domain of the implementation of design requirements in a local context in Africa. The cross-referencing between relevant literature and requirements can be found in Appendix F. These papers have acknowledged the same requirements for digital libraries, serving as validation for the identified requirements instead of a source to identify requirements. The relevant papers and their identified requirements in relation with our identified requirements are discussed below.

Mamabolo and Durodolu [165]

This paper aims to address the challenges and their corresponding requirements of accessing digital library services in the specific context of rural areas in the Capricorn District Municipality in South-Africa, which is characterized by poverty, uneven distribution of services, and lack of proper infrastructure. This paper is only focused on the challenges in rural areas and does not provide the overall requirements. Requirements for digital libraries in rural areas according to the paper, include the necessity of having reliable internet connectivity, mobile phone compatibility, user-friendly and responsive design, high-quality resources, the importance of a supportive community, a reliable system, and the provision of digital literacy training.

Candela et al. [169]

This paper aims to identify user requirements for digital libraries through a detailed analysis of user prioritization on a variety of functionalities. The paper identified several requirements that users prioritize, these requirements are mostly correspond to our developed design requirements: the integration of knowledge through relevant resources by organizing them, search and navigation functionalities, the administration of content such as content updates, personalized content and

services, detailed information on the resources, collaboration through email, video calls and chat, downloading and uploading of content, and multilingual support.

Antona et al. [225]
This paper aims to understand the user experience by identifying the functional and non-functional requirements during the user life-cycle. It discusses the following requirements: easy search and navigation functionalities, personalization of content, collaboration and communication with other users, downloading and uploading functionalities, user-friendly interface, disability support, security, privacy, and safety.

Wulandari et al. [226]
This paper aims to identify the User Requirements for digital libraries by using Quality Function Deployment. The paper identified the following requirements: the digital library should be accessible from anywhere at any time, contains relevant resources, search and retrieval functionalities, sharing of information between users, user feedback features, gamification features, downloading of content, collaboration between users, and bridging the digital divide.

6.4.2 Design principle validation

The validation of the design principles is investigated through two validation methods: self-validation through cross-referencing and the validation through expert interviews. Through these validation methods, changes are made to the design principles and their prioritization.

6.4.2.1 Design principle validation - Cross-referencing

This section provides a self-validation of the constructed design principles. The self-validation is conducted by cross-referencing our developed design principles with relevant scientific literature in the domain of digital libraries. It has to be said that no papers were found which investigated the design principles of information systems or technologies in a similar West African context. Therefore, design principles tailored to the specific local West African context cannot be validated through cross-referencing. This self-validation is focused on validating the design principles relevant to digital libraries in general. The relevant papers in relation with our constructed design principles are discussed below.

Chowdhury and Chowdhury [159]
This paper aims to fully understand digital libraries, including their concepts, principles, and technologies. The paper constructed eight design principles for the development of digital libraries: user-centered design (corresponding to DP2), Content organization and retrieval (corresponding to DP2), metadata standards and management, interoperability and integration (corresponding to DP4), long-term access and ensure sustainability of the digital library (corresponding to DP10), accessibility for users with diverse abilities (corresponding with DP1), usability testing and evaluation to gather feedback from users and improve the design (corresponding with DP2 and LDP3), and security and privacy to protect the data and digital resources (corresponding with DP7).

McCray and Gallagher [227]
McCray and Gallager suggested ten essential design principles for building digital library. They indicate that these principles will enhance both short-term and long-term effects for its users and content. Their identified design principles in relation with our constructed design principles are elaborated in Table 14.

DPs paper	*Explanation*	*Corresponding with*
Expect change	It should be flexible and adaptable to new technological advancements and user needs.	DP2, DP10
Know your content	Understand and manage the content within the digital library.	DP4, DP10, LDP3, LDP4
Involve the right people	Individuals from diverse backgrounds and expertise should be engaged for the development.	DP1, LDP3, LDP4
Design usable systems	Ensure user-friendliness, accessibility and adaptability to technologies and users.	DP2
Ensure open access	Ensure accessibility for everyone.	DP1, DP3, DP5, DP6
Be aware of data rights	Ensure that intellectual property rights are not violated.	DP4, DP7
Automate whenever possible	Utilize automated tools to optimize processes within the library.	DP10
Adopt and adhere to standards	Implement domain standards to ensure scalability and interoperability.	DP1
Ensure quality	Include quality assessment to the library for creation and maintenance of the library and content.	DP4
Be concerned about persistence	Ensure the long-term accessibility and availability of content.	DP4

Table 14: McCray and Gallager's [229] ten design principles of digital library development.

Sastry and Reddy [228]

This paper focuses on user interface (UI) design principles for digital libraries, corresponding to DP2. The paper suggests the following UI design principles for digital libraries to ensure effective user interaction and implementation: clear and simple UI, profile support for users, the UI should feel familiar and build on prior knowledge, provide informative feedback, multilingual support, future implementation of technologies, sharing of information, efficient search and retrieval, error prevention, multimedia support, and the platform should provide accurate information. These principles are all formulated through User Stories in Appendix D.

6.4.2.2 Design principle validation – Expert interview

This section provides a validation of the constructed design principles through expert interviews. Three expert interviews are taken to validate the constructed design principles.

S. Dankyira [RI.1]

First and foremost, Dankyira [RI.1] indicates that the infrastructure is essential in enabling the utilization of digital libraries within ICT centres and schools. The infrastructure is essential in both urban and rural areas for the implementation of a local digital library, corresponding to LDP2. The most important aspect of the infrastructure within the ICT centre is a reliable internet connection. The design should enable users to access the digital library with varying internet bandwidths, , corresponding to DP3.

Second, besides the implementation of the IT centre, users should have mobile access, aligning with DP5. This enables parents or students with sufficient digital literacy skills to access and download content in the digital library through their mobile devices, corresponding with DP6. As parents might be reluctant to provide access for their children to their phones, provision of a local facility, such as a community centre, becomes essential to access digital resources. By establishing an ICT centre in schools or central places, communities can gain access to essential resources and equipment, aligning with LDP2. These centres will especially be helpful in areas where individuals lack the financial resources for the necessary equipment and infrastructure.

Community engagement is essential for the provision of this infrastructure, which corresponds to LDP5. The community and families provide practical and technological support to enhance the learning experience of children. By fostering collaboration between stakeholders, including opinion leaders, school heads, authorities, teachers, parents, students, and external organizations, communities can provide practical and technological support to enhance the learning experience of children and therewith enhance the technological initiatives in a local context, which corresponds to DP10 and LDP3. The external organizations mostly support the community with their expertise to assist them in the best way possible. The engagement of the community ensures the acceptability to new opportunities and the tailoring of the design and implementation process.

Security and data privacy is also an essential aspect of the whole process, which corresponds to DP7. By adhering to the data policies, the user and library data is safeguarded. Without security measures, the necessary infrastructure risks being stolen or misused due to poverty within most communities.

Additionally, Dankyira [RI.1] indicates that it is important that the content must align with the curriculum to ensure resource relevance for students, corresponding to DP4. By integrating curriculum-aligned content, digital libraries become an essential tool for supporting education within a country.

Lastly, each technological initiative should prioritize user-friendliness to provide access to individuals with basic levels of literacy and digital skills, corresponding to DP2. Individuals without any experience should find it intuitive and accessible to utilize the platform, facilitating the widespread adoption and inclusivity through developing countries.

K. Kuguba [RI.2.2]

According to Kuguba [RI.2.2], there are several key design principles for digital educational libraries in West African countries. First, the actual design should be piloted for at least one academic calendar or year on various schools, aligning with LDP3. The developers should deploy the digital library on different types of schools, especially at the basic level, including different public and private schools in rural and urban areas.

Secondly, at the start of the implementation phase, it is essential to have necessary content available. Utilizing local content for system development and updates is essential in this process, aligning with DP4. Additionally, the content should be checked through an expert in that specific

content domain, e.g. resources for the physics subject should be checked by physics teachers, aligning with DP4.

Thirdly, according to Kubuga [RI.2.2], cultural adjustments is another key design principle, aligning with LDP4. West Africa, including Ghana, consists of diverse cultures and is more heterogeneous than most people think. Content should be mindful and knowledgeable of cultural differences and represent diverse ethnic groups and traditions in the local context to avoid misunderstanding or offense.

Fourthly, the principles should include change management, aligning with DP3 and DP8. The developers should expect resistance to change within local communities when implementing new initiatives. By providing training and support, these challenges can be addressed during the transition from traditional to digital library systems. Kuguba's school actually implemented a digital library. However, the librarians experienced a loss of empowerment and therefore the project failed. Therefore, there should be preparation for change management for the relevant stakeholders.

Furthermore, through the Unified Theory of Acceptance and Use of Technology provides factors, such as age, gender, previous use, that are contributing to who is more likely to accept a new technology, i.e. a new digital library. To assess the acceptance within local communities, we developed the Community Needs Tech Assessment (CNTA), aligning with LDP3 and LDP5, which is discussed in Sub-section 6.3.4.

The system should also prioritize open-access to foster collaboration and scalability. Open-access allows for local development by community members and integration with other existing systems, such as other digital libraries, aligning with DP3, LDP4 and LDP5.

Furthermore, sustainability is essential for these systems, aligning with DP10 and LDP5. Additionally, subscription fees must be kept minimal. Instead of charging users directly, the administrators should utilize indirect methods. The majority of the students in the basic level are in public schools where parents may have challenges to afford additional fees, this approach ensures accessibility aligning with DP1. Private schools may be more capable of paying for the digital library services, fees should remain minimal. Although charging schools directly is an option, a pay-per-user would not work as it could results in schools charging fees directly to the students.

Lastly, Kuguba [RI.2.2] indicates the importance of persistence and reliability, aligning with LDP1, and LDP3. The system should be designed with quality backup and storage capabilities to ensure continuity and resilience when facing challenges that may interrupt the access to the library.

K. Asante [EI.2]

According to Asante [EI.2], the design of a digital library for West African countries should contain several key elements to effectively meet the needs of the local communities. Firstly, the library should contain educational materials relevant to the curriculum and specific needs of each West African country, including textbooks, reference materials, supplementary resources and they should be in various file formats, such as text, video, audio, images, etc, referring to DP4 and DP10.

Secondly, Asante [EI.2] indicates that Africa consists of a wide variety of languages and therefore the library design should also include multilingual support. The most popular languages in Western Africa are English, French, Arabic, and Hausa. Users should be able to access the content in their native language, which enhances their comprehension and engagement, corresponding to DP9.

Thirdly, internet connectivity is a significant challenge across Africa. Therefore, the design should also take into account offline accessibility by allowing users to easily download educational materials for later use without requiring a constant internet connection, which refers to DP2, DP3, and DP6.

Furthermore, the design should be lightweight and not too heavy for operation on low-end devices, such as smartphones and mobile phones. The platform should be compatible with low-end devices and easily accessible with limited access to technology, so that they can still benefit from the resources in the library, which corresponds to DP5.

Another essential aspect is the user-friendliness of the platform. It should be easy to navigate and easy to use when accessing and downloading content, particularly for individuals with different digital literacy skills, corresponding to DP2.

According to Asante [EI.2], the platform should also implement interactive features, such as quizzes, games, and multimedia. Interactive features enhances student engagement and facilitates active learning, which refers to DP10.

There should also be easy access for users with disabilities, such as visual impairment, text-to-speech, screen reader compatibility, and adjustable font sizes. This corresponds to DP1.

Additionally, teacher support materials, including teaching guides and professional development should be integrated to enhance the teacher's effectiveness in the classroom. As this is part of the educational materials, which refers to DP4.

Lastly, Asante [EI.2] indicates the importance of regular data maintenance to keep the library content current, accurate, and aligned with evolving educational standards and practices in West-Africa, corresponding to DP10.

R. Castillo [EI.4.2]

Castillo [EI.4.2] categorizes the design principles of digital libraries in Western Africa into infrastructure and educational principles. The infrastructure principles involves the access to technology, which includes the availability of computers and reliable internet connectivity at an affordable cost. While this may be seen as a basic requirement, many families and schools have challenges in the access to functional computers and reliable internet. These principles correspond to DP1, DP3, DP5, DP10, LDP2.

Furthermore, Castillo [EI.4.2] indicates the educational principles as the importance for students in developing countries to have sufficient literacy levels, including reading, writing, and digital literacy. This shows the need of digital literacy training, as addressed in LDP1. Additionally, she also indicated the need for digital libraries in developing countries to provide multilingual support to support children when their English proficiency is not sufficient to understand complex concepts, as discussed in DP9.

7 Conclusion

This Section provides the conclusions drawn from this research. First, the seven sub-research questions are answered to provide the foundation for the main research question. Secondly, the main research question is answered by providing an overview of the design process in this research.

7.1 Answering the Research Questions

First, the research questions that are formulated in Sub-section 1.3 are answered. The sub-research questions are answered to be able to answer the main research question. The research questions are formulated with the goal to develop design principles that can be applied to digital libraries in the educational domain in a West African context. In order to develop the design principles, we need the problem context, the requirements and the concepts of a digital library in the educational domain. The answers on the sub-research questions provide the context and foundation for the design principles.

7.1.1 SRQ1: Current educational landscape in Ghana.

Before developing the design principles and answer the main research question, it is essential to understand the educational landscape in a West African context. This research question answers several important aspects of the educational context, i.e. the problem context, including the context of design, the user-centric approach, the challenges and opportunities in the West African educational system, serve the goals of education, and optimize the use of available resources. By understanding the context of the educational landscape, researchers can tailor the design principles to address the user needs, leverage opportunities, and utilize the appropriate technologies for the local context. Another aim is to illustrate the current educational landscape in West Africa and in specific Ghana, to provide updated information as most of the research in West Africa is outdated. The educational system context is mostly similar between the Economic Community of West African States (ECOWAS) countries, because of the same curriculum and learning environments. Nevertheless, Ghana is advanced in the implementation of innovative technologies, including the internet, compared to other ECOWAS countries. However, Ghana also has a long way to go with regards to the full implementation of technology as in Western countries. The educational system in developing countries is still far behind those in most western countries. Specifically, the educational system in West Africa faces significant challenges in ICT infrastructure, including inadequate equipment, unreliable internet connectivity, and proper facilities. These challenges are amplified by the limited community, family, and external support. Besides the lacking ICT infrastructure, the educational system is also lacking in terms of teaching and learning methods required to effectively leverage technology for education. As most developing countries are still bound to traditional education compared to interactive and practical education utilizing technology in western countries. The goal is to transition traditional education in developing countries into a system where underprivileged students can benefit from the opportunities of digital education, such as hybrid learning and access to education from anywhere at any time. Such a transformation would enable many more students to access a wide variety of educational resources and courses to choose from, thus expanding educational opportunities and access for everyone.

The Human-rights based approach (HRBA) framework suggests four main drivers (4As) for assessing the educational landscape of developing countries: availability, accessibility, acceptability, and adaptability. Availability and accessibility are closely related. Accessibility focuses on accessibility to education for all individuals without discrimination, such as economic situation or race, while availability focuses on the available resources and educational institutions to provide the access. Acceptability refers to ensuring that the educational system, its content, and the environment is acceptable for all students without discrimination, meaning that education

should be inclusive and diverse. Lastly, adaptability refers to which extent education can adapt based on changing societal and technological needs.

Our developed EDUlandscape framework explores the factors influencing the 4A dimensions, thereby shaping the current educational landscape in a West Africa context, including opportunities and challenges with regards to 21st-century knowledge and skills.

The educational landscape in Ghana and West Africa is a complex interplay of factors, influenced by socio-economic, governmental, geographical, and cultural dynamics. Various factors are influencing the accessibility, availability, quality, and adaptability of education, and therewith the design principles. The main overarching determinants are the type of school and the rural-urban divide. In Ghana, both public and private schools are playing a significant role in the educational system. However, the curriculum developed by the government and the ECOWAS is for both private and public schools the same. The differences lie in the resources and infrastructure, while these are mostly perceived better for private schools despite the high fees. Rural areas face challenges with limited resources and infrastructure, which results in lower enrolment rates compared to urban areas. Nevertheless, children are obliged to follow school because of government policies. As students progress to senior high school levels, public schools are preferred due to the experienced and qualified teachers and perceived higher quality of education.

The rural-urban divide mainly shows that the educational resources and infrastructure in the rural areas are limited. The urban areas are mostly consisting of a developed infrastructure, wide variety of economic activities, and diverse educational resources, while rural areas mainly engage in small scale agriculture with limited resources and infrastructure.

7.1.2 SRQ2: State-of-the-art innovative technologies for digital libraries.

The current landscape of state-of-the-art technologies for digital educational libraries within the domain of ICT4D is rich and diverse, offering innovative technologies aimed at enhancing learning experiences, usability, and knowledge building. A systematic literature review together with expert and researcher interviews are the basis that forms the overview of current state-of-the-art technologies in the domain of digital educational libraries and the best practices in the development of digital libraries.

The implementation of these innovative technologies enhances the learning process as they provide accessibility from anywhere at any time, which can significantly change learning by students in rural areas in developing countries. Digital libraries advancements in combination with the internet are providing accessibility for student and educators to a wide collection of educational resources. Traditional learning is gradually transforming into e-learning with the introduction of these new technological advancements by enhancing student performance, wide availability of resources, and the quality of educational resources. The biggest challenge is to bridge the gap between physical and digital education and extending learning opportunities for students in areas with limited internet connectivity. There is a huge potential in West Africa in the access to these technologies with mobile phones, as the number of smartphone subscriptions in West Africa is on the rise with 68% of the population having access to a mobile phone, compared to only 6.3% and 0.7% through laptops or tablets and desktop computers respectively.

Cloud computing is already making a huge impact on digital library development and is promising for the future, while providing scalable and accessible solutions for managing and storing digital resources. The cloud ensures the availability and accessibility of educational resources from anywhere at any time, without human interference. Nowadays, it is essential to develop a cloud-based system for digital libraries. Additionally, cloud-based libraries should also have the option to locally download the necessary resources to local servers and mobile devices to provide accessibility to the educational resources for areas without a reliable and stable internet connection.

Furthermore, Artificial Intelligence (AI) and Machine Learning (ML) technologies are one of the most promising in innovative technologies to revolutionize education and digital libraries. AI and ML provide personalized learning environments, content recommendation systems, and

interactive learning experiences to users. Natural Language Interaction (NLI) is part of AI and enables personalized and human-like interactions with computers through natural language. These interactions aim to enhance user engagement and efficiency in digital libraries by providing this supportive automated question and answering services through chatbots and embodied conversational agents. Another technology with huge potential is the concept of gamification. Gamification incorporates game-like elements into learning experiences to enhance user engagement and motivation. Virtual Reality (VR) and Augmented Reality (AR) technologies can enhance gamification by creating immersive learning environments. VR and AR enhance student engagement and a better understanding of complex contexts.

Mobile Learning leverages mobile technologies to provide learning from anywhere at any time while having access to a wide variety of educational resources. Mobile learning would significantly influence the ability to learn in rural areas in West Africa as they have limited access to traditional educational institutions and educational resources. Open Educational Resources (OER) can enhance the accessibility to high-quality digital educational resources to underprivileged communities at low cost even further.

Lastly, Virtual Classrooms (VCs) enable remote communication, collaboration and knowledge building between student-student and student-teacher. VCs can facilitate education for students in remote areas with the requirement to have a reliable and stable internet connection.

In summary, the provided state-of-the-art technologies are transforming digital educational libraries by enhancing accessibility, usability, personalization, and engagement. These features all contribute to the usability and enhancement of knowledge building for learners all over the world.

7.1.3 SRQ3: Concepts and characteristics for digital educational libraries.

This fourth sub-research question aims to provide the concepts and characteristics for digital educational libraries. The concepts and characteristics follow the requirements identified in sub-research question three. Digital educational libraries are complex information systems, integrated with several technologies, designed to provide access from anywhere at any time to digital information resources with the purpose of using it for education. A Unified Modeling Languages (UML) class diagram is employed to visualize the conceptual structure and the relationships between the components of a digital educational library.

The central player of a digital library is the Digital Library Management System (DLMS), responsible for the creation, management and publishment of digital content. Section 4.7.3 identified the main functionalities of a DLMS, including easy installation and usage, metadata assignment, search and retrieval features, user account management, technical support, user-friendly interface, customization, and mobile phone integration.

The DLMS typically consists of three main components: the Content Management System (CMS), the User Management System (UMS), and the Workflow Management System (WFMS). The CMS is responsible for organizing and collecting the resources, while the WFMS automates the workflow processes by assigning the tasks and responsibilities to relevant stakeholders. The WFMS is responsible for managing the resource from the creation of the author until the publication in the library. With the integration of the revised Techniques of Electronic Resource Management (TERMS) framework, the resources are effectively managed during the resource lifecycle. The UMS is another important component, as it is responsible for the management of user accounts and the assignment roles to different users.

Another component of the conceptual structure of a digital library is the publication process. The publication process consists of submission of the created content, an expert review which evaluates the quality of the content, revision by the author if the content is declined by the expert review, copyright assessment by the digital librarian, and the publication of the content. This process ensure the quality and usability of the educational resources provided in the digital library.

These concepts and characteristics are essential for the functionality and effectiveness of digital educational libraries with the aim to provide accessible, high-quality educational resources while staying up-to-date with changing digital technologies and user needs.

7.1.4 SRQ4: Requirements for digital educational library to enhance usability and knowledge building.

The design of digital educational libraries in a West African context utilizes the requirements engineering (RE) approach, which serves as the foundation for successful software and information system development. By integrating Abstraction-oriented Frames (AoF) framework, the RE process consists of the following phases: Requirements Elicitation, Analysis, and Specification. The Requirements Analysis and Specification phase were combined to provide a comprehensive overview of the formulated design requirements.

Requirements Elicitation involves understanding the domain context, identifying relevant stakeholders, and eliciting requirements through various sources, including interviews, domain analysis, introspection, group work brainstorming, and observation. Stakeholder identification is essential in this process to ensure that all functionalities and constraints of the system are covered. User Stories are employed to formulate the design requirements, which has shown to be easy to understand for people without notation or modelling skills. 55 User Stories have been identified through the relevant stakeholders, as elaborated in Appendix D. From the elicited User Stories, 36 design requirements were constructed (See Appendix E).

In the subsequent Requirements Analysis and Specification phase categorizes requirements into User Requirements and Consequential Requirements. In addition, these Requirements are divided into functional and non-functional requirements. This categorization provides a comprehensive framework for understanding user needs and system constraints, which is essential for the development of digital educational libraries in West Africa.

Lastly, the prioritization of requirements through the Requirements Specification phase ensure that the development process focuses on iteratively developed functionalities that are most important to users. By adhering to these processes and integrating the AoF framework, digital educational libraries can be tailored effectively to meet the unique challenges and opportunities in the West African educational landscape with the goal to enhance accessibility, usability, and knowledge building for youth in the region.

7.1.5 SRQ5: Design principles for digital libraries in a West African context.

The formulation of design principles for digital educational libraries in a West African context provide a comprehensive framework that serves as the foundation for the development and implementation of these platforms tailored to the specific needs and challenges of West African regions. By conducting a systematic literature review and interviews, and formulating User Stories and design requirements, various design principles were formulated with the focus on user-centric design. The focus was on user-centric design to ensure a successful implementation for digital educational libraries in a West African context, as discussed in Sub-section 4.6.2.

By utilizing the framework proposed by Gregor et al. [88], the design principles provide a structured approach to address various aspects of digital educational libraries in a West African context, as elaborated Appendix H.1. These design principles cover all aspects of digital educational libraries in a West African context by ensuring the development of an accessible, inclusive, user-friendly, and impactful platform that helps individual in West African regions to access quality education, thereby enhancing knowledge building and socio-economic development.

7.1.6 SRQ6: Enhanced design principles for local digital libraries.

The enhanced design principles formulated for a local digital library provide a comprehensive framework tailored specifically for a physical implementation within the context of West Africa. These Local Design Principles (LDPs) address the unique challenges and opportunities present in local areas, ensuring that digital library systems effectively meet the needs of local West African communities when physically implementing new technologies into their community.

The LDPs serve as guidelines to inform the development and implementation of local digital libraries. They encompass the importance of considering the local context, including dynamics

within the community and cultural differences. By integrating these principles in the digital library design, we can ensure that digital technologies can effectively contribute to education, empowerment of individuals, and community development within the local areas. This research formulated Five LDPs, including Literacy as Foundation, Infrastructure readiness, Continuous Local Evaluation and Improvement, Local Cultural Relevance, and Community Engagement.

To align the local digital libraries with local needs, we developed the Community Needs Tech Assessment (CNTA). This assessment tool is based on the Community Needs Assessment (CNA) framework of Waters [122] and Rotary International [121], and the KPIs provided by Smulders [59], as discussed in Sub-section 6.3.4 and Appendix J. By engaging stakeholders and gathering insights from various community members, the CNTA helps to ensure that the local digital library and other technological initiatives are tailored to the local context and effectively address the community needs.

The CNTA provided valuable insights with regards to the in-depth exploration of the local community needs of both rural and urban communities in West Africa. The results showed that the children's families in the rural area, i.e. Case A and Case C, face challenges related to living below standard living conditions, including shelter, clothing, and food. Due to these living conditions, the support from within the community for students is limited, i.e. the Community Engagement is limited.

Additionally, most schools in these local communities are lacking the necessary infrastructure and equipment to support technology-integrated education and therewith hinder their ability to adhere to the new curriculum reforms and to provide a quality learning experience for students.

7.1.7 SRQ7: Validation of requirements and design principles for digital educational libraries in a Ghanaian context.

The validation of design requirements and principles is essential to ensure an effective and relevant digital library system within the unique context of West Africa. This process ensures that the formulated design requirements and principles are supported by objective evidence and fulfil the needs of the intended use [229]. The validation process is part of the engineering cycle of Wieringa [57]. By utilizing a combination of expert validation and self-validation through literature review ensured a comprehensive understanding of the formulated design requirements and principles.

The requirement validation process involved self-validation by cross-referencing the developed design requirements with scientific literature in the domain of digital libraries and implementation in the local context, which is discussed in Appendix F. Through this process, four papers were utilized to validate the formulated requirements and ensure alignment with relevant research papers and acknowledgment of similar requirements.

The design principle validation process employed both expert interviews and self-validation through cross-referencing. The relation between the design principles and the validation methods are elaborated in Appendix H.2. Four expert interviews were conducted to validate the formulated design principles. The expert interviews provide valuable insights into the specific needs and challenges of successfully implementing digital libraries in a West African context. The key principles identified by the experts were infrastructure readiness, community engagement, content relevance, usability, accessibility by everyone, security and privacy, and sustainability. Furthermore, the self-validation process involves cross-referencing with relevant scientific literature in the domain of digital libraries. This process utilized three relevant papers to validate the formulated design principles, ensuring alignment with relevant research papers and acknowledgment of similar principles.

In summary, the validation process showed the importance of tailoring digital library systems to address the specific needs and challenges of the West African context. As technologies are often designed for Western needs, the validation process helps to ensure that the formulated design requirements and principles are also acknowledges by experts and scientific literature in the relevant domain.

7.1.8 Answering the Main Research Question

The main research question of this research is defined as: *What does a design for digital educational libraries in a West-African (ECOWAS) context look like that leads to usability and knowledge building?* The answer of the main research question is the accumulation of the findings from the six sub-research questions. By providing answers to each sub research question, we were able to design the design principles for digital educational libraries in a West African context.

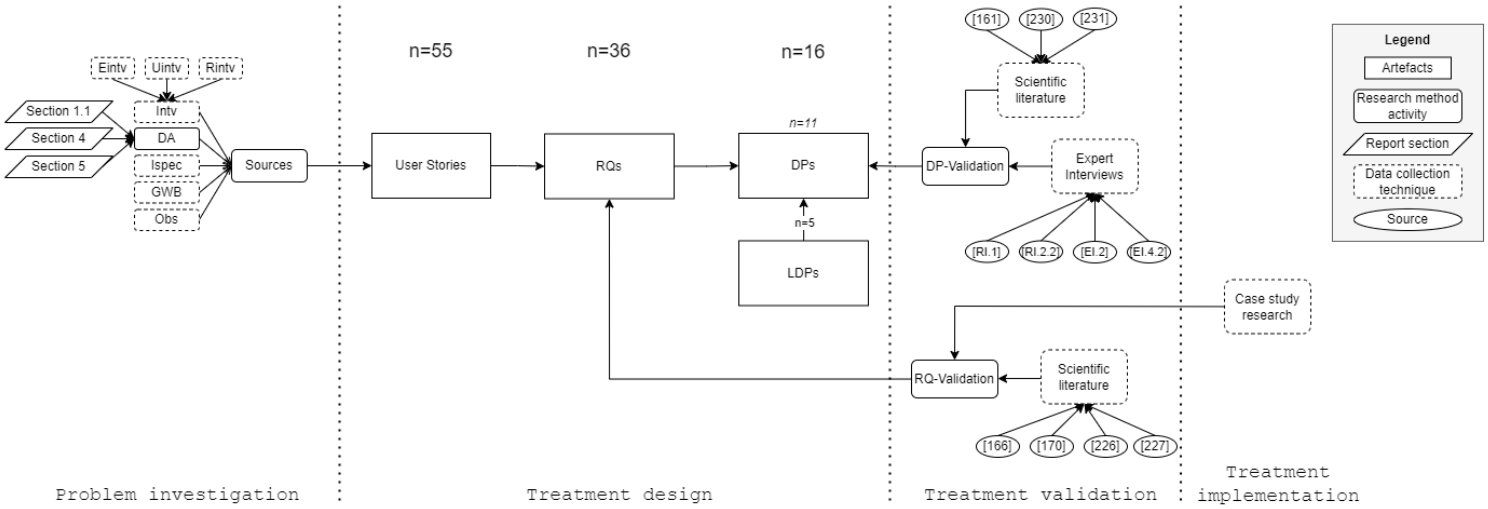


Figure 42: Overview of the research process.

Figure 29 and 42 provides an overview of the process of eliciting the design principles for digital educational libraries in a West African context and thereby the answer of the main research question. As elaborated in Sub-section 2.1, the executed design process consists of the problem investigation, the treatment design, treatment implementation, and the treatment validation.

First, the problem context is investigated in Sections 1.1, 4 and 5, which equals the Domain Analysis (DA). Consequently, 55 User Stories are derived from a variety of sources as elaborated in Sub-section 6.1.1.2, which include interviews (Intv), Domain Analysis (DA), Introspective (Ispec), Group Work Brainstorming (GWB), and Observations (Obs). The interviews consist of Expert interviews (Eintv), User interviews (Uintv), and Researcher interviews (Rintv), as discussed in Sub-section 3.3.

Subsequently, From the 55 elicited User Stories, 36 design requirements were constructed, which are elaborated in Appendix E, meaning that multiple User Stories can be part of one design requirement. These requirements were then validated by cross-referencing with four scientific papers in the domain of digital educational libraries in the context of developing countries, and by utilizing the results from the case-study research and the CNTA in Sub-section 6.3.5.

Lastly, the 36 design requirements are translated into 11 design principles (DPs) and 5 local design principles (LDPs) by utilizing the framework of Gregor et al. [88], as visualized in Figure 43. Subsequently, the design principles are validated by cross-referencing with three scientific papers and four expert interviews in the digital library domain.

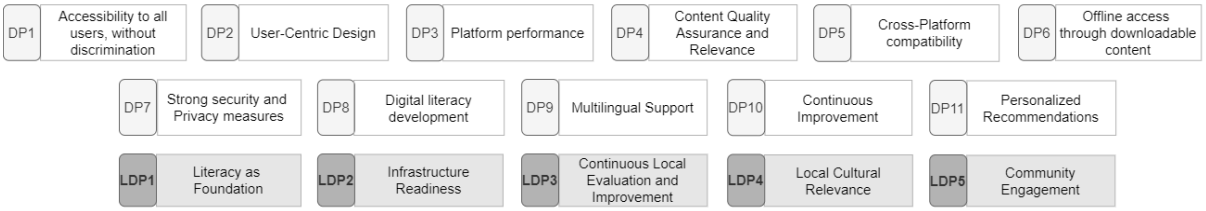


Figure 43: The constructed DPs and LDPs based on the framework of Gregor et al. [88].

8 Discussion

8.1 Limitations

This section elaborates on the identified limitations during the research process. The limitations range from conducting interviews in Ghana to performing research and aligning it with both University and external organization.

First, the influence of collaborating with a local organization on stakeholder engagement and researcher bias is discussed. Subsequently, the challenges of conducting interviews within local Ghanaian communities during the Community Needs Tech Assessment (CNTA) are elaborated, which involves cultural, societal, and hierarchical aspects. Furthermore, the significant loss of research data in Ghana is discussed. And lastly, we discuss the difficulty in balancing research/university goals with organizational goals.

8.1.1 Collaboration with Maxim Nyansa and data collection.

First, the case study research and the process to develop the design principles are within the context of the NGO Maxim Nyansa Foundation. Maxim Nyansa provided the opportunity to perform the case study research in Ghana. They also enabled the researchers to reach local Ghanaian communities and their stakeholders in the domain of their development projects, which are relevant for answering the research questions. The goal in every research is to minimize the researcher bias, however, while collaborating with Maxim Nyansa the research is not implemented into a problem context outside of Maxim Nyansa. The expertise of the stakeholders involved provided the researchers with detailed insights into the specific context of Ghana and West Africa. Furthermore, factual context data from external organizations (e.g., United Nations, WorldBank) are not Maxim Nyansa context specific, thus relevant for all regions in West Africa or Ghana, such as enrolment rates, funding allocation, or school fees. However, if the context data is available in Africa, it is mostly unpublished, outdated or incomplete. To address this issue, we verified the data found through engaging experts and researchers.

Additionally, the problem context varies significantly between regions, districts, and even local communities, as discussed in Section 5. This challenge was also identified by Smulders [RI.3] during his research in West Africa. The researchers in this research aimed to formulate design principles which is tailored and involves the different local context between regions, districts, and communities in West Africa.

8.1.2 Case study research

Time and resource constraints

Conducting interviews in local Ghanaian communities during the CNTA presented several challenges, particularly in rural areas, which made it difficult to obtain comprehensive and relevant results for the research. Firstly, the travel distances to reach local remote communities were extensive and the poor road infrastructure across Ghana hindered the research by consuming significant time and resources. This situation was both applicable to rural and urban areas. For instance, Case C in the rural area of Bolgatanga (north of Ghana) was a one-way travel of 800kms, which took 19 hours due to the poor road infrastructure and police checkpoints. Time constraints and limited resources prevented the researchers from paying multiple visits to the chosen remote areas, leading to limited data collection. For all cases, the researchers were only able to conduct one visit each, due to time constraints and organizational problems. By spending additional time locally in each case, we were able to address part of this issue.

In Case A and Case B, we were not able to conduct the Community Meeting as planned due to different cultural norms and time constraints, which is further discussed in Sub-section *Cultural Norms*. Case A was eventually, more than four months later, performed by the staff members of Maxim Nysansa. Moreover, time constraints by Maxim Nyansa staff members during the interviews further limited an in-depth and qualitative exploration of the stakeholders' perspectives.

The feeling of being in a hurry, in combination with ensuring that all interviews were stored properly, significantly limited the researcher's ability to gather quality data during the data collection. Additionally, the community needs assessments are time-consuming, which can lead to potential frustration with the interviewees. To address this issue, efforts were made to clearly communicate the time-consuming nature of the assessments to the interviewees. However, we found that the interviewees did not always fully understand and adhered to this, as discussed in Sub-sections *language and translation barriers* and *cultural norms*.

Language and translation barriers

Furthermore, language and translation barriers were identified as challenges during the interviews. Despite English being the national language, language barriers in local Ghanaian communities still persist and proved to be a challenge in order to conduct effective and efficient in-depth qualitative and quantitative interviews. As most older people in rural communities are not educated, their English proficiency is insufficient to conduct in-depth conversations about community insights with the researchers and therewith limit the quality of the data collection.

To address this challenge, we introduced the support of a translator from within the community who is fluent in both English and the local languages. By utilizing translators from within the community, the aim was that the involved community members fully embraced the translator without additional complications, such as tribal differences. The translator facilitated the opportunity for poor English speakers to fully express their feelings in their local language and in a safe environment.

However, this posed two problems. The first problem refers to the fact that the researchers are unaware of the real meaning of the expressed feelings from community members, as they communicate in their local language. The second problem refers to the inaccuracy of the translation due to varying language skills. The inaccuracy of the translation can lead to misinterpretations and misunderstanding by the researchers of the initially communicated feelings, this was especially noticed during the community meeting.

Cultural norms

Moreover, the cultural norms in African communities posed significant challenges to the quality of data collection. Several cultural norms were identified that significantly limited the quality of the data, including reluctance of asking for clarification, difficulty of keeping promises, and the gathering of genuine opinions when respected and high-ranked individuals are present. To address these challenges, we changes our approach from having interviewees to fill out the surveys independently to conducting interviews personally with the researchers. The change of our approach ensured a more in-depth exploration into the experiences and feelings of the interviewees.

Obtaining true personal perspectives from community members proved to be a challenge when performing the community assessments. In many cases, Africans are reluctant to ask for clarification when they do not understand the question or instruction, mainly out of respect for authorized individuals, resulting in incomplete or inaccurate answers. For example: when asked about the quality of education at their school, participants tend to simply answer 'poor' without any additional explanation. Alternatively, they simply use the answers from their neighbour, which also results in incomplete, unusable or biased data. This refers to the issue of socially desirable answers, where participants are changing their answers based on what they perceive is socially acceptable. Socially desirable answers can be related to the Hawthorne effect, meaning that participants may further influence their behaviour and answers because they know that they are being observed [230]. The issue of socially desirable answers can affect the quality and accuracy of the data collection within assessments and interviews and therefore may have influenced the results. This effect was also experienced by Smulders in West Africa [RI.3].

Another factor contributing to this issue is the limited digital literacy and literacy of our local interviewees, which posed challenges in formulating questions that participants can understand

and effectively answer. Especially in rural areas, many participants had little to no experience with computers, which limited their ability to understand and effectively answer to questions related to technological innovations. Consequently, the limited technological adoption rates in Africa also limited my data collection.

Moreover, the community members are reluctant to express their true feelings and perspectives in Community Meetings, especially with the presence of high-ranked individuals. In these situations, the high-ranked individual aims to push their own perspective forward to value other perspectives as less important. To address this issue, we suggest to divide the Community Meeting into two groups: one group consisting of teachers, students, parents, and the other group consisting of elderly, chief, and higher ranks. This approach ensures that all opinions are heard without being influenced by others. We were not able to implement this approach due to the time and resource constraints.

Additionally, a significant challenge encountered during my case study research was the inconsistency of Ghanaians to keep their promises and punctuality. Smulders [RI.3] experienced the same cultural challenge during his research in West Africa. Despite making the arrangements, these were often not followed or dismissed by Ghanaians due to other priorities without informing the researchers. It was common for Ghanaians to arrive late or not show up at all at the appointments, making it a challenge to schedule and perform interviews. For example, in Case A and Case B, we were not able to conduct the Community Meeting as planned due to our local spokesperson failing to organize and invite relevant local community members, which resulted in the cancellation of the Community Meeting during the trip. The local spokespersons had other priorities and did not inform us about the fact that they did not arrange the meeting. The researchers made efforts to arrange new Community Meetings, however, due to time constraints, we were not able to conduct the Community Meetings for these cases in person. In Case A, the staff members of Maxim Nysansa eventually arranged the Community Meeting more than four months later than originally planned due to conflicting priorities.

Additionally, due to conflicting priorities among community members and the failure of the local spokesperson to inform relevant stakeholders, the attendance of community members for the Community Meeting was very low. Therefore, we recommend to financially or practically compensate the stakeholders involved.

8.1.3 Significant loss of data

The interviews generated significant amounts of data, consuming large amounts of storage space. Because of the lack of internet connectivity in rural areas, recording and documenting the interviews was essential for the data collection process of this research. To address the storage issue, we decided to utilize an additional mobile phone including a large storage capacity. However, due to time constraints and pressure from stakeholders, we were unable to document all interviews on paper for later processing into the cloud. Unfortunately, at the end of the case study research, the phone containing all the data was stolen in Accra before the data was uploaded to the cloud. Consequently, we experienced a significant loss of data from both the expert interviews and the case study interviews of all cases. As discussed, the lack of internet connectivity posed another challenge during this research. Smulders [RI.3] also experienced the limited internet connectivity as a significant limitation. Case C was especially affected due to the lack of an internet connection. The expert interviews with the Head Teacher and the Chief were lost during Case Study Research C. The Head Teacher interview from Case B was also lost in this process. Nevertheless, most of the interviews were directly uploaded to Google Forms when internet was available, which ensured the continuation of this research project.

The significant loss of data had a direct influence on the outcomes of the research. The lost interviews could have changed the outcomes and therewith changed the requirements and the design principles. Table 15 elaborated on the interviews lost during this research.

Stakeholder interviews	Case A	Case B	Case C
Teacher interviews	8	5	6
Student interviews	0	6	14
Expert interviews	1	1	3

Table 15: The amount of interviews lost during the research process.

8.1.4 University vs organization

Lastly, a recurring limitation was the challenge of balancing the research objectives of the university together with the objectives of the organization. Throughout the research process, the goals of Maxim Nyansa, which focused on practical outcomes and the enhancement of their digital library, differed from the goals of Utrecht University, which is performing academic research. Especially in the beginning stages of the research, this issue was prevalent during the formulation of the research, including research goals and research questions. To address this issue, the researcher performed multiple discussions with supervisors from both the university and the organization. These conversations aimed to ensure a mutual understanding and alignment of research objectives. By facilitating this collaboration, the aim was to ensure that the needs and expectations of the research objectives of both parties were met.

8.2 Implications

To the best knowledge of the researchers, currently no design for digital educational libraries tailored to the West African context exists. Most existing designs focus on broader domains outside of education and are typically tailored to the needs of Western and developed countries. Therefore, this research aims to fill this gap by contributing to the current field of study regarding designing technological initiatives in the EDU4D domain. Its goal is to enhance the quality of life and provide better career perspectives for individuals in local underprivileged communities by providing new in-depth insights into the needs, opportunities, and challenges of local communities in West Africa.

By investigating the design requirements through User Stories involving all relevant stakeholders, this research provides a comprehensive overview of the necessary requirements for digital educational libraries in a West African context. It was found in literature that EDU4D projects are often unsuccessful, because the developers are designing the technologies based on their own assumptions instead of the true opinions of the relevant stakeholders, including users. This research addresses this problem by developing a user-centric design process that gains in-depth insights into the design requirements and principles for digital educational libraries specific to this context. Additionally, local design principles are formulated to ensure the successful implementation of digital libraries within local communities through ICT labs in schools or community centres.

Moreover, the research results, in particular the design principles, can directly be applied in practice. The results of this project will be applied at Maxim Nyansa for its digital library project. Thereby, contributing to the performance of development projects, the educational situation, and the future perspectives of students in developing countries. Maxim Nyansa has the goal to enhance their digital educational library for West Africa and locally implement the digital library in various schools across Ghana and other West African countries, such as Burkina Faso, Sierra Leone, and The Gambia. The ultimate goal is to spread these local digital libraries and digital educational library through the whole continent of Africa.

Furthermore, the development of the Community Needs Tech Assessment (CNTA) contributes to research by aiming to understand the technological and local needs of local West African communities, particularly in the context of implementing digital educational libraries, ICT labs, or similar technological initiatives. This assessment contributes by gaining insights into the societal, economic, and educational situation in West Africa, including their living conditions and challenges, and thereby enhance the understanding of the digital library context and design.

Moreover, if multiple CNTAs are executed on various schools and areas, the digital library context and design can be enhanced in the future.

Additionally, this research provides an exhaustive systematic literature review, which combines the domains of ICT4D, education, user-centric design, innovative technologies, providing valuable insights into the impact of digital libraries in the educational domain, particularly in a West African context. Interesting new insights were found with regards to the unsuccessfulness of ICT4D projects in education and local communities and the impact of current state-of-the-art technologies on digital libraries in both the past and potentially the future.

Lastly, this research contributes to the transparency of development projects with relevant stakeholders by mapping insights into the real-world environment in West Africa and state-of-the art design principles for digital educational libraries. The relevant stakeholders include local governments, the ministry of education, awareness in local communities, local stakeholders, external organisations, funders, and sponsors. These results ensure that stakeholders understand the impact of these projects on local West African communities. Thereby, enhancing the importance of ICT adoption and infrastructure in education in these areas.

8.3 Future research

This section reveals a variety of opportunities for future research. First, as discussed in Section 8.2, multiple CNTAs should be performed on various schools and areas to gain an extensive overview on various context for the digital library and potential future design improvements. Particularly with extending the digital library concept to other (West) African countries, additional assessments and evaluations have to be performed to extend the features and functionalities of the digital educational library tailored to multiple local contexts. Additionally, iterative development over time can enhance the design of digital educational libraries in a West African context. This could involve user engagement, learning outcomes, and overall satisfaction with the platform.

Secondly, future research can investigate the impact and effects of digital educational libraries on local communities in West Africa. The impact and the effects are strong indicators for the educational situation in these areas.

Thirdly, future research should explore innovative technologies that can enhance digital educational libraries, including AI, VR, gamification, and personalization to enhance engagement and motivation. Additionally, Mobile learning (m-learning) possibilities should be explored and integrated within the platform, as these technologies are prevalent in developing countries.

Furthermore, the CNTA framework should be enhanced by incorporating stakeholder feedback and improving the assessment process to better understand the technological and educational needs of local communities. This could involve refined qualitative and quantitate questions and analysis techniques, but also a tool which combines all aspects while ensuring offline accessibility, including data analysis and abilities for performing the assessments. Maxim Nyansa has deployed a local Mwater survey tool that syncs survey results with the cloud when an internet connection is available. However, this tool is limited as it lacks robust data analytics. Additionally, strategies should be explored to enhance community engagement within local communities. This includes collaboration between local organizations, community leaders, community members, and parents.

Moreover, the formulated design principles should be implemented into the real-world environment by collaborating with local institutions, NGOs, and the government to deploy and scale digital educational libraries across West Africa and potentially other African countries.

Lastly, future research should investigate the potential integration of learning management systems (LMS) within digital educational libraries to enhance the process of content management, quality reviews, tracking of student progress, and gaining overviews of national scores towards digital literacy skills. This could improve the overall student experience within education and provide a comprehensive overview of the state of children's education and learning over time. As Africa currently suffers from a limited technological infrastructure, the LMS is not integrated in this design process.

9 References

[1] N. Mandela, “Quotes - Education is the most powerful weapon we can use to change the world,” *The launch of the Mindset Network*. 2003.

[2] Human Journey, “Education in the developing world,” *The Human Journey*. Jun. 2017. Accessed: Oct. 17, 2023. [Online]. Available: https://humanjourney.us/health-and-education-in-the-modern-world/education-in-the-developing-world/

[3] UNICEF Ghana, “Ghana Education Budget Brief 2023,” 2023. Accessed: Jan. 08, 2024. [Online]. Available: https://www.unicef.org/ghana/media/4996/file/2023%20Education%20Budget%20Brief.pdf

[4] S. Owusu-Ansah, “One laptop per child policy in Ghana: Any impact on teaching and learning,” *Library Philosophy and Practice*, pp. 1–20, 2015.

[5] D. Owoyokun, “Poor quality education in Africa: The trends and threats - Fetters Off.,” *Fetters Off* -. Fetters Off, Feb. 2022. Accessed: Oct. 17, 2023. [Online]. Available: https://fettersoff.com/poor-quality-education-in-africa-the-trends-and-threats/

[6] Ł. Goczek, E. Witkowska, and B. Witkowski, “How does education quality affect economic growth?,” *Sustainability*, vol. 13, no. 11, p. 6437, Jun. 2021.

[7] C. Avgerou, “Information systems in developing countries: a critical research review,” *Journal of information Technology*, vol. 23, pp. 133–146, 2008.

[8] J. P. Dunne and N. Masiyandima, “Bilateral FDI from South Africa and income convergence in SADC,” *African Development Review*, vol. 29, no. 3, pp. 403–415, 2017.

[9] A. B. Fanta and D. Makina, “Equity, bonds, institutional debt and economic growth: Evidence from South Africa,” *South African Journal of Economics*, vol. 85, no. 1, pp. 86–97, 2017.

[10] P. K. Adom, E. E. O. Opoku, and I. K.-M. Yan, “Energy demand–FDI nexus in Africa: do FDIs induce dichotomous paths?,” *Energy Econ*, vol. 81, pp. 928–941, 2019.

[11] N. A. Boamah, “The relevance of global sector influence in African sector portfolios,” *African Journal of Economic and Management Studies*, vol. 8, no. 2, pp. 205–220, 2017.

[12] S. L. Gui-Diby, “Impact of foreign direct investments on economic growth in Africa: Evidence from three decades of panel data analyses,” *Research in economics*, vol. 68, no. 3, pp. 248–256, 2014.

[13] B. N. Adeleye, F. Adedoyin, and S. Nathaniel, “The criticality of ICT-trade nexus on economic and inclusive growth,” *Inf Technol Dev*, vol. 27, no. 2, pp. 293–313, 2021.

[14] L. Ngongalah, W. Emerson, N. N. Rawlings, and J. Muleme Musisi, “Research challenges in Africa – an exploratory study on the experiences and opinions of African researchers,” *bioRxiv*, Oct. 2018, Accessed: Oct. 17, 2023. [Online]. Available: https://doi.org/10.1101/446328.

[15] N. Adeleye and C. Eboagu, “Evaluation of ICT development and economic growth in Africa,” *NETNOMICS: Economic research and electronic networking*, vol. 20, pp. 31–53, 2019.

[16] J. R. Minkoua Nzie, J.-C. Bidogeza, and N. Azinwi Ngum, “Mobile phone use, transaction costs, and price: Evidence from rural vegetable farmers in Cameroon,” *Journal of African Business*, vol. 19, no. 3, pp. 323–342, 2018.

[17] H. Issahaku, B. M. Abu, and P. K. Nkegbe, “Does the use of mobile phones by smallholder maize farmers affect productivity in Ghana?,” *Journal of African Business*, vol. 19, no. 3, pp. 302–322, 2018.

[18] A. Gosavi, “Can mobile money help firms mitigate the problem of access to finance in Eastern sub-Saharan Africa?,” *Journal of African Business*, vol. 19, no. 3, pp. 343–360, 2018.

[19] A. Touray, A. Salminen, and A. Mursu, “ICT barriers and critical success factors in developing countries,” *The Electronic Journal of Information Systems in Developing Countries*, vol. 56, no. 1, pp. 1–17, 2013.
[20] M. O. Yusuf, “Information and communication technology and education: Analysing the Nigerian national policy for information technology,” *International education journal*, vol. 6, no. 3, pp. 316–321, 2005.
[21] M. Odedra, “Sub-Saharan Africa: a technological desert,” *Commun ACM*, vol. 35, no. 2, pp. 25–29, 1993.
[22] M. Odedra-Straub, *Global Information Technology and Socio-economic Development*. Nashua, New Hampshire, 1996.
[23] S. R. Ponelis and M. A. Holmner, “ICT in Africa: Building a better life for all,” *Inf. Technol. Dev.*, vol. 21, no. 2, pp. 163–177, Apr. 2015.
[24] N. Davis and P. Tearle, “A Core Curriculum for Telematics in Teacher Training.,” in *Teleteaching 98 Conference*, Vienna, 1998, pp. 239–250.
[25] C. Lemke and E. C. Coughlin, *Technology in American Schools: Seven Dimensions for Gauging Progress. A Policymaker’s Guide.* IEEE, 1998.
[26] T. H. Brown, “Towards a model for m-learning in Africa,” *International Journal on E-learning*, vol. 4, no. 3, pp. 299–315, 2005.
[27] Ministry of Education (MoE), “Education Strategic Plan (2018 - 2030).,” 2017.
[28] L. De Bruine, “How ICT interventions in education contribute to better career perspectives,” 2020. Accessed: Oct. 17, 2023. [Online]. Available: https://maximnyansa.com/wp-content/uploads/2020/08/ICT-interventions-in-education-Ghana-and-Sierra-Leone-BSC-Thesis.pdf
[29] J. S. Quaicoe and K. Pata, “Basic school teachers’ perspective to digital teaching and learning in Ghana,” *Educ Inf Technol (Dordr)*, vol. 23, no. 3, pp. 1159–1173, 2018, doi: 10.1007/s10639-017-9660-8.
[30] E. H. Diniz, D. E. Bailey, and D. Sholler, “Achieving ICT4D project success by altering context, not technology,” *Information Technologies & International Development*, vol. 10, no. 4, p. pp–15, 2014.
[31] J. M. and Y. J. Huang Ronghuai and Spector, “Learning in the Context of Technologies,” in *Educational Technology: A Primer for the 21st Century*, Singapore: Springer Singapore, 2019, pp. 33–48. doi: 10.1007/978-981-13-6643-7_2.
[32] J. D. Gould and C. Lewis, “Designing for usability: key principles and what designers think,” *Commun ACM*, vol. 28, no. 3, pp. 300–311, 1985.
[33] E. H. Diniz, D. E. Bailey, and D. Sholler, “Achieving ICT4D project success by altering context, not technology,” *Information Technologies & International Development*, vol. 10, no. 4, p. pp–15, 2014.
[34] R. Heeks, “Most eGovernment-for-development projects fail: how can risks be reduced?,” 2003.
[35] Maxim Nyansa, “Maxim Nyansa - About us,” Maxim Nyansa Foundation - The best of two worlds.
[36] J. Natia and S. Al-hassan, “Promoting teaching and learning in Ghanaian Basic Schools through ICT,” *International Journal of Education and Development using ICT*, vol. 11, no. 2, 2015.
[37] L. Adam, “Information and communication technologies in higher education in Africa: Initiatives and challenges,” *Journal of Higher Education in Africa/Revue de l’enseignement supérieur en Afrique*, pp. 195–221, 2003.
[38] P. Mozelius, H. Hansson, E. Kigozi Kahiigi, and L. Ekenberg, “Important aspects in ICT4D projects: towards a model for quality assessment,” *Revista de investigaciones UNAD*, vol. 8, no. 1, pp. 29–42, 2009.
[39] M. Tayebinik and M. Puteh, “Blended learning or E-learning?,” Jun. 2013.

[40] M. Poblet, “Introduction to mobile technologies, conflict management, and ODR: Exploring common grounds,” in *Law, Governance and Technology Series*, Dordrecht: Springer Netherlands, 2011, pp. 1–12.
[41] S. K. Aikins, *Leveraging Broadband for e-Government and Development in Africa: Opportunities and Challenges*. 2015.
[42] M. Ford and A. Botha, “A pragmatic framework for integrating ICT into education in South Africa,” in *2010 IST-Africa*, IEEE, 2010, pp. 1–10.
[43] M. Ayere, F. Odera, and J. Agak, “E-Learning in Secondary Schools in Kenya: A Case of the NEPAD E-Schools,” *Educ Res Rev*, vol. 5, pp. 218–223, 2010.
[44] Ä. Leijen, W. Admiraal, L. Wildschut, and P. Robert-Jan Simons, “Students’ perspectives on e-learning and the use of a virtual learning environment in dance education,” *Research in Dance Education*, vol. 9, pp. 147–162, 2008, doi: 10.1080/14647890802087951.
[45] J. Hellström and P.-E. Tröften, *The innovative use of mobile applications in East Africa*. Swedish international development cooperation agency (Sida), 2010.
[46] International Telecommunication Union (ITU), “The World in 2009: ICT Facts and Figures,” 2009. Accessed: Oct. 24, 2023. [Online]. Available: http://www.itu.int/dms_pub/itu-d/opb/ind/D-IND-RPM.AF-2009-PDF-E.pdf
[47] International Telecommunication Union (ITU), “Information Society Statistical Profiles 2009 – Africa,” 2009. Accessed: Oct. 24, 2023. [Online]. Available: https://www.itu.int/ITU-D/ict/material/ISSP09-AFR_final-en.pdf
[48] M. Ford and A. Botha, “MobiLED: mobile-led and leading via mobile,” 2009.
[49] N. B. Gyan, “The Web, Speech Technologies and Rural Development in West Africa An ICT4D Approach,” 2016.
[50] A. Momunalieva, A. Urdaletova, R. Ismailova, and E. Abdykeev, “The quality of higher education in Kyrgyzstan through the eyes of students,” *Quality in Higher Education*, vol. 26, no. 3, pp. 337–354, Sep. 2020, doi: 10.1080/13538322.2020.1790122.
[51] A. Yousefi, “The impact of information and communication technology on economic growth: evidence from developed and developing countries,” *Economics of Innovation and New Technology*, vol. 20, no. 6, pp. 581–596, Sep. 2011, doi: 10.1080/10438599.2010.544470.
[52] B. A. Kitchenham, T. Dyba, and M. Jorgensen, “Evidence-based software engineering,” in *Proceedings. 26th International Conference on Software Engineering*, 2004, pp. 273–281.
[53] B. Kitchenham, O. P. Brereton, D. Budgen, M. Turner, J. Bailey, and S. Linkman, “Systematic literature reviews in software engineering-a systematic literature review.,” *Inf Softw Technol*, vol. 51, no. 1, pp. 7–15, 2009.
[54] J. S. Quaicoe, K. Pata, and E. Jeladze, “Digital learning ecosystem services and educational change in Ghana’s basic schools,” in *EDULEARN16 Proceedings, 8th annual International Conference on Education and New Learning Technologies* , IATED, Jul. 2016, pp. 4887–4895.
[55] Maxim Nyansa, “Maxim Nyansa - What we do,” Maxim Nyansa Foundation - The best of two worlds.
[56] A. R. Hevner, “A three cycle view of design science research,” *Scandinavian journal of information systems*, vol. 19, no. 2, p. 4, 2007.
[57] R. J. Wieringa, *Design science methodology for information systems and software engineering*, 2014th ed. Berlin, Germany: Springer, 2014.
[58] P. Runeson, M. Host, A. Rainer, and B. Regnell, *Case study research in software engineering: Guidelines and examples*. John Wiley & Sons, 2012.
[59] M. Smulders, S. Overbeek, F. Dalpiaz, and D. Van Der Stelt, “Situational Method Engineering for ICT4D: Performing Impact Assessments for Educational Programs,” 2020. Accessed: Oct. 16, 2023. [Online]. Available: https://maximnyansa.com/research-reports/
[60] T. Dyba, B. A. Kitchenham, and M. Jorgensen, “Evidence-based software engineering for practitioners,” *IEEE Softw*, vol. 22, no. 1, pp. 58–65, 2005.

[61] M. Jorgensen, T. Dyba, and B. Kitchenham, “Teaching evidence-based software engineering to university students,” in *11th IEEE International Software Metrics Symposium (METRICS’05)*, IEEE, 2005.
[62] M. V Zelkowitz, D. R. Wallace, and D. W. Binkley, “Experimental validation of new software technology,” in *Lecture Notes on Empirical Software Engineering*, WORLD SCIENTIFIC, 2003, pp. 229–263.
[63] Y. Xiao and M. Watson, “Guidance on conducting a systematic literature review,” *J. Plan. Educ. Res.*, vol. 39, no. 1, pp. 93–112, Mar. 2019.
[64] B. A. Kitchenham, “Procedures for Undertaking Systematic Reviews,” *Computer Science Depart-ment, Keele University (TRISE-0401) and National ICT Australia Ltd (0400011T. 1), Joint Technical Report*, vol. 33, 2004.
[65] V. Garousi, M. Felderer, and M. V Mäntylä, “Guidelines for including grey literature and conducting multivocal literature reviews in software engineering,” *Inf. Softw. Technol.*, vol. 106, pp. 101–121, Feb. 2019.
[66] J. Tyndall, “AACODS checklist,” 2008.
[67] C. Wohlin, “Guidelines for snowballing in systematic literature studies and a replication in software engineering,” in *Proceedings of the 18th international conference on evaluation and assessment in software engineering*, 2014, pp. 1–10.
[68] T. Meline, “Selecting studies for systemic review: Inclusion and exclusion criteria,” *Contemp. Issues Commun. Sci. Disord.*, vol. 33, no. Spring, pp. 21–27, Mar. 2006.
[69] A. Davis, O. Dieste, A. Hickey, N. Juristo, and A. M. Moreno, “Effectiveness of requirements elicitation techniques: Empirical results derived from a systematic review,” in *14th IEEE International Requirements Engineering Conference (RE’06)*, IEEE, Sep. 2006, pp. 179–188.
[70] R. K. Yin, “Design and methods,” *Case study research*, vol. 3, no. 9.2, p. 84, 2003.
[71] G. Pervan and M. Maimbo, “Designing a case study protocol for application in IS research,” in *Proceedings of the ninth pacific asia conference on information systems*, 2005, pp. 1281–1292.
[72] Maxim Nyansa, “concept paper Maxim Nyansa 2023 [not published],” 2023.
[73] J. Anto, D. Van der Stelt, S. K. Dankyira, and Hui Bei, “Enhancing teacher-student classroom participation through an integrated learning transformation programme (ILTP): A first insight into a more interactive educational system in Ghana.,” Aug. 2020.
[74] Maxim Nyansa, “Local digital library [not published],” 2022.
[75] R. E. Roberts, “Qualitative Interview Questions: Guidance for Novice Researchers.,” *Qualitative Report*, vol. 25, no. 9, 2020.
[76] D. S. Cruzes, T. Dybå, P. Runeson, and M. Höst, “Case studies synthesis: a thematic, cross-case, and narrative synthesis worked example,” *Empir Softw Eng*, vol. 20, pp. 1634–1665, 2015.
[77] P. Runeson and M. Höst, “Guidelines for conducting and reporting case study research in software engineering,” *Empir. Softw. Eng.*, vol. 14, no. 2, pp. 131–164, Apr. 2009.
[78] R. B. Johnson, “Examining the validity structure of qualitative research,” *Education (Chula Vista)*, vol. 118, no. 2, pp. 282–292, 1997.
[79] C. M. Patino and J. C. Ferreira, “Internal and external validity: can you apply research study results to your patients?,” *Jornal Brasileiro de Pneumologia*, vol. 44, no. 3, pp. 183–183, May 2018, doi: 10.1590/s1806-37562018000000164.
[80] T. D. Cook and D. T. Campbell, *Quasi-experimentation: Design and analysis issues for field settings*. 1979.
[81] K. K. Fu, M. C. Yang, and K. L. Wood, “Design principles: The foundation of design,” in *Volume 7: 27th International Conference on Design Theory and Methodology*, American Society of Mechanical Engineers, Aug. 2015.
[82] D. C. Edelson, “Design research: What we learn when we engage in design,” *The Journal of the Learning sciences*, vol. 11, no. 1, pp. 105–121, 2002.

[83] W. Lidwell, K. Holden, and J. Butler, *Universal principles of design, updated and expanded third edition*. in Rockport Universal. New York, NY: Rock Point, 2023.
[84] S. Paavola, M. Lakkala, H. Muukkonen, K. Kosonen, and K. Karlgren, "The roles and uses of design principles for developing the trialogical approach on learning," *Research in Learning Technology*, vol. 19, no. 3, Nov. 2011, doi: 10.3402/rlt.v19i3.17112.
[85] J. Iivari, M. Rotvit Perlt Hansen, and A. Haj-Bolouri, "A proposal for minimum reusability evaluation of design principles," *Eur. J. Inf. Syst.*, vol. 30, no. 3, pp. 286–303, May 2021.
[86] L. Chandra, S. Seidel, and S. Gregor, "Prescriptive knowledge in IS research: Conceptualizing design principles in terms of materiality, action, and boundary conditions," in *2015 48th Hawaii International Conference on System Sciences*, IEEE, Jan. 2015.
[87] C. Kruse and L. Seidel, "Tensions in design principle formulation and reuse," in *Designing the Digital Transformation: DESRIST 2017. Progress Proceedings of the 12th International Conference onDesign Science Research in Information Systems and Technology*, Karlsruhe, Germany: Karlsruher Institut für Technologie (KIT), 2017.
[88] S. Gregor, L. Chandra Kruse, and S. Seidel, "The Anatomy of a Design Principle," *J Assoc Inf Syst*, vol. 21, pp. 1622–1652, Nov. 2020, doi: 10.17705/1jais.00649.
[89] S. Cronholm and H. Göbel, "Guidelines Supporting the Formulation of Design Principles," Oct. 2018.
[90] R. Heeks, "ICT4D 2.0: the Next Phase of Applying ICT for International Development," *Computer (Long Beach Calif)*, vol. 41, pp. 26–33, Jul. 2008, doi: 10.1109/MC.2008.192.
[91] T. F. Bissyandé, D. Ahmat, J. Ouoba, G. van Stam, J. Klein, and Y. Le Traon, "Sustainable ICT4D in Africa: Where Do We Go From Here?," in *Fifth International IEEE EAI Conference on e-infrastructure and e-Services for Developing Countries (AFRICOMM 2013)*, Blantyre, Malawi, Nov. 2013, pp. 1–10. [Online]. Available: https://hal.science/hal-00994230
[92] C. Avgerou, "Theoretical framing of ICT4D research," in *Information and Communication Technologies for Development: 14th IFIP WG 9.4 International Conference on Social Implications of Computers in Developing Countries, ICT4D 2017, Yogyakarta, Indonesia, May 22-24, 2017, Proceedings 14*, 2017, pp. 10–23.
[93] C. Avgerou, "The significance of context in information systems and organizational change," *Information systems journal*, vol. 11, no. 1, pp. 43–63, 2001.
[94] S. Sahay, M. K. Sein, and C. Urquhart, "Flipping the context: ICT4D, the next grand challenge for IS research and practice," *J Assoc Inf Syst*, vol. 18, no. 12, p. 5, 2017.
[95] G. Walsham, "ICT4D research: reflections on history and future agenda," *Inf Technol Dev*, vol. 23, no. 1, pp. 18–41, Jan. 2017, doi: 10.1080/02681102.2016.1246406.
[96] W. Chipidza and D. Leidner, "A review of the ICT-enabled development literature: Towards a power parity theory of ICT4D," *The Journal of Strategic Information Systems*, vol. 28, no. 2, pp. 145–174, 2019.
[97] S. Dewan and F. J. Riggins, "The digital divide: Current and future research directions," *J Assoc Inf Syst*, vol. 6, no. 12, pp. 298–337, 2005.
[98] G. Walsham and S. Sahay, "Research on information systems in developing countries: Current landscape and future prospects," *Inf Technol Dev*, vol. 12, no. 1, pp. 7–24, 2006.
[99] M. Abubakre and M. Mkansi, "How do technologists do 'ICT for development'? A contextualised perspective on ICT4D in South Africa," *European Journal of Information Systems*, vol. 31, no. 1, pp. 7–24, Jan. 2022, doi: 10.1080/0960085X.2021.1978343.
[100] Independent Evaluation Group (IEG), *Capturing technology for development : An evaluation of World Bank Group activities in information and communication technologies.*, vol. 1. World Bank: Washington, DC, 2011. Accessed: Oct. 18, 2023. [Online]. Available: http://hdl.handle.net/10986/2370
[101] C. I. C. Lin, F.-Y. Kuo, & Myers, C. I. C. Lin, F.-Y. Kuo, and M. D. Myers, "Extending ICT4D studies: The value of critical research," 2015. [Online]. Available: http://misq.org/extending-ict4d-studies-the-value-of-critical-research.html

[102] T. Le, S. Overbeek, D. van der Stelt, and S. España, “Development of a computer-based tool for supporting impact assessments of EDU4D projects,” *International Journal of ICT Research in Africa and the Middle East (IJICTRAME)*, vol. 11, no. 1, pp. 1–27, 2022.
[103] E. Jeladze, K. Pata, and J. S. Quaicoe, “Factors Determining Digital Learning Ecosystem Smartness in Schools.,” *IxD\&A*, vol. 35, pp. 32–55, 2017.
[104] J. Awuni and E. Akotuko Ayimbila, “Teachers’ Perceptions of Ibox Use for Integrated Science Lessons in Secondary Education Improvement Project Schools,” *Int J Sci Res Sci Technol*, pp. 319–336, Nov. 2022, doi: 10.32628/IJSRST229615.
[105] J. Cullen, J. Mallet, and K. Murphy, “The opportunities and challenges for developing ICT-based science learning and teaching in Ghana,” 2019.
[106] S. Edwards, “Ghana launches $30M education outcomes fund to get kids into school,” *Devex*, Mar. 06, 2023. Accessed: Jan. 09, 2024. [Online]. Available: https://www.devex.com/news/ghana-launches-30m-education-outcomes-fund-to-get-kids-into-school-105066
[107] World Connected, “Africa ICT Right,” World Connected. Accessed: Dec. 10, 2023. [Online]. Available: https://1worldconnected.org/project/africa_digitalskills_gender_health_youth_africaictrightghana/
[108] J. Hartung, “Programme for Sustainable Economic Development (PSED) in Ghana,” *Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH*. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Accra, Sep. 2021. Accessed: Jan. 08, 2024. [Online]. Available: https://www.giz.de/de/downloads/giz2021-en-digital-transformation-center-dtc.pdf
[109] C. Avgerou and K. McGrath, “14 Rationalities and emotions in IS innovation,” *Handbook of Critical Information Systems Research*, p. 299, 2005.
[110] N. Letch and J. Carroll, “Excluded again: Implications of integrated E-government systems for those at the margins,” *Information Technology & People*, vol. 21, no. 3, pp. 283–299, 2008.
[111] M. S. Adam and M. D. Myers, “Have you got anything to declare? Neo-colonialism, information systems, and the imposition of customs and duties in a third world country,” in *Organizational Information Systems in the Context of Globalization: IFIP TC8 & TC9/WG8. 2 & WG9. 4 Working Conference on Information Systems Perspectives and Challenges in the Context of Globalization June 15–17, 2003, Athens, Greece*, 2003, pp. 101–115.
[112] R. W. Harris, “How ICT4D research fails the poor,” *Inf Technol Dev*, vol. 22, no. 1, pp. 177–192, 2016.
[113] R. M. Davison, “Making a world of a difference,” *Journal of Information Technology*, vol. 27, pp. 100–101, 2012.
[114] S. Qureshi, “Are we making a better world with information and communication technology for development (ICT4D) research? Findings from the field and theory building,” *Information Technology for Development*, vol. 21, no. 4. Taylor & Francis, pp. 511–522, 2015.
[115] R. Heeks, “Information systems and developing countries: Failure, success, and local improvisations,” *The information society*, vol. 18, no. 2, pp. 101–112, 2002.
[116] D. Kleine and T. Unwin, “Technological revolution, evolution and new dependencies: What’s new about ICT4D?,” *Third World Q*, vol. 30, no. 5, pp. 1045–1067, 2009.
[117] M. L. Best and R. Kumar, “Sustainability failures of rural telecenters: Challenges from the sustainable access in rural india (sari) project,” *Information Technologies & International Development*, vol. 4, no. 4, p. pp–31, 2008.
[118] R. Cervantes, M. Warschauer, B. Nardi, and N. Sambasivan, “Infrastructures for low-cost laptop use in Mexican schools,” in *Proceedings of the SIGCHI conference on human factors in computing systems*, 2011, pp. 945–954.

[119] M. Pozzebon and E. Van Heck, "Local adaptations of generic application systems: the case of Veiling Holambra in Brazil," *Journal of Information Technology*, vol. 21, no. 2, pp. 73–85, 2006.
[120] V. Van Reijswoud, "Appropriate ICT as a tool to increase effectiveness in ICT4D: Theoretical considerations and illustrating cases," *The Electronic Journal of Information Systems in Developing Countries*, vol. 38, no. 1, pp. 1–18, 2009.
[121] Rotary International, "Community Assessment Tools: A resource for Rotary projects," Aug. 2023. Accessed: Oct. 25, 2023. [Online]. Available: https://my-cms.rotary.org/en/document/community-assessment-tools
[122] A. Waters, "Community Needs Assessment: The Resources and Examples Your Organization Needs," *getconnected*, 2023, Accessed: Oct. 25, 2023. [Online]. Available: https://www.galaxydigital.com/blog/community-needs-assessment#D
[123] C. Avgerou and G. Walsham, "Introduction: IT in developing countries," in *Information technology in context*, Routledge, 2017, pp. 1–8.
[124] F. D. Davis, "Perceived usefulness, perceived ease of use, and user acceptance of information technology," *MIS quarterly*, pp. 319–340, 1989.
[125] T. Georgiev, E. Georgieva, and A. Smrikarov, "M-learning-a New Stage of E-Learning," in *International conference on computer systems and technologies-CompSysTech*, 2004, pp. 1–4.
[126] D. Keegan, *Foundations of distance education*. Routledge, 2013.
[127] S. O. Gunga and I. W. Ricketts, "Facing the challenges of e-learning initiatives in African universities," *Br. J. Educ. Technol.*, vol. 38, no. 5, pp. 896–906, Sep. 2007.
[128] P. Taylor, "Sub Saharan Africa: smartphone subscriptions 2011-2028," *Statista*. 2023. Accessed: Oct. 17, 2023. [Online]. Available: https://www.statista.com/statistics/1133777/sub-saharan-africa-smartphone-subscriptions/
[129] C. Quin, "mLearning: Mobile, wireless, in-your-pocket learning. LiNE Zine Retrieved," *LiNE Zine*, vol. 2006, no. 1, 2000.
[130] P. J. Bates, "Making e-learning mobile - a brief overview of developments in m-learning," in *2002 Online Education Conference*, Berlin, Germany, 2002.
[131] S. Criollo-C, A. Guerrero-Arias, Á. Jaramillo-Alcázar, and S. Luján-Mora, "Mobile learning technologies for education: Benefits and pending issues," *Applied Sciences*, vol. 11, no. 9, 2021.
[132] M. Denk, M. Weber, and R. Belfin, "Mobile learning–challenges and potentials," *International Journal of Mobile Learning and Organisation*, vol. 1, no. 2, pp. 122–139, 2007.
[133] K. Nitsche, "Acceptance of mobile, classroom-bound E-learning systems from the perspective of students and lectures," in *2013 IEEE 13th International Conference on Advanced Learning Technologies*, IEEE, Jul. 2013, pp. 508–509.
[134] N. F. D. Filho and E. F. Barbosa, "A contribution to the establishment of reference architectures for mobile learning environments," *IEEE Rev. Iberoam. Tecnol. Aprendiz.*, vol. 10, no. 4, pp. 234–241, Nov. 2015.
[135] T. Cherner, J. Dix, and C. Lee, "Cleaning Up That Mess: A Framework for Classifying Educational Apps," *Contemp. Issues Technol. Teach. Educ*, vol. 14, pp. 158–193, 2014.
[136] K. Burden and P. Hopkins, "Barriers and challenges facing pre-service teachers' use of mobile technologies for teaching and learning," *Int. J. Mob. Blended Learn.*, vol. 8, pp. 1–20, 2016.
[137] A. Dabalen and J. Tei Mensah, "Ten Facts About Digital Technology Adoption in Ghana," Africa can end poverty. Accessed: Jan. 24, 2024. [Online]. Available: https://blogs.worldbank.org/africacan/ten-facts-about-digital-technology-adoption-ghana
[138] I. K. Suartama, P. Setyosari, S. Sulthoni, and S. Ulfa, "Development of Ubiquitous Learning Environment Based on Moodle Learning Management System," *International Journal of*

Interactive Mobile Technologies (iJIM), vol. 14, pp. 182–204, Aug. 2020, doi: 10.3991/ijim.v14i14.11775.
[139] S. K. Dankyira, "Educational landscape and digitization, interactive learning [personal communication]," Jan. 15, 2024.
[140] S. Aithal and P. S. Aithal, "Effects of AI-Based ChatGPT on Higher Education Libraries," *International Journal of Management, Technology, and Social Sciences (IJMTS)*, vol. 8, no. 2, pp. 95–108, 2023.
[141] V. Gherheș, C. E. Stoian, M. A. Fărcașiu, and M. Stanici, "E-learning vs. face-to-face learning: Analyzing students' preferences and behaviors," *Sustainability*, vol. 13, no. 8, p. 4381, 2021.
[142] N. Shukla and S. Prasad, "COVID-19 Impact: Blended Learning in Sustainable Management Education-The New Normal," *ECS Trans. 2022*, vol. 107, pp. 9103–9117, 2022.
[143] W. Bao, "COVID-19 and online teaching in higher education: a case study of Peking University, Human Behavior and Emerging Technologies," *Hum Behav Emerg Technol*, vol. 2, no. 2, pp. 113–115, 2020.
[144] C. E. Stoian, M. A. Fărcașiu, G.-M. Dragomir, and V. Gherheș, "Transition from online to face-to-face education after COVID-19: The benefits of online education from students' perspective," *Sustainability*, vol. 14, no. 19, p. 12812, Oct. 2022.
[145] A. Haleem, M. Javaid, M. A. Qadri, and R. Suman, "Understanding the role of digital technologies in education: A review," *Sustainable Operations and Computers*, vol. 3, pp. 275–285, 2022.
[146] H. Munir, "Reshaping Sustainable University Education in Post-Pandemic World: Lessons Learned from an Empirical Study," *Educ. Sci*, vol. 12, no. 8, pp. 0–524, 2022.
[147] M. Tagoe, "Students' perceptions on incorporating e-learning into teaching and learning at the University of Ghana," *International Journal of Education and Development using ICT*, vol. 8, no. 1, pp. 91–103, 2012.
[148] J. Jeng, "Usability assessment of academic digital libraries: effectiveness, efficiency, satisfaction, and learnability," 2005.
[149] N. Sithole, "An Assessment of the Usability of the Africa University Digital Library, Mutare, Zimbabwe.," *International Journal of Emerging Trends & Technology in Computer Science*, vol. Vol. 3, Mar. 2018.
[150] R. Benbunan-Fich, "Using protocol analysis to evaluate the usability of a commercial web site," *Information & management*, vol. 39, no. 2, pp. 151–163, 2001.
[151] R. Rogers and H. Preston, "Usability analysis for redesign of a Caribbean academic library web site: a case study," *OCLC Systems & Services: International digital library perspectives*, vol. 25, no. 3, pp. 200–211, 2009.
[152] C. Abras, D. Maloney-Krichmar, J. Preece, and others, "User-centered design," *Bainbridge, W. Encyclopedia of Human-Computer Interaction. Thousand Oaks: Sage Publications*, vol. 37, no. 4, pp. 445–456, 2004.
[153] R. K. France, L. T. Nowell, E. Fox, R. A. Saad, and J. Zhao, "Use and usability in a digital library search system," *ArXiv*, vol. cs.DL/9902013, 1999.
[154] P. F. (Peter F. Drucker, *The age of discontinuity: guidelines to our changing society*. London : Heinemann, 1969., 1969. [Online]. Available: https://search.library.wisc.edu/catalog/999809605202121
[155] A. S. Weber, "The role of education in knowledge economies in developing countries," *Procedia-Social and Behavioral Sciences*, vol. 15, pp. 2589–2594, 2011.
[156] J.-E. Aubert and J.-L. Reiffers, *Knowledge economies in the Middle East and North Africa: Toward new development strategies*. World Bank Publications, 2003.
[157] M. Scardamalia and C. Bereiter, "A brief history of knowledge building," *Canadian Journal of Learning and Technology/La revue canadienne de l'apprentissage et de la technologie*, vol. 36, no. 1, 2010.

[158] C. K. K. Chan and J. van Aalst, “Knowledge building: Theory, design, and analysis,” in *International handbook of the learning sciences*, Routledge, 2018, pp. 295–307.
[159] G. G. Chowdhury and S. Chowdhury, *Introduction to digital libraries*. Facet publishing, 2003.
[160] E. A. Fox, R. M. Akscyn, R. K. Furuta, and J. J. Leggett, “Digital libraries,” *Commun ACM*, vol. 38, no. 4, pp. 22–28, 1995.
[161] G. Marchionini and H. Maurer, “The roles of digital libraries in teaching and learning,” *Commun. ACM*, vol. 38, no. 4, pp. 67–75, Apr. 1995.
[162] H. G. Wells, *World Brain*. London: Methuen and Co., 1938.
[163] I. Xie and K. K. Matusiak, “Chapter 1 - Introduction to digital libraries,” in *Discover Digital Libraries*, I. K. Xie K, Ed., 2016, pp. 1–35. doi: 10.1016/B978-0-12-417112-1.00001-6.
[164] R. Sharifabadi, “How digital libraries can support e-learning.,” *The Electronic Library*, vol. 24, no. 3, pp. 389–401, 2006.
[165] M. J. Mamabolo and O. O. Durodolu, “Rural accessibility to digital libraries: requirements and challenges,” *Digit Libr Perspect*, vol. 39, no. 4, pp. 551–570, Jan. 2023, doi: 10.1108/DLP-04-2023-0025.
[166] P. B. Zirra, A. J. Ibrahim, and N. Abdulganiyyi, “A review of digital libraries and their impact in Africa,” *American Journal of Computer Science and Technology*, vol. 2, no. 4, pp. 60–67, 2019.
[167] I. Da Rosa, I. Shmorgun, and D. Lamas, *Enabling mobile access to digital libraries in digital divide contexts*. 2012.
[168] I. W. Juma, C. Wekullo, and J. Wamukoya, “The role of digital libraries in bridging the knowledge gap in Africa,” *Mousaion*, vol. 32, no. 1, pp. 64–83, 2014.
[169] L. Candela *et al.*, *Current Digital Library Systems: User Requirements vs Provided Functionality*. 2006.
[170] R. Sanchati and G. Kulkarni, “Cloud computing in digital and university libraries,” *Global Journal of computer science and technology*, vol. 11, no. 12, pp. 37–42, 2011.
[171] T. P. Ayeni, “The barriers to open internet in Africa,” *The American journal of interdisciplinary innovations and research*, vol. 1, no. 04, 2019.
[172] D. Berardi, D. Calvanese, and G. De Giacomo, “Reasoning on UML class diagrams,” *Artif Intell*, vol. 168, no. 1–2, pp. 70–118, 2005.
[173] Bhumika, “Class Diagram | Unified Modeling Language (UML),” GeeksforGeeks. Accessed: Jan. 27, 2024. [Online]. Available: https://www.geeksforgeeks.org/unified-modeling-language-uml-class-diagrams/
[174] S. A. Khan and K. Shahzad, “Key features of digital library management system (DLMS) for developing digital libraries: An investigation from LIS practitioners in Pakistan,” *Journal of Librarianship and Information Science*, p. 09610006221127033, Oct. 2022, doi: 10.1177/09610006221127033.
[175] H. Yu, *Content and workflow management for library Web sites: Case studies*. IGI Global, 2005.
[176] Maxim Nyansa, “Requirements of a digital library [not published],” 2020.
[177] Y. Han, “Digital content management: the search for a content management system,” *Library Hi Tech*, vol. 22, no. 4, pp. 355–365, 2004.
[178] W. Bentil, C. L. Liew, and B. Chawner, “An examination of electronic resource management in academic libraries in Ghana through the Techniques of Electronic Resource Management (TERMS) framework,” *The Journal of Academic Librarianship*, vol. 47, no. 1, p. 102265, 2021, doi: https://doi.org/10.1016/j.acalib.2020.102265.
[179] J. K. Lippincott, “Developing collaborative relationships: librarians, students, and faculty creating learning communities,” *College & Research Libraries News*, vol. 63, no. 3, pp. 190–192, 2002.
[180] R. Cooper and P. R. Dempsey, “Remote library users; needs and expectations,” *Libr Trends*, vol. 47, no. 1, pp. 42–64, 1998.

[181] J.-L. Shih, G.-J. Hwang, Y.-C. Chu, and C.-W. Chuang, "An investigation-based learning model for using digital libraries to support mobile learning activities," *The Electronic Library*, vol. 29, no. 4, pp. 488–505, 2011.
[182] H.-C. Chu, G.-J. Hwang, S.-X. Huang, and T.-T. Wu, "A knowledge engineering approach to developing e-libraries for mobile learning," *The Electronic Library*, vol. 26, no. 3, pp. 303–317, 2008.
[183] R. K. Das and M. S. U. Islam, "Application of artificial intelligence and machine learning in libraries: a systematic review," *arXiv preprint arXiv:2112.04573*, 2021.
[184] G. Gujral, S. J, and P. Choukimath, *Perceptions and Prospects of Artificial Intelligence Technologies for Academic Libraries: An Overview of Global Trends*. 2020.
[185] P. Fernandez, "'Through the looking glass: envisioning new library technologies' understanding artificial intelligence," *Library Hi Tech News*, vol. 33, no. 3, pp. 20–23, Jan. 2016, doi: 10.1108/LHTN-03-2016-0013.
[186] B. Massis, "Artificial intelligence arrives in the library," *Information and Learning Science*, vol. 119, no. 7/8, pp. 456–459, 2018.
[187] M. E. Foster, "Enhancing human-computer interaction with embodied conversational agents," in *Universal Access in Human-Computer Interaction. Ambient Interaction: 4th International Conference on Universal Access in Human-Computer Interaction, UAHCI 2007 Held as Part of HCI International 2007 Beijing, China, July 22-27, 2007 Proceedings, Part II 4*, 2007, pp. 828–837.
[188] K. Felker and E. Phetteplace, "Gamification in libraries: the state of the art," *Reference and User Services Quarterly*, vol. 54, no. 2, pp. 19–23, 2014.
[189] S. Kamunya, E. Mirirti, R. Oboko, and E. Maina, "An adaptive gamification model for e-learning," in *2020 IST-Africa Conference (IST-Africa)*, 2020, pp. 1–10.
[190] A. Bhattacharya, "Augmented Reality applications in modern day library: A study," *Journal of Indian Library Association*, vol. 54, no. 4, pp. 189–194, 2019.
[191] N. Alalwan, L. Cheng, H. Al-Samarraie, R. Yousef, A. I. Alzahrani, and S. M. Sarsam, "Challenges and prospects of virtual reality and augmented reality utilization among primary school teachers: A developing country perspective," *Studies in Educational Evaluation*, vol. 66, p. 100876, 2020.
[192] J. I. Hess, A. J. Nann, and K. E. Riddle, "Navigating OER: The library's role in bringing OER to campus," *Ser Libr*, vol. 70, no. 1–4, pp. 128–134, 2016.
[193] C. Chen, "Research on the Construction of Digital Library Platform Based on Cloud Computing Technology," *International Core Journal of Engineering*, vol. 2, no. 12, 2016.
[194] J. Esteve-Romero *et al.*, "Use of virtual classroom as a tool for E-learning in the master," 2018.
[195] D. McCullough, K. Hatipoglu, and N. Burnett, "Free" government schools and low cost private schools: What households really spend on education in Kasoa, Ghana," *Results for Development Institute for the IJBS Optimus Foundation. Retrieved on*, Oct. 2015, Accessed: Jan. 24, 2024. [Online]. Available: https://r4d.org/resources/exploring-public-and-private-education-costs-ghana/
[196] K. Obirikorang, C. Wongnaa, E. Nkrumah, and M. Ansong, "Uneven Development: Urban and industrial growth and Its Environmental Implications for Rural and Urban Communities in Ghana," 2018, pp. 39–54.
[197] F. Osei, A. Stein, and S. Nyadanu, "Spatial and temporal heterogeneities of district-level typhoid morbidities in Ghana: A requisite insight for informed public health response," *PLoS One*, vol. 13, p. e0208006, Nov. 2018, doi: 10.1371/journal.pone.0208006.
[198] R. Donkoh, L. Wing-On, and J. Donkor, "Educational Development Issues in Ghana in Light of Educational Policy and Planning," *International Journal of Educational Development in Africa*, vol. 5, pp. 21–pages, 2020.

[199] M. A. Anlimachie, “Towards equity in access and quality in basic education in Ghana: Comparative strategies for the rural and urban milieu,” *American Journal of Social Issues and Humanities*, vol. 5, no. 2, pp. 400–426, 2015.
[200] K. Tomaševski, *Human rights obligations in education: the 4-A scheme*. Wolf Legal Publishers, 2006.
[201] Girls’ Education Unit (GEU), “A National Vision for Girls’ Education in Ghana and a Framework for Action: Charting the Way Forward,” Accra, Jan. 2002.
[202] S. A. Takyi, O. Amponsah, M. O. Asibey, and R. A. Ayambire, “An overview of Ghana’s educational system and its implication for educational equity,” *International Journal of Leadership in Education*, 2019.
[203] J. Appiah-Kubi, A. Ceter, and Z. Luboder, “Gender inequality in key sectors in Ghana: Current trends, causes and interventions,” *Ulisa: Journal of international studies*, vol. 4, no. 1, pp. 75–87, 2020, Accessed: Jan. 19, 2024. [Online]. Available: https://pdf.usaid.gov/pdf_docs/PNACR829.pdf
[204] E. Awotwe, P. A. Sam, and D. A. G. Tackie, “Higher education financing in Ghana: A review of gaps in Practice,” *IOSR Journal of Humanities and Social Science*, vol. 25, no. 10, pp. 57–65, 2020.
[205] L. de Bruine, “ICT implementation in primary and secondary schools in Sierra Leone. Taking a local needs perspective.,” 2021.
[206] E. Aryeetey and S. M. R. Kanbur, *The economy of Ghana sixty years after independence*. Oxford University Press, 2017.
[207] B. Bedasso, R. Nagesh, T. Le, and M. Kojo Abreh, “Feeding Ghana’s Future: Navigating Challenges for Sustainable School Feeding in Ghana,” *Center for Global Development*, Aug. 2023, Accessed: Jan. 19, 2024. [Online]. Available: https://www.cgdev.org/blog/feeding-ghanas-future-navigating-challenges-sustainable-school-feeding-ghana
[208] A. Harris and J. Goodall, “Do parents know they matter? Engaging all parents in learning,” *Educational research*, vol. 50, no. 3, pp. 277–289, 2008.
[209] A. Varghese and P. Nagaraj, “Improving the reading achievement of tribal learners through direction instruction method,” *Language in India*, vol. 13, no. 5, pp. 677–689, 2013.
[210] S. K. Dankyira and K. S. Asante, “Rich picture drawing of Ghanaian educational landscape [personal communication],” Feb. 07, 2024.
[211] S. Bell, T. Berg, and S. Morse, *Rich pictures: Encouraging resilient communities*. Routledge, 2016.
[212] K. Kotiadis and S. Robinson, “Conceptual modelling: knowledge acquisition and model abstraction,” in *2008 Winter Simulation Conference*, 2008, pp. 951–958.
[213] P. Barbrook-Johnson and A. S. Penn, *Systems Mapping: How to build and use causal models of systems*. Springer Nature, 2022.
[214] S. Bell, T. Berg, and S. Morse, “Towards an understanding of rich picture interpretation,” *Syst Pract Action Res*, vol. 32, pp. 601–614, 2019.
[215] D. Zowghi and C. Coulin, “Requirements elicitation: A survey of techniques, approaches, and tools,” *Engineering and managing software requirements*, pp. 19–46, 2005.
[216] B. Bastani, “A requirements analysis framework for open systems requirements engineering,” *ACM SIGSOFT Software Engineering Notes*, vol. 32, no. 2, pp. 1–19, 2007.
[217] C. Mauger, T. Schwartz, J.-Y. Dantan, and L. Harbouche, *Improving users satisfaction by using requirements engineering approaches in the conceptual phase of construction projects: The elicitation process*. 2010. doi: 10.1109/IEEM.2010.5674471.
[218] G. Lucassen, F. Dalpiaz, J. M. E. M. van der Werf, and S. Brinkkemper, “The use and effectiveness of user stories in practice,” in *Requirements Engineering: Foundation for Software Quality: 22nd International Working Conference, REFSQ 2016, Gothenburg, Sweden, March 14-17, 2016, Proceedings 22*, 2016, pp. 205–222.

[219] M. Cohn, *User stories applied: For agile software development*. Addison-Wesley Professional, 2004.
[220] L. J. Ball and T. C. Ormerod, “Putting ethnography to work: the case for a cognitive ethnography of design,” *Int J Hum Comput Stud*, vol. 53, no. 1, pp. 147–168, 2000.
[221] P. Loucopoulos and V. Karakostas, *System requirements engineering*. McGraw-Hill, Inc., 1995.
[222] J. A. Goguen and C. Linde, “Techniques for requirements elicitation,” in *[1993] Proceedings of the IEEE International Symposium on Requirements Engineering*, 1993, pp. 152–164.
[223] M. Sadiq and S. K. Jain, “Stakeholder identification method in goal oriented requirements elicitation process,” in *2014 ieee 5th international workshop on requirements prioritization and communication (reprico)*, 2014, pp. 25–33.
[224] M. Glinz and R. J. Wieringa, “Guest editors’ introduction: Stakeholders in requirements engineering,” *IEEE Softw*, vol. 24, no. 2, pp. 18–20, 2007.
[225] M. Antona, A. Mourouzis, G. Kartakis, and C. Stephanidis, “User requirements and usage life-cycle for digital libraries,” in *Proc. of the HCII2005 Conference (CD-ROM)*, 2005.
[226] L. Wulandari, L. Sularto, T. Yusnitasari, and D. Ikasari, “User Requirements Analysis For Digital Library Application Using Quality Function Deployment.,” in *Journal of Physics: Conference Series*, 2017, p. 12004.
[227] A. T. McCray and M. E. Gallagher, “Principles for digital library development,” *Commun ACM*, vol. 44, no. 5, pp. 48–54, 2001.
[228] H. G. Sastry and L. C. Reddy, “User interface design principles for digital libraries,” *International Journal of Web Applications*, vol. 1, no. 2, pp. 86–91, 2009.
[229] J. ISO and others, “ISO 9000: 2015 Quality management systems—Fundamentals and vocabulary,” *2.2 Fundamental Concepts*. International Standards Organisation Geneva, 2015.
[230] S. R. G. Jones, “Was there a Hawthorne effect?,” *American Journal of sociology*, vol. 98, no. 3, pp. 451–468, 1992.
[231] K. Kuguba, “EduSector Digital Maturity Index [soon published],” 2024.

10 Appendices

A. Literature search protocol

Steps		Description
Search terms	Design process	*"Design Science Research" AND ("Software Engineering" AND "Evidence") AND ("Design Principle" OR Requirement OR "User Story" OR "Validation" OR "Prioritization") AND ("Structure" OR "Framework") AND "User-centric design"*
	Digital development in education in West Africa	*("Learning transformation" OR "ICT adoption") AND "Developing countries" AND ("e-learning" OR "m-learning") AND "Education" AND ("West Africa" OR "ECOWAS" OR "Ghana") AND ("EDU4D" OR "ICT4D") AND "Digital divide" AND ("Engagement" OR "Motivation")*
	Digital library design	*"Digital library" AND "E-learning" AND "Innovative technologies" AND "Usability" AND "Knowledge Building" AND "e-learning" AND "Education" AND "ICT" AND "Cloud" AND "Information system" AND ("DLMS" OR "CMS" OR "UMS" OR "WFMS") AND "User Experience" AND "Information retrieval" AND "Content quality"*
	Case study research	*"Case study" AND "Community Needs Assessment" AND ("Qualitative Research" OR "Quantitative Research") AND "KPIs" AND "Interviews" AND "Data analysis" AND "Community Engagement"*
	West African context	*("West Africa" OR "Ghana") AND "poverty" AND "ICT4D" AND ("Challenge" OR "Opportunity") AND ("Knowledge gap" OR "Knowledge") AND ("Community needs" OR "Cultural adaptation") AND "policies" AND "Socio-economic factors" AND ("HRBA framework" OR "Availability" OR "Accessibility" OR "Acceptability" OR "Adaptability") AND ("Language diversity" OR "Community Engagement" OR "Infrastructure" OR "Equipment") AND ("Rural" OR "Urban OR "rural-urban divide")*
Search strategy		Forward snowballing, backward snowballing
Databases		Google Scholar
Inclusion criteria		- Research within scope of research - Main focus on ICT4D and EDU4D - Language: English or Dutch - Scientific publication
Exclusion criteria		- Research is a duplicate of another results - Research in another language than English or Dutch - Research is not available through UU Library Access - An older version of original research - Papers not available for download
Selection approach		Basic search, create additional search terms, read titles and abstracts, define inclusion and exclusion criteria

Table A. 1: Literature search protocol.

B. Interviews

The protocol can be found in the following Yoda folder: /research-overb102-msc-ispm-tan/Interviews/Interview_protocollen

The recordings can be found in Yoda folder: /research-overb102-msc-ispm-tan/…_Interviews/Recordings

The transcriptions can be found in Yoda folder: /research-overb102-msc-ispm-tan/…_Interviews/Transcriptions

B.1 Expert interviews

Ref.nr.	*Name*	*Role*	*Expertise*
EI.1	S. K. Dankyira	CEO Maxim Nyansa Ghana, ICT teacher	Digital educational libraries, Ghana educational landscape, Digitization in education, EDU4D
EI.2	K. S. Asante	Digital librarian	Digital educational libraries, Ghana education system
EI.3	Daniella E. Darlington	CEO of Copianto AI	Artificial Intelligence (AI), innovative technologies (in education)
EI.4	A. Rosa-Castillo	Data scientist, AI Engineer, PhD Computer Science, teacher	DeepLearning, data-driven machine learning models, tech community needs, optimization of AI models, ML developer
EI.5	Chief Sadik	Chief of Gambibgo	Community needs
EI.6	Head teacher 1	School director Gambibgo JHS	Childrens' needs, educational system, initiatives
EI.7	Head teacher 2	School director Asofan cluster	Childrens' needs, educational system, initiatives
EI.8	Head teacher 3	School director Adanwomase	Childrens' needs, educational system, initiatives
EI.9	Student	9 Students Gambibgo	Experiences and feelings with the educational system
EI.10	Student	9 students Asofan	Experiences and feelings with the educational system
EI.11	Student	4 students Adanwomase	Experiences and feelings with the educational system

Table B.1: Expert interviews overview including links.

Ref.nr.	*IEEE reference*
EI.1.2	[1] S. K. Dankyira and K. S. Asante, "Rich picture drawing of Ghanaian educational landscape [personal communication]," Feb. 07, 2024.
EI.1	[2] S. K. Dankyira, "Educational landscape and digitization, interactive learning [personal communication]," Jan. 15, 2024.
EI.1.2	[1] S. K. Dankyira and K. S. Asante, "Rich picture drawing of Ghanaian educational landscape [personal communication]," Feb. 07, 2024.
EI.2	[2] K. S. Asante, "Validation of design principles for digital educational libraries in a West African context [personal communication]," Feb. 26, 2024.
EI.3	[3] D. Darlington, "Innovative technologies and the potential of AI [personal communication]," Feb. 06, 2024.
EI.4	[4] A. Rosa-Castillo, "AI and ML engineering, developer perspective of potential innovative technologies, and future of digital libraries [personal communication]," Feb. 15, 2024.

EI.4.2	[5] A. Rosa-Castillo, "Validation of design principles for digital educational libraries in a West African context [personal communication]," Feb. 25, 2024.
EI.5	[5] Chief Gambibgo, "Community needs in rural areas in Ghana [personal communication]," Okt. 13, 2023.
EI.6	[6] Headteacher1, "The needs of children and the schools' perspective [personal communication]" Okt. 12, 2023.
EI.7	[7] Headteacher2, "The needs of children and the schools' perspective [personal communication]" Nov. 06, 2023
EI.8	[8] Headteacher3, "The needs of children and the schools' perspective [personal communication]" Okt. 20, 2023.
EI.9	[9] Studentsgambibgo, "The students' needs and perspective [personal communication]" Okt. 12, 2023.
EI.10	[10] Studentsasofan, "The students' needs and perspective [personal communication]" Nov. 06, 2023.
EI.11	[11] Studentsadanwomase, "The students' needs and perspective [personal communication]" Okt. 20, 2023.

Figure B.2: Reference per expert.

B.2 User interviews

STAKEHOLDER INTERVIEWS	Case A	Case B	Case C
Teacher interviews	15	18	18
Student interviews	17	15	16

Table B.2: User interviews.

B.3 Researcher interviews

Ref.	*Name*	*Expertise*	*Papers*
RI.1	S.K. Dankyira	Digitization in education, EDU4D, interactive learning, ICT teaching	[73]
RI.2	K. Kuguba	Ghana education system, Digitization of education, EDU4D, interactive learning, ICT teaching	[73], [231]
RI.3	M. Smulders	EDU4D, ICT4D, Impact Assessment Method	[59]
RI.4	T. Le	EDU4D, ICT4D, Impact Assessment tool	[102]
RI.5	Rotary International	Community Needs Assessment tools and tailoring to the local context	[76]

Table 16: Researcher interviews overview, including papers and links.

Ref.nr.	*IEEE reference*
RI.1	[1] K. S. Dankyira, "Validation of design principles for digital educational libraries in a West African context [personal communication]," Feb. 26, 2024.
RI.2	[2] K. Kubuga, "Education and potential innovative technologies, interactive learning [personal communication]," Oct. 28, 2023.
RI.2.2	[3] K. Kubuga, "Validation of design principles for digital educational libraries in a West African context [personal communication]," March, 18, 2024.
RI.3	[4] M. Smulders, "EDU4D and his situational impact assessment method [personal communication]," Jan. 10, 2024.
RI.4	[5] T. Le, "EDU4D and her tool for supporting impact assessments [personal communication]," Jan. 09, 2024.
RI.5	[6] Rotary International, "Community Needs Assessment tools and tailoring to the local Ghanaian context [personal communication]," Oct. 18, 2023.

Figure B.3: Reference per researcher.

C. Stakeholders - Requirements Engineering

EDUsystem stakeholders

- **National government representative**

This stakeholder represents the government body, mainly the GES, responsible for managing education at the national level, such as policies, resource allocation, and support.

- **Chiefs**

Chiefs refer to the traditional leaders within local communities in most of the West African countries. The involvement of a chief may be beneficial for community support and educational resources. Chiefs are responsible for decision-making in a district. Chiefs are especially important in rural areas, in urban areas this individual is called the Chief Executive.

- **Elders of the community**

Elders refer to important, respected and experienced individuals within West African communities. They can serve as advisors and understand the needs of their local community.

- **Educational head (or School Director)**

Refers to the individual responsible of leading and managing a school. The school may be utilized to implement the local digital library for utilization by students and community members. The Educational Head is responsible for the school, the teachers, and the students. The teachers and students are users of the digital educational library and therefore categorized under "*User stakeholders*"

- **Parents**

Parents are important stakeholders as they play an important role in the education of their children, both financially as practically, as summarized in Sub-section 5.3.1.6.

User stakeholders

- **Teachers**

Teachers are the end-users of the digital educational library and are essential for the implementation and facilitation of learning to its students by providing the appropriate content. The feedback of teachers are important for the success of the library projects. Teachers, in the role of community members, may also be end-users of the library.

- **Students**

Students are the primary end-users and benefit the most from the implementation of a digital educational library. They utilize the library for learning and access to educational resources.

- **Community members**

Community members are important in providing online education through the Community Engagement. Community Engagement ensures the facilitation of online education through financial and practical support, for example: gathering equipment, such as computers or mobile phones.

The goal is to also allow community members to have access to the digital educational library. A community member is an individual living within a community. In rural areas, community members are mostly working in the agriculture and these people also deserve additional education for their tasks, for example: which crops are the best to grow in January? These users may need additional requirements, as these individuals are mostly older people and communicating through their local language.

Content administration stakeholders

- **Digital librarian**

A digital librarian is an information professional responsible for managing and publishing digital resources to support education, research, and community development. In the publishing process, the digital librarian evaluates the newly submitted content on copyright compliance and subsequently is responsible for the publishing. Their role involves organizing digital courses and resources, ensuring access to the digital library, and develop digital literacy skills within the communities.

The digital librarian is also responsible for assuring that the digital library is tailored to the needs of users and implemented with the most recent technologies. In summary, the digital librarian has the most important role within the digital library.

- **Experts**

An expert is a qualified individual with advanced knowledge, skills, and experience in a certain area. The expertise of the individual is necessary to evaluate the newly submitted resources, i.e. the expert review. The expert review is an important process for publishing content within the digital library platform.

- **Author**

The author is the creator of the content, including the submission of new resources and ensuring that their published content remains up-to-date.

D. Requirements Engineering through User Stories

Stakeholder	*US*	*User stories - description*
Teacher	US1	As a teacher, I want to quickly and effectively search for educational resources relevant to my given courses, so that I can enhance the quality of my course and relevant resources.
	US2	As a teacher, I want access to various high-quality educational resources (e.g., videos, PDFs, interactive material), so that I can enhance my teaching and courses.
	US3	As a teacher, I want to receive resource recommendations for my courses, so that the content is tailored to student needs.
	US4	As a teacher, I want to provide direct feedback to my students, so that they can understand their strengths and potential improvements.
	US5	As a teacher, I want access to professional and technical training resources, so that I can enhance my teaching skills and digital literacy.
	US6	As a teacher, I want to assess my students, so that I can evaluate students' understanding of the learning concepts.
	US7	As a teacher. I want to have access to digital libraries in addition to physical resources and other educational systems, so I that can provide a broad learning experience for my students.
User	US8	As a user, I want fast and accurate search functionality, so that I can find resources easily and effectively.
	US9	As a user, I want offline access by downloading relevant resources, so that I can continue learning without internet.
	US10	As a user, I want to have personalized recommendations based on my previous enrolled courses, so that I can explore relevant courses.
	US11	As a user, I want to receive technical training, so that I can enhance my digital literacy.
	US12	As a user, I want the platform to load quickly and perform smoothly, so that I can have access to resources without interruptions.
	US13	As a user, I want to have strong security measures, so that my data is protected.
	US14	As a user, I want a system that is easy to navigate, so that I can quickly search for the information I need for my studies. (usability)
	US15	As a user, I want a responsive and accessible platform on different devices, such as mobile phones, tablets, computers, so that I can access it anytime, anywhere. (usability) – cross-platform compatibility
	US16	As a user, I need mobile phone compatibility, so that I can use my mobile phone for access to education.
	US17	As a user, I want to receive clear and informative error messages, so that I can understand what went wrong and how I can solve the issue.
Students	US18	As a student, I want access to a variety of learning resources in multiple formats (text, audio, video), so that I can learn through diverse learning styles.
	US19	As a student, I want to be able to download educational materials for offline access, so that I can access the resources in areas with limited internet connectivity.
	US20	As a student, I want interactive content, so that I can test my understanding of the material and track my progress in the course.
	US21	As a student, I want to receive personalized course recommendations based on my interests and academic needs, so that I can enhance my knowledge.

	US22	As a student, I want to receive feedback and guidance from teachers, so that I can learn more effectively.
	US23	As a student, I want a user-friendly system that is intuitive, so that it is simple to search for my information. (usability)
	US24	As a student, I want to provide feedback to teachers and courses, so that I can contribute to the enhancement of both. (usability)
	US25	As a student, I want to enrol and participate in courses, so that I can enhance my knowledge
	US26	As a student with disabilities, I want to have accessible formats such as audio, so that I can fully participate in my education.
	US27	As a student, I want to follow the courses in my local West African language, so that I can better understand the presented learning concepts
	US28	As a student, I need financial and practical support from my family and community, such as equipment, so that I can participate in e-learning.
	US29	As a student, I want to collaborate with my peers, so that we can use each other's strengths and share knowledge.
CM	US30	As a community member, I want access to educational resources, so that I can enhance my knowledge and skill development.
	US31	As a community member, I want to access resources that promote entrepreneurship, vocational training, and preparation for the job market, so that I have more job opportunities in the future.
	US32	As a community member, I want to access resources on health, agriculture, and other practical skills, so that I can enhance my quality of life.
	US33	As a community member, I want to have access with local languages, so that we can engage a wider audience.
DL	US34	As a digital librarian, I want a multilingual interface, so that I can provide access to users who speak different local languages.
	US35	As a digital librarian, I want to provide relevant resources and subjects related to the users' needs, so that we can effectively engage students.
	US36	As a digital librarian, I want to provide digital literacy training, so that users know how to utilize the library effectively and can maximize their knowledge building.
	US37	As a digital librarian, I want to comply with copyright regulations, so that we are not interfering intellectual property rights. (open access, ethical)
	US38	As a digital librarian, I want to leverage mobile technologies by developing mobile-friendly interfaces, so that we can benefit from the significant rise in West African smartphone subscriptions.
	US39	As a digital librarian, I want to collaborate with local educators and community leaders, so that I can identify resources addressing specific educational challenges and opportunities in West Africa.
	US40	As a digital librarian, I want the system to function smoothly with low bandwidth internet connectivity, so that students in these areas can also participate in learning through the digital library while remaining usable.
	US41	As a digital librarian, I want to assess the impact of the digital library on educational outcomes and community development, so that I can continuously enhance the library.
	US42	As a digital librarian, I want to integrate emerging technologies, so that we can continuously enhance the digital library's functionality and user experience.
	US43	As a digital librarian, I want to provide access for all individuals in West Africa to educational resources, so that we can enhance knowledge for all individuals without discrimination (performance, scalability)

	US44	As a digital librarian, I want experts to evaluate new resources, so that the digital library meets a high quality standard.
	US45	As a digital librarian, I want to provide resources related to the curriculum, so that students learn the relevant information.
	US46	As a digital librarian in West Africa, I want to bridge the digital divide in African countries, so that the knowledge gap between African countries and countries outside of Africa becomes smaller.
Experts	US47	As an expert reviewer, I want to easily access the resource submission platform, so that I can efficiently review new materials.
	US48	As an expert reviewer, I want to have clear criteria, so that I can effectively evaluate the quality and relevance of educational materials.
	US49	As an expert reviewer, I want to provide constructive feedback to content creators, so that they can enhance their content.
	US50	As an expert reviewer, I want to collaborate with other reviewers, so that I can ensure consistency and fairness in the review process.
	US51	As an expert reviewer, I want to ensure that resources are high-quality, so that users can maximize their knowledge building.
Authors	US52	As an author, I want to easily upload my educational resources to the digital library platform, so that I can efficiently share my knowledge and contribute to the library's content.
	US53	As an author, I want to hold ownership over my submitted materials, so that I have control over how my content is used and distributed.
	US54	As an author, I want to update and enhance my resources, so that I can keep them up-to-date.
	US55	As an author, I want to receive feedback on my submitted resources, so that I can enhance the quality and relevance.

Table D.1: Requirements Elicitation per stakeholder through User Stories.

E. Requirements Elicitation

RQ	*US*	*Name*	*Definition*
R1	US1,8	Effective and fast search and retrieval	Users can effectively and quickly search for and retrieve educational resources relevant to their needs.
R2	US2,18,30,51	Diverse and high-quality resources	Provide users with access to a diverse range of educational resources in multiple formats (text, audio, video) of high quality to enhance knowledge building and facilitate diverse learning styles, while ensuring that the content meets quality standards.
R3	US3,10,21,35	Personalized recommendation	Provide user recommendations for resources and courses, based on personal needs and past interactions with the platform. It enhances user engagement and satisfaction.
R4	US4,22	Feedback mechanism	Ensure educators to provide direct feedback to their students to enhance their learning experience.
R5	US5,11,36	Digital literacy training	Users in developing countries often lack the foundation for the necessary digital skills to fully utilize all aspects of the digital library. Therefore, it is essential for users and educators to receive training and enhance their digital skills, which will be valuable for their future and learning.
R6	US6	Student assessment	Provide tools for educators and students to assess the students' understanding of the course concepts.
R7	US7	Integrate into educational systems and institutions	Ensure that digital libraries/resources are integrated into current educational systems, software (such as a Learning Management System), and institutions to enhance enhancing the learning experience by providing access to information and support to physical education.
R8	US9,19	Offline access through downloadable content	Enable users to download content for offline access, so that they can continue their learning process in an area without internet.
R9	US12	High Platform performance	Optimize platform performance to ensure fast loading times, reliability, and responsive interfaces.
R10	US13	Strong security measures	Implement strong security measures to protect user data and ensure privacy for users.
R11	US14	Easy navigation	Ensure that the system is easy to navigate, so that users can easily find the appropriate information.
R12	US15	Cross-Platform compatibility	Provide compatibility with various devices, such as computers, laptops, and mobile phones, to ensure that users have good accessibility to the platform on all devices. It ensures accessibility from anywhere, anytime.
R12+	US16,38	Mobile phone (low-end devices) support	In the past years, smartphone subscriptions in West Africa has been significantly rising, with 68% of the population having access to smartphones (compared to 6..3% for computers and 0.7% for tablets). The smartphones in West Africa are mostly low-end devices. Therefore, it is essential that the digital library works seamlessly on these devices, optimized

			for mobile phone formats and specifications (Sub-section 4.4).
R13	US17	Error Handling	Ensure that the system provides clear and concise error messages to the user when something goes wrong and how the user can solve it.
R14	US20	Interactive learning	Involve interactive learning into the digital library to enhance student engagement, e.g., through Gamification (Sub-section 4.7.5.3).
R15	US23	User-friendly	Design with a user-centric approach to make it easy to use, navigate, and understand for all users with different digital skill levels. As digital skill levels are mostly low in West Africa, it is essential to ensure a user-friendly interface for everyone.
R16	US24	User review	Allow users to leave reviews for teachers and courses, so that the quality of the learning experience can be enhanced.
R17	US25	Student enrolment	Enable students to enrol in courses and access educational materials.
R18	US26	Inclusive design	Provide accessibility for everyone, including users with all abilities and disabilities, such as audio support or alternative text.
R19	US27,33,34	Multilingual support	English literacy levels for young students and older people in West Africa are sometimes lacking, therefore concepts can be better understood through their local language. By providing multiple languages in the platform, it can reach a broader audience (especially in rural areas).
R20	US28	Community Engagement	Community Engagement is essential for the educational development of children, as they provide financial and practical support. The resources and infrastructure is essential for local students to have access to the digital library (Sub-section 5.3.1.6).
R21	US29,50	Collaboration	Facilitate collaboration between users and their peers, and between experts, so that they can share knowledge and ideas.
R22	US31	Vocational and entrepreneurial skills	Help users to acquire practical skills and knowledge for their future career and entrepreneurship.
R23	US32	Life-enhancing skills	Provide resources for community members that can enhance the quality of life, including health, financial, agriculture, and life skills. Agriculture is important, as farming is the most prevalent job in most local communities.
R24	US37,53	Copyright compliance	Ensure that the educational resources comply to copyright regulations to prevent unauthorized use. OER can be a good solution to this issue (Sub-section 4.7.5.6).
R25	US39	Local collaboration	Ensure collaboration with local educators, institutions, and the community, to ensure that local expertise is utilized to enhance the platform.

R26	US40	Performance with low-bandwidth internet connectivity	Ensure optimal platform performance in areas with low-bandwidth internet connectivity to ensure that individuals in these areas can fully participate in education.
R27	US41	Impact assessment	Assess the platform's impact on educational outcomes and community development. Smulders [59] developed such an impact assessment.
R28	US42	Integration of innovative technologies	Integrate emerging technologies into the platform to enhance its functionality and user experience, ensuring it remains up-to-date and delivers its maximum performance.
R29	US43	Scalable access for all individuals	Ensure that the platform and its resources is accessible for all users without discrimination, including location, background, or (digital) literacy skill level.
R30	US44	Expert review mechanism	Ensure an easy and clear expert review process to assess the quality of newly submitted resources.
R31	US45	Curriculum adherence	The educational resources in the digital library have to be relevant to the existing curriculum, which includes textbooks, assessments, etc..
R32	US46	Bridge the digital divide	The digital divide between African countries and other countries outside of Africa is significant, e.g. because of the limited digital literacy and limited ICT infrastructure. By bridging the digital divide, we can make the knowledge gap smaller. Knowledge is inherent to development, so by bridging the digital divide, African countries can develop on educational, technical, economical, and social aspect.
R33	US47,52	User-friendly process for new resources	Provide a user-friendly process for authors to easily upload their educational resources, ensuring an easy process without barriers for new publications.
R34	US48	Expert evaluation standards	Provide clear criteria for expert reviewers to effectively asses the quality and relevance of newly submitted educational resources.
R35	US49,55	Expert feedback	Enable expert reviews to provide constructive feedback to the content creators to enhance the quality of the newly submitted resource.
R36	US54	Resource update	Allow authors to update and enhance their resources over time to ensure the future relevance.

Table E.1: Requirements Elicitation – definition.

F. Requirements vs sources

***Sources* / RQ**	*Uintv*	*Eintv*	*Rintv*	*DA*	*Ispec*	*GWB*	*Obs*	[165]	[169]	[225]	[226]
R1	X				X			X	X	X	X
R2		X		X	X			X	X	X	
R3		X	X						X	X	X
R4	X				X		X		X		X
R5	X	X			X	X	X	X			
R6	X	X			X	X	X				
R7		X		X		X	X	X			X
R8	X	X	X		X	X	X	X	X	X	X
R9				X	X			X		X	X
R10	X	X		X	X		X			X	X
R11	X	X			X		X	X	X	X	
R12		X			X	X	X	X			X
R12+		X			X	X	X	X			X
R13					X					X	
R14		X			X		X				X
R15	X	X		X	X	X	X	X	X	X	
R16					X				X		X
R17	X	X		X	X	X	X				
R18					X					X	X
R19	X	X			X	X	X		X	X	
R20	X	X	X	X	X	X	X	X			
R21	X	X		X	X		X		X	X	X
R22		X		X	X		X	X			
R23	X	X		X	X	X	X	X			
R24				X				X			
R25	X	X	X	X	X		X				X
R26	X	X		X	X	X	X	X		X	X
R27		X	X	X	X		X				
R28		X		X	X		X	X	X	X	
R29	X	X		X	X	X	X	X			X
R30		X		X	X				X		
R31	X	X		X	X		X	X			
R32		X		X	X	X	X	X			X
R33		X		X	X				X	X	
R34				X	X			X			
R35		X		X	X						
R36		X		X				X	X	X	X

Table F.1: Requirements and their corresponding sources.

G. Requirement vs Dimension

Dimension/ RQ	*Acceptability*	*Availability*	*Accessibility*	*Adaptability*	*Usability*	*Knowledge Building*
R1			X		X	
R2	X	X			X	X
R3				X		
R4	X				X	X
R5			X			X
R6			X			X
R7		X	X			
R8		X	X		X	
R9		X			X	
R10	X				X	
R11			X		X	
R12			X		X	
R12+			X		X	
R13	X	X	X	X	X	
R14				X		X
R15			X		X	
R16	X				X	X
R17			X		X	
R18	X		X			
R19	X		X		X	
R20	X	X	X	X	X	X
R21					X	X
R22	X		X			X
R23	X		X			X
R24	X	X				
R25				X		X
R26		X	X		X	
R27	X					X
R28	X				X	X
R29				X	X	X
R30	X					X
R31	X		X		X	X
R32		X	X		X	X
R33			X		X	
R34					X	X
R35						X
R36				X		X

Table G.1: Requirements vs Dimension.

H. Design principles

H.1 Design principle elicitation through the structure of Gregor et al. [88].

	Definition through the structure of Gregor et al. [88].
DP1	For platform developers and designers (Implementer I) to ensure the platform is accessible to all users, regardless of abilities, gender, digital literacy, socio-economic status, or background (Aim A) for individuals who interact with the platform (User U) in taking into account the diverse user backgrounds and needs of users during the design process (Context C), they should employ various features such as text-to-speech, keyboard navigation, and adjustable font sizes to ensure accessibility for users with varying levels of digital literacy (Mechanisms M), involving users who cannot use the platform without these features (Enactors E), because of enhancing usability and ensuring universal access to educational resources (Rationale R).
DP2	For platform developers and designers (Implementer I) to develop a platform that aligns with users' needs and desired functionalities (Aim A) for individuals who utilize the platform (User U) in understanding user needs and desires (Context C), they should employ conducting user research, analysing performance and user experience, and iterative feedback (Mechanisms M), involving users who provide feedback and interact with the platform (Enactors E), because of enhancing user satisfaction and engagement by prioritizing the needs of users (Rationale R).
DP3	For platform developers and designers (Implementer I) to ensure optimal platform performance in all contexts, including areas with low-bandwidth internet connectivity (Aim A) for individuals accessing the platform (User U) in areas with varying internet connectivity and different capability levels of devices (Context C), they should employ optimizing loading times, reliability, error handling, and responsive interfaces (Mechanisms M), involving users who need platform performance to access the platform (Enactors E), because of ensuring a seamless user experience and universal access to resources in different contexts (Rationale R).
DP4	For platform developers, the digital librarian, and content creators with regards to content selection and publishing (Implementer I) to ensure high-quality and relevant educational resources on the platform (Aim A) for individuals accessing the platform (User U) in alignment with curriculum guidelines and user needs (Context C), they should employ expert review mechanisms, user feedback mechanisms, and ensuring compliance with copyright regulations (Mechanisms M), involving content authors, expert reviewers, users, and digital librarians (Enactors E), because of enhancing learning outcomes and user satisfaction by providing high-quality and relevant content (Rationale R).
DP5	For platform developers and designers (Implementer I) to ensure compatibility with various devices and platforms for seamless access to the library (Aim A) for individuals accessing the platform from different devices (User U) in taking into account diverse capabilities of devices and technologies (Context C), they should employ to prioritize compatibility with smartphones, tailoring interfaces to different screen sizes, and ensuring a functioning platform on different devices (Mechanisms M), involving users accessing the platform from different devices (Enactors E), because of providing access to educational resources for users with diverse technological capabilities (Rationale R).
DP6	For platform developers and designers (Implementer I) to enable offline access to educational resources for users in areas with limited internet connectivity (Aim A) for individuals accessing the platform without a reliable internet connection (User U) in areas with limited internet access and connectivity (Context C), they should employ features to download content for offline use and updates whenever an internet connection is available (Mechanisms M), involving users accessing the platform offline

	(Enactors E), because of facilitating access to educational resources in areas with limited connectivity, ensuring continuous learning opportunities (Rationale R).
DP7	For platform developers and designers (Implementer I) to ensure data security and privacy protection for users of the platform (Aim A) for individuals providing personal information and accessing platform resources (User U) in compliance with data protection regulations and protecting user information (Context C), they should employ data protection measures for sensitive data and data protection regulations such as encryption (Mechanisms M), involving platform administrators and users interacting with personal data (Enactors E), because of ensuring a trustable environment for users and protecting sensitive data from unauthorized users (Rationale R).
DP8	For users, platform administrators, and external organizations providing the training (Implementer I) to provide comprehensive digital literacy training to enhance the digital skills of users and ensure effective utilization of the platform (Aim A) for individuals with varying levels of digital literacy (User U) in addressing the knowledge gap and digital divide in underdeveloped areas (Context C), they should employ the provision of tutorials and interactive learning resources, and tailored training programs to varying skill levels either through the platform or in person (Mechanisms M), involving users participating in digital literacy training programs (Enactors E), because of providing the essential skills and tools to enhance the users' ability to effectively engage in the platform's content (Rationale R).
DP9	For platform developers and designers (Implementer I) to facilitate access to educational content in local languages to enhance understanding and engagement (Aim A) for individuals accessing educational content in their native language (User U) in areas with different languages and the importance of language in learning (Context C), they should employ providing support for native languages in Africa, and ensuring accessibility of content in multiple languages (Mechanisms M), involving users utilizing the platform in their preferred language (Enactors E), because of enhancing inclusivity and understanding for users by providing content in their native languages (Rationale R).
DP10	For platform developers, designers, and administrators (Implementer I) to ensure continuous review, feedback, and updating of resources to ensure relevance and effectiveness (Aim A) for individuals benefiting from updated and relevant educational resources (User U) in the changing content requirements and user needs (Context C), they should employ actively stakeholder feedback mechanisms, regularly reviewing and updating content, stay up-to-date with innovative educational technologies (Mechanisms M), involving platform administrators and users who provide feedback and engage with the content (Enactors E), because of ensuring the platform's ability to tailor and remain relevant to the changing educational landscape and user needs (Rationale R).
DP11	For platform developers and designers (Implementer I) to ensure personalized recommendations for resources and courses based on the needs and interactions of users (Aim A) for individuals utilizing the digital library (User U) in the context of diverse learning goals and desires (Context C), they should employ AI-driven recommendation algorithms and data analysis mechanisms (Mechanisms M), involving users benefiting from personalized recommendations (Enactors E), because of delivering relevant and tailored content to enhance users' engagement, motivation, and learning outcomes (Rationale R).
LDP1	For local educators, users and community leaders (Implementer I) to ensure users possess basic reading, writing, and literacy skills necessary to engage with digital library content (Aim A) for students and community members accessing educational resources (User U) in the educational landscape of West Africa (Context C), they should employ literacy programs and support to enhance basic skills, providing accessible resources for literacy development (Mechanisms M), involving educators, community leaders,

	and literacy program participants (Enactors E), because of the fundamental need of literacy to effectively utilize and understand the platform and its educational content (Rationale R).
LDP2	For local institutions and community stakeholders (Implementer I) to ensure the availability of physical and technological infrastructure to support the implementation of digital educational libraries (Aim A) for students, educators, and community members utilizing digital library resources (User U) in knowing the importance of infrastructure in supporting technology-integrated education (Context C), they should employ building ICT labs or community libraries, provide the necessary hardware and software, and ensure internet connectivity (Mechanisms M), involving school administrators, community leaders, and ICT personnel (Enactors E), because of ensuring the provision of the necessary resources and equipment for the successful implementation and functioning of digital libraries in the local context (Rationale R).
LDP3	For local educators, leaders, and experts (Implementer I) to enhance continuous evaluation and improvement of local digital libraries to maintain relevance and acceptance of its content (Aim A) for students, educators, and community members utilizing benefiting from enhanced services (User U) in the knowledge of diverse and changing needs of local communities (Context C), they should employ engaging local stakeholders in this process, tailoring content to local contexts, piloting new library designs in various environments (Mechanisms M), involving local community members during the evaluation and improvement process (Enactors E), because of supporting the tailoring of the digital library to the specific needs and desires of local communities and enhance their acceptance and effectivity (Rationale R).
LDP4	For local educators, experts, and community members (Implementer I) to ensure digital library content is relevant to their culture and tailored to the needs of the local community (Aim A) for students and community members utilizing culturally relevant educational resources (User U) in the importance of ensuring the local heritage and traditions within educational content (Context C), they should employ involving local institutions and experts in content creation and publish culturally relevant content (Mechanisms M), involving local content creators, educators, and experts within the local community (Enactors E), because of ensuring that cultural heritage is preserved and the engagement of educational content within the local community (Rationale R).
LDP5	For community leaders, educators, and stakeholders (Implementer I) to enhance community support and engagement to facilitate the necessary infrastructure for the successful implementation of technological initiatives (Aim A) for students, educators, and community members utilizing the infrastructure for technology-integrated (User U) in knowing the importance of community engagement in education and infrastructure development (Context C), they should employ the provision financial and practical support and conducting community needs assessments (Mechanisms M), involving community members by actively participating in the initiatives, providing support, and assessments (Enactors E), because of ensuring the sustainability and effectiveness of digital library systems within local communities (Rationale R).

Table I.1: Design principle elicitation through the framework of Gregor et al. [88]**.**

H.2 Design principles Validation and relation with main research goals.

			Literature Validation			*Expert validation*			
	Usability	Knowledge building	[159]	[227]	[228]	[RI.1]	[RI.2.2]	[EI.2]	[EI.4.2]
DP1		X	X	X	X			X	X
DP2	X	X	X	X		X		X	
DP3	X	X		X		X	X	X	X
DP4	X	X	X	X		X	X	X	
DP5	X	X		X				X	X
DP6	X	X		X		X		X	
DP7	X		X	X		X			
DP8	X	X					X		
DP9	X	X						X	X
DP10	X	X	X	X		X	X	X	X
DP11	X	X							
LDP1	X	X					X		X
LDP2	X					X		X	X
LDP3	X		X	X		X	X		
LDP4	X	X		X			X		
LDP5	X	X				X	X		

Table H.2: Design principle validation, including the relation with the main research goals.

I. UML Class Diagram

I.1 Classes

The main classes in digital educational libraries are the following:

Classes	**Meaning**
Library database	Represents a structured collection of content for the digital library.
User	Represents individuals interacting with the system, including staff, students, instructors, and experts.
Instructor	Represents an educator who is responsible for teaching and guiding students in various courses and curricula.
Student	Represents the individuals enrolled in courses.
Staff	Represents staff or employees working for the digital library having a specific role, which can be a course manager or a curriculum manager.
CourseManager	Represents a staff member responsible for the course content.
CurriculumManager	Represents a staff member responsible for the curriculum/subject content.
Expert	Represents a qualified individual with advanced knowledge, skills, and experience in a certain area.
ExpertReview	Represents the quality check of the content by experts.
Account	Represents a personalized page where individuals can access and interact with different system components (e.g., their enrolled courses).
Librarian	Represents an individual who manages the key components of the library, such as: courses, curricula, resources, and users.
Course	Represents an organized collection of educational resources available through the digital library to reach specific learning goals.
Curriculum	Represents a specific study topic or field to organize associated educational courses and resources.
Community	Represents a group of users having access to specific curricula or courses without a subscription (e.g. children from the Asofan school enrolled in maths).
Review	Represents a review written by a student for a specific course or instructor.
Resource	Represents educational materials such as textbooks, videos, audio, images, or interactive content.
Author	Represents the creator of the resource.

Table I.1: The classes of the digital library's UML class diagram.

I.2 Attributes & methods

The UML class diagram of digital educational libraries, visible in Figure .., contains various attributes and methods of each class. In the following table, we will provide an overview of the attributes and methods of the UML class diagram:

Class	***Visibility***	***Attribute***	***Visibility***	***Method***
Library database (2)	- + + +	DatabaseID CourseID(n) CurriculumID(n) ResourceID(n)	+ + + + + +	AddResource() RemoveResource() AddCourse() RemoveCourse() AddCurriculum() RemoveCurriculum()
User (3)	+ - - -	UserID Username Password Role	+ + + + + + + + +	Login() Register() Logout() SearchCourse() SearchCurriculum() ViewResource() EnrollCourse() ViewAccount() ChangeSubscription()
Instructor (4)	+ + - - + - + -	InstructorID UserID Name Expertise CourseID(n) Rating ReviewID(n) StudentsEnrolled	+ + + + + +	CreateCourse() UpdateCourse() ViewResource() ViewStudents() AddResource() RemoveResource() GiveFeedback()
Student (5)	+ + - - + +	StudentID UserID Username Password CourseID(n) CurriculumID(n)	+ + + + + +	ViewAccount() ViewMyCourses() ReviewCourse() ReviewInstructor() ReceiveFeedback() ViewResource() SubmitAssessment()
Staff (6)	- + - -	StaffID UserID(n) Name Role	+ + + + +	AssignCourseToCurr() RemoveCourse() AddCurriculum() RemoveCurriculum() ViewCurriculum()
CourseManager (7)	- +	CoMID CourseID(n)	+ + +	AddCourse() RemoveCourse() ViewCourses()
CurriculumManager (8)	- + +	CMID CourseID(n) CurriculumID(n)	+ + + + +	AddCurriculum() RemoveCurriculum() AssignCourseToCurr() RemoveCourseFromCurr() ViewCurriculum()
Expert (9)	+ +	ExpertID UserID(n)	+ +	CreateExpReview(), CheckResource()

	+	ResourceID(n)		
	+	ExpReviewID(n)		
ExpertReview (10)	+	ExpReviewID	+	ViewReview()
	+	ExpertID(n)		
	+	ResourceID		
	-	Rating		
	-	Comment		
Account (11)	+	UserID	+	ViewAccount()
	-	Username	+	ViewMyCourses()
	-	Password	+	ViewEnrollment()
	-	RegisterDate	+	ChangeSubscription()
	-	SubStatus	+	ViewCurriculum()
	+	CourseID(n)		
	+	CurriculumID(n)		
Librarian (12)	-	LibrarianID	+	AddUser()
	-	Username	+	RemoveUser()
	-	Password	+	ManageResources()
	-	Permissions	+	ManageCourses()
			+	GrantAccess()
			+	ManagePermission()
Course (13)	+	CourseID	+	EnrollStudent()
	+	InstructorID	+	ViewResource()
	-	Title	+	ViewReview()
	-	Description		
	-	Price		
	-	Duration		
	+	ResourceID(n)		
Curriculum (14)	+	CurriculumID	+	AddCourse()
	-	CurriculumName	+	RemoveCourse()
	+	CourseID(n)	+	CreateCurriculum()
			+	ViewCourses()
Community (15)	-	CommunityID	+	AddUser()
	+	UserID(n)	+	RemoveUser()
	+	CurriculumID(n)	+	AddCurriculum()
			+	RemoveCurriculum()
Review (16)	+	ReviewID	+	ViewReview()
	-	StudentID	+	CreateReview()
	+	CourseID		
	+	InstructorID		
	-	Rating		
	-	Comment		
Resource (17)	+	ResourceID	+	UploadResource()
	+	CourseID(n)	+	UpdateResource()
	+	ExpReviewID	+	RemoveResource()
	-	Type	+	ShowResource()
	-	Title	+	ContactAuthor()
	-	AuthorID(n)		
	-	Url		
Author (18)	-	AuthorID	+	CreateResource()
	+	ResourceID(n)	+	ImproveResource()

Table I.2: Digital Library UML Class Diagram - methods, attributes, and visibility.
"n" = corresponds to the specific identifier(s) of that specific class.

I.3 Methods

Each class also contains specific methods, as visible in Table 11. The following sections provide a detailed description of the methods identified in each class:

Library database
The library database is a structured collection of data related to digital library resources, such as books, images, videos, and interactive content. The library database stores and manages the available digital library content; i.e., curricula, courses, and resources.

User
The user is able to search for courses, curricula and view content in the digital library. Especially in developing countries, the usability is crucial for effective learning outcomes and course enrolment. The user is able to login, logout and register for the digital library. The last important aspect is account management, where they can view their enrolled courses and available content, and also their status of their subscription.

Instructor
The instructor manages the resources, ensuring that content of curricula and courses remain up-to-date. In addition to delivering lectures and facilitating learning, instructors are also involved in course management by creating and updating courses. The instructor can also provide direct feedback to students for their assignments or questions.

Student
A student is one of the users of the digital library. The methods of students are associated with enrolling in courses, view and create instructor and course reviews, and complete assessments for the course. Additionally, the students can receive feedback from instructors for their assignments and questions.

Staff
The staff covers the methods of all staff roles.

Course Manager
The responsibilities, and thus the methods, of the course manager range from adding and removing courses to adding resources to the courses.

Curriculum Manager
The most important methods and role of a curriculum manager is to manage curricula and also add or remove courses relevant to the curriculum.

Expert
An expert is an individual with advanced knowledge, skills, and experience in a certain area. An expert assess the resources on their content to ensure quality content in the digital library.

ExpertReview
Experts, in the field of the reviewed resource, conduct reviews to assess the quality of the resource. As elaborated in the resource class, the first step in the publication of resources is the content quality check by experts. A resource cannot be used before approval of experts in that area. The expert review class can look at the review and find out whether the resource has been approved.

Account
Users can view their enrolled courses and curricula in their account. Additionally, users can also change their subscription plan.

Librarian
The librarian is responsible for an effectively working library, thus the methods are related to managing courses, curricula and users. Additionally, the librarian can also grant permissions to users based on their roles and requirements.

Course
Students are enrolled in courses and these courses can cover a variety of curricula and resources. Methods associated with this class can be used to manage courses within the curriculum, such as adding or removing courses, and retrieving the list of courses.

Curriculum
The curriculum methods can create, remove and manage curricula in the library.

Community
The community methods are associated with getting access to specific curricula and courses without a subscription.

Review
Students can create reviews for instructors and courses. The reviews make sure that improvements can be made by the teacher. Other students can also view the rating and comments made about teachers and the courses to make a well-rounded decision on which course they want to follow.

Resource
The resource class performs operations related to resources, such as adding, removing, updating, and showing. The resources are used as content for courses to provide effective learning outcomes. The publication of resources resides in two steps; 1) Content quality check by a review of experts, and 2) Copyright and usability check by the librarian. The experts can either accept or reject the resource in their expert review. When rejected, the resource will go back to the author for improvement.

Author
An author is the content creator for the digital library. The author creates resources essential for courses. Authors can be instructors or external, and their resources require an approval through expert reviews and the librarian before publication. When rejected, the author is required to make improvements to their resource.

I.4 Attributes

Each class is characterized by specific attributes. The following sections will provide a detailed description of each attribute within every class.

Class	*Attribute*	*Description*
Library database	*DatabaseID*	Unique identifier for the library database.
	CourseID(n)	Identifier(s) for course(s) associated with the library.
	CurriculumID(n)	Identifier(s) for curriculum(s) associated with the library database.
	ResourceID(n)	Identifier(s) for resource(s) associated with the library database.
User	*UserID*	Unique identifier for the user.
	Username	The username of the user.
	Password	Password for user security and authentication.
	Role	Role of the user (e.g., expert, staff, student, instructor, librarian).
Instructor	*InstructorID*	Unique identifier for the instructor.
	UserID	Unique identifier for instructor as a user.
	Name	Name of the instructor.
	Expertise	Area of expertise.
	CourseID(n)	Identifier(s) for course(s) associated with the instructor.
	Rating	Rating associated with the instructor, retrieved from the review(s).
	ReviewID(n)	Identifier(s) for review(s) from student(s) who attended the instructor's courses.
	StudentsEnrolled	Number of students enrolled in courses taught by the instructor.
Student	*StudentID*	Unique identifier for the student.
	UserID	Unique identifier for the student as a user.
	Username	The username of the user.
	CourseID(n)	Identifier(s) for course(s) associated with the student.
	CurriculumID(n)	Identifier(s) for curriculum(s) associated with the student.
Staff	*StaffID*	Unique identifier for staff member.
	UserID(n)	Unique identifier(s) for user(s) in the staff.
	Name	Name of the staff member.
	Role	Role of the staff member (e.g. CourseManager or CurriculumManager)
Course Manager	*CoMID*	Unique identifier for the course manager.
	CourseID(n)	Identifier(s) for course(s) associated with the CourseManager.
Curriculum Manager	*CMID*	Unique identifier for the curriculum manager.
	CourseID(n)	Identifier(s) for course(s) associated with the curriculumManager.
	CurriculumID(n)	Identifier(s) for curriculum(s) associated with the curriculumManager.
Expert	*ExpertID*	Unique identifier for the expert.

	UserID(n)	Unique identifier(s) for user(s) as expert.
	ResourceID(n)	Identifier(s) for resource(s) associated with the expert.
	ExpReviewID(n)	Identifier(s) for expert review(s) associated with the expert.
Expert Review	*ExpReviewID*	Unique identifier for the expert review.
	ExpertID(n)	Identifier(s) for the expert(s) providing the review.
	ResourceID	Identifier for the resource being reviewed.
	Rating	Rating given in the expert review.
	Comment	Comments or feedback in the expert review.
Account	*UserID*	Unique identifier for the account.
	Username	The username of the user.
	Password	Password for account security.
	RegisterDate	Date when the account was registered.
	SubStatus	The current subscription plan of a user.
	CourseID(n)	Identifier(s) for course(s) associated with the account.
	CurriculumID(n)	Identifier(s) for curriculum(s) associated with the account.
Librarian	*LibrarianID*	Unique identifier for the librarian.
	UserID	Unique identifier for the librarian as a user.
	Username	The username of the librarian.
	Password	Password for librarian security.
	Permissions	Permissions or access rights for all users, accessible by the librarian.
Course	*CourseID*	Unique identifier for the course.
	InstructorID	Identifier for the instructor associated with the course.
	Title	Name of the course.
	Description	Description of the course.
	Price	Price of the course.
	Duration	Duration of the course.
	ResourceID(n)	Identifier(s) for resource(s) associated with the course.
Curriculum	*CurriculumID*	Unique identifier for the curriculum.
	CurriculumName	Name of the curriculum.
	CourseID(n)	Identifier(s) for course(s) associated with the curriculum.
Community	*CommunityID*	Unique identifier for the community.
	UserID(n)	Identifier(s) for user(s) associated with the community.
	CurrIiculumD(n)	Identifier(s) for curriculum(s) associated with the community.
Review	*ReviewID*	Unique identifier for the review.
	StudentID	Identifier for the student providing the review.
	CourseID	Identifier for the course being reviewed.
	InstructorID	Identifier for the instructor being reviewed.
	Rating	Rating for the course or instructor, given in the review.
	Comment	Feedback in the review by the student.
Resource	*ResourceID*	Unique identifier for the resource.

	CourseID(n)	Identifier(s) for course(s) associated with the resource.
	ExpReviewID	Identifier for the expert review associated with the resource.
	Type	Type of resource (e.g., textbook, video, image, interactive).
	Title	Name of the resource.
	AuthorID(n)	Author(n) of the resource.
	URL	Location of the resource.
Author	*AuthorID*	Unique identifier for the author.
	ResourceID(n)	Identifier(s) for resource(s) associated with the author

Table I.4: The attributes of the classes.

I.5 Relationships and multiplicity

Class	***Associated class***	***Relation***	***Direction***	***Multiplicity***	***Label***
Library database	Curriculum	Composition	Bidirectional	One-to-many	Holds
Library database	Course	Composition	Bidirectional	One-to-many	Contains
Library database	Resource	Aggregation	Bidirectional	One-to-many	Contains
User	Expert	Inheritance	Unidirectional	←	-
User	Staff	Inheritance	Unidirectional	←	-
User	Student	Inheritance	Unidirectional	←	-
User	Librarian	Inheritance	Unidirectional	←	-
User	Instructor	Inheritance	Unidirectional	←	-
User	Account	Composition	Bidirectional	One-to-one	Has
User	Resource	Association	Bidirectional	Many-to-many	Uses
Instructor	Course	Association	Bidirectional	One-to-many	Teaches
Instructor	Review	Association	Bidirectional	One-to-many	Has
Instructor	Student	Association	Unidirectional	One-to-many	Assesses
Student	Course	Association	Bidirectional	Many-to-many	Takes
Student	Course	Association	Bidirectional	Many-to-many	Enrols for
Student	Review	Association	Unidirectional	One-to-many	Creates
Staff	Course Manager	Composition	Bidirectional	One-to-many	Has
Staff	Curriculum Manager	Composition	Bidirectional	One-to-many	Has
Course Manager	Course	Association	Bidirectional	One-to-many	Manages
Curriculum Manager	Curriculum	Association	Bidirectional	One-to-many	Manages
Expert	Expert Review	Aggregation	Bidirectional	Many-to-many	Conducts
ExpertReview	Resource	Association	Unidirectional	One-to-many	Reviews
Librarian	Course	Association	Bidirectional	Many-to-many	Manages
Librarian	Account	Association	Unidirectional	One-to-many	Grants access

Librarian	Resource	Association	Bidirectional	One-to-many	Publishes/ Checks
Librarian	Curriculum	Association	Bidirectional	Many-to-many	Has
Course	Resource	Aggregation	Bidirectional	Many-to-many	Has
Course	Review	Association	Bidirectional	One-to-many	Has
Curriculum	Course	Aggregation	Bidirectional	One-to-many	Has
Community	User	Aggregation	Bidirectional	Many-to-many	Has
Community	Curriculum	Association	Bidirectional	Many-to-many	Access to
Author	Resource	Association	Bidirectional	Many-to-many	Creates

Table I.5: The relationships and multiplicities of the classes in Table I.1.

The following relationships and multiplicities are identified in each class, including a detailed description and the number of instances

Library Database

Composition between Library Database and Curriculum

Multiplicity: Library Database (1) ----- Curriculum (0..*)
Description: A library database holds information about various curricula or subjects (a curriculum has to be in the database to be used) & Each curriculum can only have one library database.

Composition between Library Database and Course

Multiplicity: Library Database (1) ----- Courses (0..*)
Description: A library database contains information about different courses (a course has to be in the database to be used) & Each course can have only one library database.

Aggregation between Library Database and Resource

Multiplicity: Library Database (1) ----- Resource (*)
Description: A library database contains the resources of different courses (a resource has to be in the database to be used, but can exist independently when being checked by the expert review) & Each resource can only have one library database.

User

Generalization

A user can be an expert, staff, student, librarian or instructor.

Composition between User and Account

Multiplicity: User (1) ----- Account (1)
Description: Each user needs to have an account to enrol in courses & Each account can have one user (an account cannot exist without a user).

Association between User and Resource

Multiplicity: User (0..*) ----- Resource (0..*)
Description: Each user uses multiple resources when enrolled in courses & Each resource can have multiple users.

Instructor

Association between Instructor and Courses

Multiplicity: Instructor (1) ----- Courses (0..*)
Description: Each instructor can teach multiple courses & Each course has one instructor.

Association between Instructor and Review
Multiplicity: Instructor (1) ----- Review (0..*)
Description: Each teacher can have zero or multiple reviews from students about them or about the course & Each review is associated with one teacher.

Association between Instructor and Student
Multiplicity: Instructor (1) --→ Student (0..*)
Description: Each Instructor can provide direct feedback to multiple users on their assignment and questions.

Students

Association between Student and Course
Multiplicity: Student (*) ----- Course (0..*)
Description: Each student can take multiple courses & Each course can be taken by multiple students.

Association between Student and Course
Multiplicity: Student (*) ----- Course (0..*)
Description: Each student enrols for zero or many courses & Each course can have many enrolled students.

Association between Student and Review
Multiplicity: Student (1) ----- Review (0..*)
Description: Each student can create zero or multiple reviews about an instructor or a course.

Staff

Composition between Staff and CourseManager
Multiplicity: Staff (1..*) ----- CourseManager (1)
Description: Each staff consists of at least one course manager. & Each course manager has one staff.

Composition between Staff and CurriculumManager
Multiplicity: Staff (1..*) ----- CurriculumManager (1)
Description: Each staff consists of at least one curriculum manager & Each curriculum manager has one staff.

CourseManager

Association between CourseManager and Course
Multiplicity: CourseManager (1..*) ----- Course (1)
Description: Each course has one course manager & Each course manager can manage many courses.

CurriculumManager

Association between CurriculumManager and Curriculum
Multiplicity: CurriculumManager (1..*) ----- Curriculum (1)
Description: Each curriculum has one curriculum manager & Each curriculum manager can manage many courses.

Expert

Aggregation between Expert and ExpertReview
Multiplicity: Expert (1..*) ----- ExpertReview (1..*)

Description: Each Expert conducts at least one expert review & Each expert review is conducted by at least one experts.

ExpertReview

Association between Expertreview and Resource

Multiplicity: ExpertReview (1..*) ----- Resource (1)
Description: Each expert review can review one resource.

Librarian

Association between Librarian and Course

Multiplicity: Librarian (1..*) ----- Course (*)
Each librarian manages many courses & Each course is managed by at least one librarian.

Association between Librarian and Account

Multiplicity: Librarian (1) --→ Account (0..*)
Description: Each Librarian can grant access to many users.

Association between Librarian and Resource

Multiplicity: Librarian (1..*) ----- Resource (1)
Description: Each librarian can publish and check many resources & Each resource needs to be published and reviewed by a librarian.

Association between Librarian and Curriculum

Multiplicity: Librarian (1..*) ----- Curriculum (*)
Description: Each librarian can manage multiple curricula & Each curricula is managed by at least one librarian.

Course

Aggregation between Course and Resource

Multiplicity: Course (*) ----- Resource (1..*)
Description: Each course can have multiple resources (the resources can also exist independently when the resource is being reviewed by an expert review) & Each resource can be in many courses.

Association between Course and Review

Multiplicity: Course (1) ----- Review (0..*)
Description: Each course can have zero or multiple reviews & Each review is associated with one course.

Curriculum

Aggregation between Curriculum and Course

Multiplicity: Curriculum (1) ----- Course (0..*)
Description: Each course can have one curriculum (a course cannot exist without a curriculum) & Each curriculum can have zero or many courses.

Community

Aggregation between Community and User

Multiplicity: Community (0..*) ----- User (1..*)
Description: Each community has at least one user & Each user can be in zero or many communities (a user is not obliged to be in a community).

Association between Community and Curriculum
Multiplicity: Community (0..*) ----- Curriculum (0..*)
Description: Each community has access to zero or many curricula & Each curriculum can be in zero or many communities (a curriculum is not obliged to be in a community).

Author
Association between Author and Resource
Multiplicity: Author (1..*) ----- Resource (1..*)
Description: Each author creates one or more resources & Each resource has one or more authors (A resource cannot exist without an author).

J. Community Needs Tech Assessment (CNTA)

The Community Needs Tech Assessments (CNTAs) can be found in the Yoda folder: /research-overb102-msc-ispm-tan/Community_Needs_Tech_Assessment_(CNTA)/

The **results** can be found in the Yoda folder: /research-overb102-msc-ispm-tan/Community_Needs_Tech_Assessment_(CNTA)/[assessment]/results

Ref.nr.	*Name*	*Stakeholders*
CA.1	Quick Scan	Educational Head, MN staff
CA.2	Community meeting	Chief, educational head, elders in community, teachers, parents, notetaker, digital librarian(s) (DL), Maxim Nyansa (MN) staff
CA.3	Asset Inventory (J.2)	Educational Head, DL, MN staff
CA.4	Survey – Student (J.1)	Students
CA.5	Survey – teacher (J.1)	General teachers, ICT teachers, DL
CA.6	Focus Group	Teachers, School directors, DL, parents, MN staff

Table J: Community assessment protocols.

J.1 CA.4/CA.5) Student/teacher survey protocol: Translation of metrics, method fragments into survey questions.

The student survey protocol is formulated based on the framework of Waters [122] and Rotary International [121], and the improvement of the KPIs provided by Smulders [59].

The full document is available on:

/research-overb102-msc-ispm-tan/Community_Needs_Tech_Assessment_(CNTA)/Survey_-_student/

Method fragment	**Metric**	**Survey* (S/T)**	**Survey questions**
Demographic	Age	S/T	What is your age?
Demographic	Gender	S/T	What is your gender?
Demographic	Country	S/T	In what country do you go to school?
Demographic	Place of residence	S/T	In what city, town or village do you live?
Demographic	Place of school	S/T	In what city, town or village do you go (teach) to school?
Demographic	School name	S/T	What is the name of the school?
Demographic	School type	S/T	What type of school are you going to/teaching?
Demographic	Number of jobs	T	What is the number of jobs you had in the past (including current job if applicable)?
Demographic	Taught subjects	T	Which subjects did you teach?
Information needs	Information source	S/T	What is your main source of general information?
Information needs	Information types	S/T	What type of information do you need?
Accessibility	Distance to school	S/T	How far is your home from school? In km and minutes?

Accessibility	Mode of transportation	S/T	How do you get to school?
Accessibility	Facilities	S	What facilities are available at your school?
Accessibility	Safety	S	Do you feel safe at school?
General information	Attendance	S	Do you ever not attend school? Why?
General information	Priority	T	Which option is more a priority? Renovating the washroom *or* the provision of an ICT lab and computers
Education level	Qualification	T	What is currently your highest education level?
General knowledge	Literacy	S/T	How would you rate your literacy?
General knowledge	Digital literacy	S/T	How would you rate your IT literacy?
Internet usage	Usage history	S/T	Have you ever used internet services?
Internet usage	Use of internet	S/T	What do you use the internet for
Computer usage	Usage history	S/T	Have you ever used a computer?
Computer usage	Personal access	S/T	Do you have access to a personal computer or laptop?
Computer usage	Location	S/T	Where do you make use of a computer in general?
Computer usage	PC usage Purpose	S/T	For what purpose do you use a computer?
Tech Infrastructure	Computers available	S/T	Are there computers at your school?
Tech Infrastructure	IT lab availability	S	Is there an IT lab at your school?
Service and support	Failure frequency computer	S/T	What is the frequency of failure of the computer you use in the school environment?
Service and support	Restore time	S/T	When there is a failure with a PC, how long does it take to restore the fault?
Service and support	Type of computer failure	S/T	What is the most common computer failure?
Smartphone usage	Usage history	S/T	Have you ever used a smartphone/tablet before?
Smartphone usage	Smartphone accessibility	S/T	Do you have access to a smartphone/tablet?
Smartphone usage	Smartphone usage purpose	S/T	For what purpose would/do/did you use a smartphone/tablet?
Additional effects	Effects personally	S/T	Do you think the IT lab would have/has a positive effect on your personal life?
Additional effects	Effects on others	S/T	Do you think the IT lab would have/has a positive effect on other students?
Content quality	Content value	S/T	What aspects of this course were most useful or valuable?
Content quality	Content improvement	S/T	How would you improve this course?
School insights	Overall improvements	T	What could be done to make the school better for the students? This can be anything from facilities (e.g., electricity) to resources (e.g., books).

School insights	Improvements for teachers	T	What could be done to make your job as a teacher easier, better, or more enjoyable? This can include improvement to the facilities, resources for teaching, or job training.
School insights	Change management	S/T	If there was one thing you could change about your school, what would it be?
School insights	Specific improvements	S/T	Is there anything else that you would like us to know about your school to make it better? Please share it here. (could also be non-IT related)

Table J.1: Translation of metrices into survey questions - teacher/student.

* = This metric is part of the protocol of the student survey (S) or/and the teacher survey (T).

Personal statement questions for students and teachers.

Method fragment	Metric	Survey statement (likert scale)
Education level	Satisfaction level of education	I think that the education I receive is too easy.
Education level	Satisfaction ICT knowledge teacher	I am satisfied with the level of ICT knowledge of my teacher(s).
Education level	Satisfaction ICT level lessons	I am satisfied with the difficulty level of ICT lessons that are provided.
Education level	Satisfaction ICT quantity lessons	I am satisfied with the quantity of ICT lessons that are provided.
PC usage	Satisfaction computer availability	I am satisfied with the number of times I have access to a computer or laptop.
Internet usage	Satisfaction internet usage	I am satisfied with the number of times I have access to the internet.
Network speed and quality	Satisfaction internet speed	I am satisfied with the internet speed available at school.
Network speed and quality	Perception restore time	I am satisfied with the time it takes to restore a network connection failure.
Information needs	Availability digital content	I think that there is enough digital educational material available at my school.
Information needs	Availability digital interactive content	I think that there is enough digital interactive educational material available at my school.
TPACK	Content knowledge	I know the basic theories and concepts for ICT.
Self-Efficacy	Self-efficacy information searching	I am good at searching for information on the internet.
Self-Efficacy	Confidence PC usage	I am confident in using a computer at school.
Self-Efficacy	Perceived ease of use 1	I can carry out school tasks quickly using a computer.
Self-Efficacy	Perceived ease of use 2	I can carry out school tasks quickly using a smartphone.
Self-Efficacy	Confidence smartphone usage	I feel confident in using a smartphone.

Value of technology	Added value technology 1	I think that the availability of internet is of added value in education.
Value of technology	Added value technology 2	I think that the availability of computers is of added value in education.
Value of technology	Added value technology 3	I think that the availability of smartphones or tablets is of added value in education.
Livelihood	Survival support	My family has enough income to cover costs to ensure basic survival needs (food, clothing, shelter, etc.).
Livelihood	Development support	My family has enough income to cover costs to maintain access to healthcare and school.
IT lab knowledge	Skill level 1	Level of skill/knowledge at start of ICT course
IT lab knowledge	Skill level 2	Level of skill/knowledge at end of ICT course
IT lab knowledge	Skill level 3	Level of skill/knowledge required to complete the ICT course
IT Teacher quality	Effective teaching 1	Teacher was interesting.
IT Teacher quality	Effective teaching 2	Teacher was clear and organized.
IT Teacher quality	Motivational teaching	Teacher motivated me.
IT Teacher quality	Teaching quality 1	Teacher completed class in time.
IT Teacher quality	Teaching quality 2	Teacher was available and helpful.
IT Teacher quality	Teacher grading	Grading was prompt and had useful feedback.
Content quality	Content objectives	Learning objectives were clear
Content quality	Content organization	Course content was organized and well planned
Content quality	Content workload	Course workload was appropriate
Content quality	Participation in content	Course organized to allow all students to participate fully

Table J.1.1: Translation of metrices into personal statements - student.

Method fragment	**Metric**	**Survey statement (likert scale)**
Education level	Satisfaction ICT knowledge	I am satisfied with my own level of ICT knowledge and expertise.
ICT employment	Motivation ICT professionals	The ICT professionals at my school are motivated.
ICT employment	Qualification ICT professionals	The ICT professionals at my school are qualified and experienced.
ICT employment	Retainment ICT professionals	I recognize that my school retains experienced and qualified ICT professionals.
ICT employment	Quantity of ICT teachers	I think that my school has enough ICT professionals to support me in my workplace.
ICT employment	ICT/career importance	I think that ICT literacy is important for my career progression.
PC usage	Satisfaction computer availability	I am satisfied with the number of times I have access to a personal computer or laptop.
PC usage	Perceived productivity	Computers increase my productivity.

TPACK	Technological knowledge 1	I can solve ICT related problems.
TPACK	Technological knowledge 2	I am familiar with new technologies and their features.
TPACK	Technological knowledge 3	I know websites with online materials for studying ICT.
TPACK	Technological knowledge 4	I know technologies which I can use to illustrate difficult contents in ICT.
TPACK	Technological knowledge 5	I have sufficient knowledge in developing contents for ICT.
TPACK	Content knowledge	I know the basic theories and concepts for ICT.
TPACK	Content knowledge	I know the history and development of important theories in ICT.
TPACK	Content knowledge	I am familiar with recent research in ICT.
Internet usage	Satisfaction internet usage	I am satisfied with the number of times I have access to the internet.
Network speed and quality	Satisfaction internet speed	I am satisfied with the internet speed.
Network speed and quality	Perception restore time	I am satisfied with the time it takes to restore a network connection failure.
Information needs	Availability digital content	I think that there is enough digital educational material available at my school.
Information needs	Availability digital interactive content	I think that there is enough digital interactive educational material available at my school.
Self-Efficacy	Perceived ease of use 1	Operating a computer to carry out simple tasks is easy.
Self-Efficacy	Perceived ease of use 2	Operating a smartphone to carry out simple tasks is easy.
Self-Efficacy	Confidence PC usage	I feel confident in using a computer at school.
Self-Efficacy	Perceived quality 1	I believe that by using a computer the quality of the education increases.
Self-Efficacy	Perceived quality 2	I believe that by using a smartphone the quality of the education increases.
Self-Efficacy	Confidence smartphone usage	I feel confident in using a smartphone at school.
Value of technology	Added value technology 1.1	I think that the availability of internet is of added value in education.
Value of technology	Added value technology 1.2	I think that the availability of internet is of added value for personal development.
Value of technology	Added value technology 2.1	I think that the availability of computers is of added value in education.
Value of technology	Added value technology 2.2	I think that the availability of computers is of added value for personal development.
Value of technology	Added value technology 3.1	I think that the availability of smartphones or tablets is of added value in education.
Value of technology	Added value technology 3.2	I think that the availability of smartphones or tablets is of added value for personal development.
IT lab knowledge	Skill level 1	Level of skill/knowledge at start of ICT course
IT lab knowledge	Skill level 2	Level of skill/knowledge at end of ICT course

IT lab knowledge	Skill level 3	Level of skill/knowledge required to complete the ICT course
Content quality	Content objectives	Learning objectives were clear.
Content quality	Content organization	Course content was organized and well planned.
Content quality	Content workload	Course workload was appropriate.
Content quality	Participation in content	Course organized to allow all students to participate fully.

Table J.1.2: Translation of metrices into personal statements - teacher.

J.2 Asset Inventory: CNTA metrics, method fragments and questions.

Method fragment	Metric	Survey statement (likert scale)
General school information	Name	What is the name of the school?
General school information	Contact 1	What is the phone number of the school?
General school information	Contact 2	What is the email of the school?
General school information	Address	What is the address of the school?
General school information	Location	In which city/region/country is the school located?
General school information	Type	What is the type of school? Public/private
General school information	Education levels	Which levels of education are offered?
General school information	Place type	What is the place type of the school? Rural/urban
General school information	Number of students	What is the total number of students in your school?
General school information	Repeater ratio	What is the number of year repeaters?
General school information	Average student grade overall	What is the general school national final exams rating (in %)?
General school information	Average student grade ICT class	What is the ICT school results rating (in %)?
General school information	ICT teacher skills	What is the skill level of the ICT teachers?
General school information	Curricular activities	What are the additional curricular activities?
General school information	Power source	What is the source of regular power supply?
Availability	Teacher availability 1	What are the total number of teachers on your school?
Availability	Teacher availability 2	How many new teachers per year?
Availability	Teacher availability 3	How many teachers leave per year?
Availability	Available IT teachers	What are the total number of ICT teachers on your school?
Availability	Available non-teaching staff	What is the total number of non-teaching staff?
Availability	Hardware availability	Hardware checklist (14 areas), and how many?
Availability	Available security measures	Security checklist (7 areas)
Availability	Digital content	Is digital content available?
Availability	Content software	Which software is being used for the digital content?

Availability	Learning management software	Do you have Learning Management Software (LMS) in place? And which?
Availability	School Management software	Do you have School Management Software (SMS) in place? And which?
Tech Infrastructure	IT lab availability	Does the school have an IT lab? And what is the location?
Tech Infrastructure	IT lab maintenance	If yes, by which company is the ICT lab maintained?
Tech infrastructure	DL availability	Is there a digital librarian (DL)?
Accessibility	Active use	What are the active number of students making use of ICT facilities?
Accessibility	Freely accessible	How many hours/days a week are the computers at your ICT facility freely accessible?
Accessibility	Scheduled lessons	How many hours/days a week are the computers at your school/project environment in use for scheduled lessons?
Accessibility	Personal account	Do students and employees have a personal account?
Service and support	Frequency power failure	How often does power failure occur and you are unable to use your computer?
Service and support	Internet restoration	How long does it take to restore an internet network failure?
Affordability	IT infrastructure cost	What are the total cost of running the IT resources per year? (in euros)
Affordability	Internet costs	What are the total internet costs per year? (in euros)
Affordability	Maintenance costs	What are the total maintenance costs per year? (in euros)
Affordability	Budget for ICT training teachers	What is the budget for teachers to learn IT skills?
Internet usage	Provider	Which company is the internet provider?
Internet usage	Internet satisfaction	Are you satisfied with the internet provider?
Internet usage	Internet type	What type of internet connection?
Network speed and quality	Internet speed 1	What is the download internet speed (in MBps)?
Network speed and quality	Internet speed 2	What is the upload internet speed (in MBps)?
Network speed and quality	Internet quality	Number of possible users?
Availability	Available subjects	Which subjects are being taught in the school?
Availability	Available IT subjects	Subjects given by using the computer?
Information needs	Computer purpose	For what is the computer used within the school?
Information needs	Learning formats	Which learning formats are being used?

Table J.2: Translation of metrices into personal statements - teacher.

K. Ethics and Privacy Quick Scan

Appendix K.1: Ethics and Privacy Quick Scan (version: 5 September 2022)

Section 1. Research projects involving human participants.

		Yes	No
P1	Does your project involve human participants? This includes for example use of observation, (online) surveys, interviews, tests, focus groups, and workshops where human participants provide information or data to inform the research. If you are only using existing data sets or publicly available data (e.g., from Twitter, Reddit) without directly recruiting participants, please answer no.	**Yes**	

If no, continue with Section 2; if yes, fill in the following questions.

Recruitment

		Yes	No
P2	Does your project involve participants younger than 18 years of age?	**Yes**	
P3	Does your project involve participants with learning or communication difficulties of a severity that may impact their ability to provide informed consent?*	**Yes**	
P4	Is your project likely to involve participants engaging in illegal activities?		**No**
P5	Does your project involve patients?		**No**
P6	Does your project involve participants belonging to a vulnerable† group, other than those listed above?		**No**

If the answer to all of P2-P6 is no, continue with P8.

As you are dealing with vulnerable participants (yes to one (or more) of P2-P6) a fuller ethical review is required. Please add more detail on your participants here:

My participants will be schoolteachers, students (probably underaged) in lower, middle, and high schools in Africa. These participants could have limited functional literacy or numeracy and problems with communication regarding their English knowledge. However, if this is the case then it will be translated by locals who have knowledge of the local language.

		Yes	No
P7	Do you intend to be alone with a research participant or have to take sole responsibility for the participants at any point during your research activity?		**No**

If P7 is no continue with P8, otherwise:

As you will be alone with or solely responsible for vulnerable participants (yes to P7) a fuller ethical review is required. You may also need a Certificate of Conduct (Dutch: VOG) from the government. Please add more detail here:

		Yes	No
P8	Does your project involve participants with whom you have, or are likely to have, a working or professional relationship: for instance, staff or students at the university, professional colleagues, or clients?	**Yes**	

If the answer to P8 is yes, please answer P9, otherwise, continue with PC1.

		Yes	No
P9	Is it made clear to potential participants that not participating will in no way impact them (e.g., it will not directly impact their grade in a class)?	**Yes**	

* For informed consent people need to be able to (1) understand information provided relevant to making the consent decision, (2) retain this information long enough to be able to make a decision, (3) weigh the information, (4) communicate the decision.

† Vulnerable people include those who are legally incompetent, who may have difficulty giving or withholding consent, or who may suffer highly adverse consequences if their personal data were to become publicly available or from participating. Examples include irregular immigrants, sex workers, dissidents, and traumatized people at risk of re-traumatization.

If the answer to P9 is yes, then continue with PC1, otherwise:

 **As participants may think that not participating may harm them (yes to P8 and no to P9), participation may no longer be voluntary. Hence, a fuller ethical review is required.** Please provide more information here:

	Consent Procedures	**Yes**	**No**	**Not applicable**
PC1	Do you have set procedures that you will use for obtaining *informed* consent from all participants, including (where appropriate) parental consent for children or consent from legally authorized representatives? (See suggestions for information sheets and consent forms on the website[‡].)	**Yes**		
PC2	Will you tell participants that their participation is voluntary?	**Yes**		
PC3	Will you obtain explicit consent for participation?	**Yes**		
PC4	Will you obtain explicit consent for any sensor readings, eye tracking, photos, audio, and/or video recordings?	**Yes**		
PC5	Will you tell participants that they may withdraw from the research at any time and for any reason?	**Yes**		
PC6	Will you give potential participants time to consider participation?	**Yes**		
PC7	Will you provide participants with an opportunity to ask questions about the research before consenting to take part (e.g., by providing your contact details)?	**Yes**		

If the answer to PC1-PC7 is yes, then continue with PC8, otherwise:

 **Given your responses to the informed consent questions (a no on any of PC1-PC7), a fuller ethical review is required.** Please provide more information regarding the questions that are causing this here:

		Yes	**No**
PC8	Does your project involve concealment[§] or deliberate misleading of participants?		**No**

If the answer to PC8 no, continue with Section 2, otherwise:

 As you plan to use concealment or misleading (yes to PC8), and this may impact participants' rights to informed consent, a fuller ethical review is required. Please provide more information on the concealment/misleading here:

Section 2. Data protection, handling, and storage

The General Data Protection Regulation imposes several obligations for the use of **personal data** (defined as any information relating to an identified or identifiable living person) or including the use of personal data in research.

		Yes	**No**
D1	Are you gathering or using personal data (defined as any information relating to an identified or identifiable living person[**])?	**Yes**	

If the answer to D1 is yes, please answer the following questions; otherwise, continue with Section 3.

High-Risk Data

	Yes	**No**

‡ uu.nl/en/research/institute-of-information-and-computing-sciences/ethics-and-privacy

§ This may for example involve concealment of the study aim, of the identity of the researcher, or subliminal messaging during the study.

** This includes people's name, postal address, unique ID, IP address, voice, photo, video etc. When a person can be identified by combining multiple data points (e.g. gender + age + job role), this also constitutes personal data. When a person can be identified by a simple search online (e.g. with the content of a tweet) this also constitutes personal data. Note that Survey tool Qualtrics by default collects IP addresses and that the survey needs to be anonymized before distribution to prevent this.

DR1	Will you process personal data that would jeopardize the physical health or safety of individuals in the event of a personal data breach?		**No**
DR2	Will you combine, compare, or match personal data obtained from multiple sources, in a way that exceeds the reasonable expectations of the people whose data it is?[††]		**No**
DR3	Will you use any personal data of children or vulnerable individuals for marketing, profiling, automated decision-making, or to offer online services to them?		**No**
DR4	Will you profile individuals on a large scale[‡‡]?		**No**
DR5	Will you systematically monitor individuals in a publicly accessible area on a large scale[§§] (or use the data of such monitoring)?[***]		**No**
DR6	Will you use special category[†††] personal data, criminal offense personal data, or other sensitive personal data[‡‡‡] on a large scale?		**No**
DR7	Will you determine an individual's access to a product, service, opportunity, or benefit[§§§] based on an automated decision or special category personal data?		**No**
DR8	Will you systematically and extensively monitor or profile individuals, with significant effects[****] on them?		**No**
DR9	Will you use innovative technology[††††] to process sensitive personal data[‡‡‡‡]?		**No**

If the answer to DR1-DR9 is no, continue with DM1, otherwise:

As high-risk data processing seems involved (yes to any of DR1-DR9), a fuller privacy assessment is required. Please provide more information on the DR1-DR9 questions with a yes here:

Data Minimization

		Yes	**No**
DM1	Will you collect only personal data that is strictly necessary for the research?	**Yes**	

If you answered yes to DM1 continue with DM4, otherwise:

		Yes	**No**
DM2	Will you only collect not strictly necessary personal data because it is (1) technically unfeasible not to collect it when collecting necessary data[§§§§], or (2) needed as a source of necessary data[*****]?		

[††] This is about the combined use of data sets that have been gathered for different purposes (so not within one study), making the data more personal or sensitive. For example, combining participant data with religion or ethnic statistics data from the CBS based on zip code.

[‡‡] Large scale is for example thousands of people, all visitors to a university website, data obtained over a very large time span

[§§] Large scale is for example thousands of people, all visitors to the area, data obtained over a very large time span

[***] This may also include camera surveillance and use of drones

[†††] Special category personal data is information about a person's health, ethnic origin, politics, religion, trade union membership, genetics, biometrics (where used in identification), sex life or sexual orientation.

[‡‡‡] Other sensitive personal data includes for instance financial data (from which people's income, capital position or spending patterns can be derived), location data (from which people's movement patterns can be derived), achievement data (e.g. outcome of course work/exams, intelligence test; this excludes performance on tasks in a research study that are unrelated to their study/job), and communication data.

[§§§] Examples include: access to a mortgage, insurance, credit card, smartphone contract, course or degree programme, job opportunity.

[****] Significant effects are for example impacts on somebody's legal rights, automatic refusal of a credit application, automatic rejection for a job application.

[††††] Innovative technology includes e.g. machine learning (including deep learning), neuro measurement (e.g. brain activity), autonomous vehicles, deep fakes, wearables, blockchain, internet of things.

[‡‡‡‡] Sensitive personal data includes all data mentioned in DR6.

[§§§§] This may for instance occur when IP data is collected automatically in Qualtrics, and it is unfeasible not to do so as other personal data such as email needs to be collected.

[*****] This may, for instance, occur when audio data is captured from which audio features need extracting or a transcript needs to be produced.

DM3	Will you (1) extract any necessary data as soon as possible from the collected not strictly necessary data and (2) delete the not strictly necessary data immediately after any required extraction?††††		
DM4	Will you anonymize the data wherever possible?‡‡‡‡‡	**Yes**	
DM5	Will you pseudonymize the data if you are not able to anonymize it, replacing personal details with an identifier, and keeping the key separate from the data set?	**Yes**	

If the answer to any of DM2-DM5 is no, see warning below, otherwise continue with DC1.

As you do not seem to minimize data collection (no to any of DM2-DM5), a fuller privacy assessment is required. Please provide more information on the DM2-DM5 questions with a no here:

Using Collaborators or Contractors that Process Personal Data Securely

			Yes	**No**
DC1	Will any organization external to Utrecht University be involved in processing personal data (e.g., for transcription, data analysis, data storage)?		**Yes**	

If the answer to DC1 is yes, please complete DC2 otherwise continue with DI1.

		Yes	**No**
DC2	Will this involve data that is not anonymized?		**No**

If the answer to DC2 is yes, please complete DC3-DC5, otherwise continue with DI1.

		Yes	**No**	**Not Applicable**
DC3	Are they capable of securely§§§§§ handling data?			
DC4	Has been drawn up in a structured and generally agreed manner who is responsible for what concerning data in the collaboration?			
DC5	Is a written contract covering this data processing in place for any organization which is not another university in a joint research project?			

If the answer to any of DC3-DC5 is no, see warning below, otherwise continue with DI1.

As you do not seem to have appropriate processes in place for sharing data with collaborators or contractors (no to any of DC3-DC5), a fuller privacy assessment is required. Please provide more information on the DC3-DC5 questions with a no here:

International Personal Data Transfers

		Yes	**No**
DI1	Will any personal data be transferred to another country (including to research collaborators in a joint project)?	**Yes**	

If the answer to DI1 is yes, please complete DI2, otherwise continue with DF1.

†††† This may for instance happen when you collect audio data, extract audio features, or transcribe an audio interview as soon as possible, and delete the original audio recording once done.

‡‡‡‡‡ Possible also means given the research question. So, for example, if you have done interviews and you need to be able to at a later date link them to performance data, it is impossible to anonymize the interviews, and you will need to pseudonymize them. You can then answer yes to DM4 as you are anonymizing where it is possible, and yes to DM5 if indeed you pseudonymize. Note that in such a case you should anonymize once the linking has been done, destroying the key that links the pseudonym to the identity of the participant.

§§§§§ Secure handling includes for example: (1) only sharing data with those who legitimately need to see it, (2) data being securely stored on password-protected employer authorized IT systems (or in the case of non-digital data: in a secure locked location), (3) if portable devices such as USB sticks are used then only encrypted and password protected with data deleted as soon as it is no longer required to be portable, (4) reporting lost or stolen data immediately, (5) deleting or disposing of data as soon as it is no longer required and in a secure manner, (6) not discussing sensitive data in public places, (7) only carrying needed data when working off-site.

		Yes	No
DI2	Do all countries involved in this have an adequate data protection regime?******	**Yes**	

If the answer to DI2 is no, please complete DI3, otherwise continue with DF1.

		Yes	No
DI3	Is a legal agreement in place?		

If the answer to DI2 and DI3 is no, see warning below, otherwise, continue with DF1.

As you do not seem to have appropriate safeguards in place for international data transfers (no to DI2 and DI3), a fuller privacy assessment is required. Please provide more information on intended international data transfers here:

Fair Usage of Personal Data to Recruit Participants

		Yes	No
DF1	Is personal data used to recruit participants?††††††		**No**

If the answer to DF1 is yes please answer DF2-DF4, otherwise continue with DP1.

		Yes	No
DF2	Have potential participants provided this personal data voluntarily to be contacted about the research or is the data publicly available?		
DF3	If contact details have been provided by a third party, would participants expect their details to be passed on to the university and to be used in this way?		
DF4	If contact details have been gathered for a purpose other than research, would participants expect their details to be used in this way?		

If the answer to DF2-DF4 is yes continue with DP1, otherwise:

As there seem to be issues with your use of personal data for recruitment (no to one or more of DF2-DF4), a fuller privacy assessment is required. Please provide more information on the intended use of personal data for recruitment here:

Participants' data rights and privacy information

		Yes	No	Not Applicable
DP1	Will participants be provided with privacy information? (Recommended is to use as part of the information sheet: For details of our legal basis for using personal data and the rights you have over your data please see the University's privacy information at www.uu.nl/en/organisation/privacy.)	**Yes**		
DP2	Will participants be aware of what their data is being used for?	**Yes**		
DP3	Can participants request that their personal data be deleted?‡‡‡‡‡‡	**Yes**		
DP4	Can participants request that their personal data be rectified (in case it is incorrect)?	**Yes**		
DP5	Can participants request access to their personal data?	**Yes**		
DP6	Can participants request that personal data processing is restricted?	**Yes**		
DP7	Will participants be subjected to automated decision-making based on their personal data with an impact on them beyond the research study to which they consented?		**No**	

****** Countries with an adequate data protection regime include EU countries, Andorra, Argentina, Canada (only commercial organizations), Faroe Islands, Guernsey, Israel, Isle of Man, Jersey, New Zealand, Switzerland, Uruguay, Japan, the United Kingdom, and South Korea.

†††††† Intended here is the direct use of personal data to target a specific person. If you are using personal data indirectly to address a group of people, for example, sending a message via a *pre-existing* Microsoft Team, Blackboard course, Discord Channel, WhatsApp group, or crowd-sourcing platform, that is fine and will not be regarded as the use of personal data here. If you are asking friends or family members this will also not be regarded as use of personal data here.

‡‡‡‡‡‡ This only concerns requests for personal data that you still hold. If you can no longer link the data to a participant due to anonymization, you can no longer delete it. This should be clear to participants in the consent form. If the data is pseudonymized and you cannot access the key but the participant can (for example when the key is a WorkerID from a crowd-sourcing platform), participants should be able to request deletion on the provision of the key.

DP8	Will participants be aware of how long their data is being kept for, who it is being shared with, and any safeguards that apply in case of international sharing?	**Yes**		
DP9	If data is provided by a third party, are people whose data is in the data set provided with (1) the privacy information and (2) what categories of data you will use?	**Yes**		

If the answer to DP1-DP6, DP8, DP9 is yes and DP7 is no, continue with DE1, otherwise:

As there seem to be issues with the data rights of your participants or the provision of privacy information (no to one or more of DP1-DP6, DP8, DP9, or yes to DP7), a fuller privacy assessment is required. Please provide more detail regarding data rights and/or privacy information here:

Using data, you have not gathered directly from participants.

		Yes	**No**
DE1	Will you use any personal data[§§§§§§] that you have not gathered directly from participants (such as data from an existing data set, data gathered by a third party, data scraped from the internet)?		**No**

If the answer to DE1 is no, please continue with DS1.

		Yes	**No**
DE2	Will you use an existing dataset in your research?		

If the answer to DE2 is yes please answer DE3-DE5, otherwise, continue with DE6.

		Yes	**No**
DE3	Do you have permission to do so from the owners of the dataset?		
DE4	Have the people whose data is in the data set consented to their data being used by other researchers and/or for purposes other than that for which that data set was gathered?		
DE5	Are there any contractual conditions attached to working with or storing the data from DE2?		

		Yes	**No**
DE6	Does your project require access to personal data about participants from other parties (e.g., teachers, employers), databanks, or files[*******]?		

If the answer to DE6 is yes please answer DE7-DE8, otherwise, continue with DE9.

		Yes	**No**
DE7	Do you have a process in place to gain informed consent from these participants?		
DE8	Are there any contractual conditions attached to working with or storing the data from DE5?		

		Yes	**No**
DE9	Does the project involve collecting personal data from websites or social media (e.g., Facebook, Twitter, Reddit)?		

As there may be issues with the use of existing data (no to DE3, DE4, DE7 or yes to DE9), a fuller privacy assessment is required. Please provide more detail regarding the use of existing data here:

Secure data storage

	Yes	**No**

[§§§§§§] Defined as any data related to an identified or identifiable living person. This includes people's name, postal address, unique ID, IP address, voice, photo, video etc. When a person can be identified by combining multiple data points (e.g. gender + age + job role), this also constitutes personal data.

[*******] For example, do you get a student's grade from the teacher, in addition to data gathered directly in your study or data in an existing research data set?

DS1	Will any data be stored (temporarily or permanently) anywhere other than on password-protected University authorized computers or servers?††††††††		**No**

If the answer to DS1 is yes, please answer DS2, otherwise, continue with DS4.

		Yes	**No**
DS2	Does this only involve data stored temporarily during a session with participants (e.g. data stored on a video/audio recorder/sensing device), which is immediately transferred (directly or with the use of an encrypted and password-protected data-carrier (such as a USB stick)) to a password-protected University authorized computer or server, and deleted from the data capture and data-carrier device immediately after transfer?		

If the answer to DS2 is yes, continue with DS4, otherwise answer DS3.

		Yes	**No**
DS3	Does this only involve data stored with a collaborator or contractor?		
DS4	Excluding (1) any international data transfers mentioned above and (2) any sharing of data with collaborators and contractors, will any personal data be stored, collected, or accessed from outside the EU‡‡‡‡‡‡‡‡?	**Yes**	

If the answer to DS2 and DS3 is no, or the answer to DS4 is yes, see the warning below, otherwise continue with Section 3.

As there may be issues with secure data storage (no to DS2 and DS3, or yes to DS4), a fuller privacy assessment is required. Please provide more detail regarding data storage here:

The collection of data is done in Ghana, Africa or through the internet using virtual meetings. Furthermore, the data storage is on both Maxim Nyansa secured data server and personal data servers.

Section 3: Research that may cause harm.

Research may harm participants, researchers, the university, or society. This includes when technology has dual-use, and you investigate an innocent use, but your results could be used by others in a harmful way. If you are unsure regarding possible harm to the university or society, please discuss your concerns with the Research Support Office.

		Yes	**No**
H1	Does your project give rise to a realistic risk to the national security of any country?§§§§§§§		**No**
H2	Does your project give rise to a realistic risk of aiding human rights abuses in any country?********		**No**
H3	Does your project (and its data) give rise to a realistic risk of damaging the University's reputation? (E.g., bad press coverage, public protest.)		**No**
H4	Does your project (and in particular its data) give rise to an increased risk of attack (cyber- or otherwise) against the University? (E.g., from pressure groups.)		**No**
H5	Is the data likely to contain material that is indecent, offensive, defamatory, threatening, discriminatory, or extremist?		**No**
H6	Does your project give rise to a realistic risk of harm to the researchers?†††††††††		**No**
H7	Is there a realistic risk of any participant experiencing physical or psychological harm or discomfort?‡‡‡‡‡‡‡‡‡		**No**
H8	Is there a realistic risk of any participant experiencing a detriment to their interests as a result of participation?		**No**

†††††††† OneDrive business, Qualtrics, Microsoft Forms are ok. Do not use Google Drive/Sheets/Docs/Forms, Dropbox, OneDrive personal. See https://tools.uu.nl/tooladvisor/ for tools that are safe/not safe to use. Bachelor and master students are authorized to use a password-protected personal computer, as long as that computer is not shared with other people.

‡‡‡‡‡‡‡ This may happen, for instance, when data is collected and stored on a Utrecht University laptop whilst abroad.

§§§§§§§ For example, research that can be used for autonomous armed vehicles/drones/robots, research on automated detection of objects, research on AI-enhanced forgery of video/audio data.

******** For example, research on natural language/video/audio processing for automated identification of people's identity, sentiments, or opinions.

††††††††† For example, research that involves potentially violent participants such as criminals, research in likely unsafe locations such as war zones, research on an emotionally highly challenging topic, research in which the researcher is alone with a not previously known participant in the participant's home.

‡‡‡‡‡‡‡‡‡ For example, research that involves strenuous physical activity, research that stresses participants, research on an emotionally challenging topic.

H9	Is there a realistic risk of other types of negative externalities?§§§§§§§§		**No**

If the answer to H1-H9 is no continue with Section 4, otherwise:

As you replied yes to one (or more) of H1-H9, a fuller ethical review is required. Please provide more detail here on the potential harm, and how you will minimize risk and impact:

Section 4: Conflicts of interest

		Yes	**No**
C1	Is there any potential conflict of interest (e.g., between research funder and researchers or participants and researchers) that may potentially affect the research outcome or the dissemination of research findings?		**No**
C2	Is there a direct hierarchical relationship between researchers and participants?	**Yes**	

If the answer to C1-C2 is yes, continue with Section 5, otherwise:

As you replied yes to C1 or C2, a fuller ethical review is required. Please provide more information regarding possible conflicts of interest and how you mitigate them here:

There will not be a conflict of interest. Researchers are trying to make all the necessary inquiry about the project in question and why there is a need, and participants may include all the stakeholders which span from educational directorate though Heads of School, teachers, students, parents and even the researchers.

Section 5: Your information

This last section collects data about you and your project so that we can register that you completed the Ethics and Privacy Quick Scan, sent you (and your supervisor) the summary of what you filled out, and follow up where a fuller ethics review and/or privacy assessment is needed. For details of our legal basis for using personal data and the rights you have over your data please see the University's privacy information. Please see the guidance on the ICS Ethics and Privacy website on what happens on submission.

Z0. Which is your main department?

- ◉ Information and Computing Science
- ○ Freudenthal Institute
- ○ Other, namely:

Z1. Your full name: Thomas Tan

Z2. Your email address: t.c.tan@students.uu.nl

Z3. In what context will you conduct this research?

- ○ 1. As a student on a course with course coordinator:
- ○ 2. As a student for my bachelor thesis, supervised by:
- ◉ 3. As a student for my master thesis, supervised by: Sietse Overbeek and Sergio Cubillo
- ○ 4. As a PhD student, supervised by:
- ○ 5. As an independent researcher (e.g. research fellow, assistant/associate/full professor)

In case the answer to Z3 is 2:

Z4. Bachelor programme for which you are doing the thesis:

- ○ Artificial Intelligence (Kunstmatige Intelligentie)
- ○ Computing Science (Informatica)
- ○ Information Science (Informatiekunde)
- ○ Other:

In case the answer to Z3 is 3:

Z5. Master programme for which you are doing the thesis:

- ○ Applied Data Science
- ○ Artificial Intelligence
- ◉ Business Informatics
- ○ Computing Science
- ○ Data Science
- ○ Game and Media Technology
- ○ Human-Computer Interaction
- ○ Other:

§§§§§§§§ A negative externality is a harm produced to a third party, society in general, or the environment. For instance, intended or unintended negative ethical (e.g. bad governance or management practices), social (e.g. consumerism, inequality) or environmental effects (e.g. large CO2 footprint or e-waste production) of your project.

In case the answer to Z3 is 1, 2, 3, or 4:

Z6. Email of the course coordinator or supervisor (so that we can inform them that you filled this out and provide them with a summary): s.j.overbeek@uu.nl

In case the answer to Z3 is 2 or 3:

Z7. Email of the moderator (as provided by the coordinator of your thesis project): s.j.overbeek@uu.nl

Z8. Title of the research project/study for which you filled out this Quick Scan:

Codification of a digital educational library design in a West-African context: A case study in Ghana

Z9. Summary of what you intend to investigate and how you will investigate this (200 words max):

One of the successful initiatives is Maxim Nyansa, which developed several projects to provide career opportunities for young Africans and IT professionals using technology. Their platform, an open online digital library, offers affordable and accessible learning materials, including IT skills, soft skills, project management, all kinds of possible courses, literacy, and comprehensive reading. The platform has been recognized by the African Union as one of the promising innovations in education in Africa. Mobile technologies, where the mobile phone is the most prevalent, make it possible to provide learning opportunities, i.e., m-learning, for learners without infrastructure (Brown, 2005). Despite its success, the library's development lacks a scientific foundation, prompting the need for research to establish design principles for digital educational libraries in the West African context. The research will specifically focus on the West-African context, which is based on the limited availability of IT and accessibility of the vast amounts of data on the platform and the internet in general across many African countries (Quoichao, 2016, De Bruine, 2020). The collaborative objective is to enable personal education by utilizing current m-learning possibilities combined with Maxim Nyansa's digital educational library. Consequently, this research will conduct local testing and investigation of design principles and m-learning possibilities for digital educational libraries in Ghana. Therefore, the main research question is: What does a design for digital educational libraries in a West-African context look like that leads to usability and knowledge building?

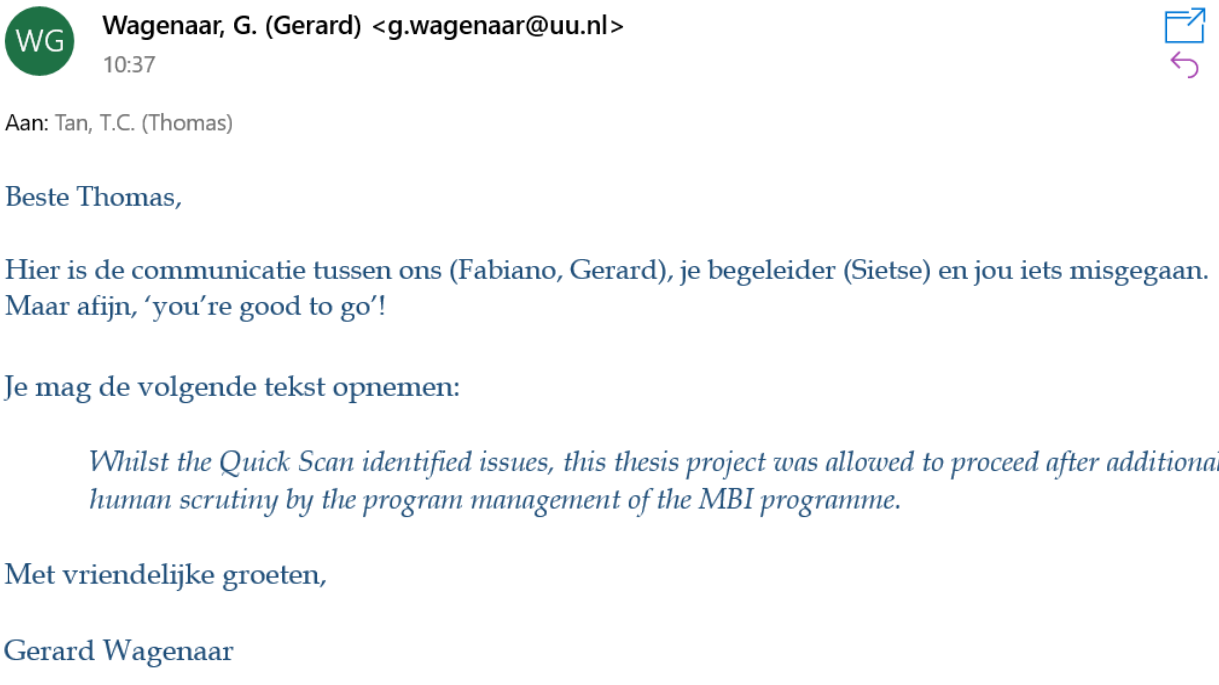
In case the answer to Z3 is 2 or 3:

		Yes	No	Not Applicable
Z10.	In case you encountered warnings in the survey, does your supervisor already have ethical approval for a research line that fully covers your project?		**No**	

In case the answer to Z9 is yes:

Z10. Provide details on the ethical approval (e.g., ethical approval number):

K.1 Ethics approval mail



WG

Wagenaar, G. (Gerard) <g.wagenaar@uu.nl>

10:37

Aan: Tan, T.C. (Thomas)

Beste Thomas,

Hier is de communicatie tussen ons (Fabiano, Gerard), je begeleider (Sietse) en jou iets misgegaan. Maar afijn, 'you're good to go'!

Je mag de volgende tekst opnemen:

> *Whilst the Quick Scan identified issues, this thesis project was allowed to proceed after additional human scrutiny by the program management of the MBI programme.*

Met vriendelijke groeten,

Gerard Wagenaar

K.2 Consent form

Utrecht University

Consent form participation master thesis

Title thesis

Codification of a digital educational library design in a West-African context: A case study in Ghana

Explanation

Dear,

Thank you for agreeing to be interviewed as part of the above research project for my master's thesis at the Utrecht University. This consent form ensures that you understand the purpose of your involvement and that you agree to the conditions of your participation.
The purpose of this research to develop a design regarding digital educational libraries and as a result increase the usability of such libraries and build knowledge. Currently, there is a lack of general design knowledge around the design of digital educational libraries and its local implementations.

RESEARCH INVESTIGATOR

Thomas Tan – t.c.tan@students.uu.nl
Department of Information and Computing Sciences
Utrecht Universiteit
Heidelberglaan 8, 3584 CS, Utrecht, The Netherlands

Supervised by: dr. Sietse J. Overbeek – s.j.overbeek@uu.nl, Dr. Sergio E. Cubillo – s.espana@uu.nl, Stanley Kwakye Dankyira - mninfo@maximnyansa.com and Diana van der Stelt – dianavanderstelt@maximnyansa.nl

CONFIDENTIALITY

Your responses to this [survey] will be anonymous. Please do not write any identifying information on your [survey]. Every effort will be made by the researcher to preserve your confidentiality including the following:

State measures taken to ensure confidentiality, such as those listed below:

- Assigning code names/numbers for participants that will be used on all research notes and documents.
- Keeping notes, interview transcriptions, and any other identifying participant information in a locked file cabinet in the personal possession of the researcher.

Participant data will be kept confidential except in cases where the researcher is legally obligated to report specific incidents. These incidents include, but may not be limited to, incidents of abuse and suicide risk.

CONTACT INFORMATION

If you have questions at any time about this study, or you experience adverse effects as the result of participating in this study, you may contact the researcher whose contact information is provided on the first page.

VOLUNTARY PARTICIPATION

Your participation in this study is voluntary. It is up to you to decide whether or not to take part in this study. If you decide to take part in this study, you will be asked to sign this consent form. After you sign the consent form, you are still free to withdraw at any time and without giving a reason. Withdrawing from this study will not affect the relationship you have, if any, with the researcher. If you withdraw from the study before data collection is completed, your data will be returned to you or destroyed. Not participating will not harm you in any way, for example: it will not impact your grade in any way in class.

CONSENT RULES

10.1.1.1 I understand that the interview will take approximately 45 minutes. I give the researcher permission to take notes and audio record during the interview. The interview can be taken in the form of a survey, multiple-choice questions, or open-ended questions.

10.1.1.2 I understand that participating the VOLUNTARY PARTICIPATION section.

10.1.1.3 I understand that the research data, without any personal information that could identify me, may be shared with others.

10.1.1.4 I understand that I am free to contact any of the people involved in the research to seek further clarification and information at any time.

10.1.1.5 I am free to decide if I want my name and company name mentioned in the research report.

CONSENT

I have read, and I understand the provided information and have had the opportunity to ask questions. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason and without cost. I understand that I will be given a copy of this consent form. I voluntarily agree to take part in this study.

Participant's signature _____ **Date** _____

Investigator's signature _____ **Date** _____

L. Quality assessment criteria for grey literature

Criteria (AACODS)	Questions
Authority	Is the publishing author/organization reputable? Is an individual author associated with a reputable organization? Has the author published other work in the field? Does the author have professional qualifications or experience? Does the work have a detailed reference list?
Accuracy	Does the item have a clearly stated aim and if so, is this met? Does the source have a stated methodology? If so, is it adhered to? Is the source supported by authoritative or credible references? Has the work been peer-reviewed? Is the work representative of the work in the field? If no, is it a valid counterbalance? Does the work cover a specific question? Does the work refer to a particular population or case
Coverage	Are any limits clearly stated?
Objectivity	It is important to identify bias: Opinion, expert or otherwise, is still opinion: is the author's standpoint clear? Does the work seem to be balanced in presentation?
Date	Does the source have a clearly stated date? If no date is given, but can be closely ascertained, is there a valid reason for its absence?
Significance	Value judgement of the work: Is the item meaningful? Does the work add context? Does it enrich or add something unique to the research? Does it strengthen or refute a current position? Does it have impact? (In the sense of influencing the work or behavior of others)

Table K.1: Quality assessment criteria for grey literature [66]**.**