Developing a mobile application to improve the learning of mathematical skills of children with Autism Spectrum Disorder in Rwanda

By

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Originality Statement

I hereby declare that this submission is my own work, and to the best of my knowledge, it contains no materials previously published or written by another person or substantial proportions of material that have been accepted for the award of any other degree or diploma at the University of Rwanda or any other educational institution, except where due acknowledgment is made in the thesis. Any contribution made to the research by others with whom I have worked at the University of Rwanda or elsewhere is explicitly acknowledged in the thesis. I also declare that the intellectual content of this thesis is the product of my own work, except to the extent that assistance from others in the project's design and conception or style, presentation, and linguistic expression is acknowledged.

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Abstract

Supporting the learning of children with Autism Spectrum Disorder (ASD) is challenging in an inclusive classroom. Different studies proved no medicine to cure the disease rather than providing intervention to improve their lives through education. Few Information Communication Technologies (ICTs) tools support existing learning systems for children with ASD in developed and developing countries. However, how to develop such a culturally sensitive digital tool for children with ASD is not yet documented in Rwanda.

In this study, I conducted systematic research activities in four phases intending to develop a human-centered mobile application in the Rwandan context to improve learning for children with ASD level 3 in Rwanda. I used Agile in software development methodology, Narrative literature review, Focus Group Discussions (FGDs), observation, quantitative data collection, and user testing as formative assessment approach to develop and evaluate the developed mobile application. In the first phase, I conducted four Focus Group Discussions (FGDs) with 54 participants: 20 teachers, 12 parents, 16 students with ASD, and six children with the standard intellectual capacity. The first phase of this study aimed to understand people's perceptions regarding the use of ICT to improve the learning of children with ASD, their effectiveness, the scope of using them in their context, and upcoming challenges during implementation. In the second phase, I conducted seven FGDs with 56 teachers and 14 parents to analyze how to adapt the available digital content to enhance the learning of children with ASD in an inclusive environment. The third phase used 55 participants: 40 children with ASD, five teachers, and ten parents of children with ASD to design, test, and evaluate the mobile application that improves the learning of children with ASD.

The first phase of this study documented those children with ASD could self-learn when they have the digital tools with the cognitive software application. The second phase established the potential to recreate and gamify the existing content in a digital platform to meet the environmental context. Afterward, in the third phase, I demonstrated the methodologies to follow while developing a human-centered mobile application to support the learning of children with ASD in a low-resource environment. This thesis has detailed findings of each phase of this study and general conclusions.

Dedication

To my family, friends, and relatives

Acknowledgment

Doing research is always a collaboration, and this work is not different. All co-writers and colleagues at the University of Rwanda (Rwanda) and the Stockholm University (Sweden) have contributed significantly to this thesis and are reviewers of the included papers.

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Thank you!

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List of abbreviation

ABA: Applied Behavior Analysis (ABA)

AR: Augmented Reality

ASD: Autism Spectrum Disorder

CBC: Competence-based Curriculum

CBI: Computer-Based Intervention

DS: Design Science

DSM: Diagnostic and Statistical Manual of Mental Disorders

FGDs: Focus Group Discussions

GUI: Graphic User Interface

ICT: Information and Communication Technology

iOs: iPhone operating system

LMIC: low- and middle-income countries

MINEDUC: Ministry of Education

QNA: Qualitative Narrative Analysis

REB: Rwanda Education Board

RPIA: Rwanda Parent's Initiative on Autism

UDL: Universal Design for Learning

VE: Virtual Environments

VTC: Technical Vocation Centers

Chapter 1. Introduction

1.1. Background to the problem

Autism Spectrum Disorder (ASD) is a Neurodevelopment Disorder characterized by a deficit in social communication plus restricted, repetitive behaviors (American Psychiatric Association, 2013). A person can present the sign of ASD at any age, but the symptoms generally appear in the first two ages of child development (Byrn, 2013). The prevalence of the disorder is increasing, and recent data showed one out of 54 people in the United States (Centers for Diseases and Control, 2021).

The current studies do not indicate the actual prevalence of ASD in Africa. However, Onaolapo & Onaolapo (2017) reported that most of the burden was 62/10,000 (approx. 1 in 161) in the review compared information from distinctive parts of the world excluding sub-Saharan Africa. The contribution of sub-Saharan Africa (SSA) to this burden is generally obscure due to a scarcity of population-based overviews and awareness of the disease (Bakare & Munir, 2011; Hahler & Elsabbagh, 2015; Ruparelia et al., 2016; and Franz et al., 2018).

Being a spectrum that may manifest with different forms, many persons with learning disabilities are present among persons with ASD (zerk, 2016). Rwanda Ministry of Education (2019) reports that the prevalence of pupils with learning disabilities is decreasing from primary to secondary education, where more than 90% do not complete basic education programs. Therefore, the Rwanda Ministry of Education developed a Competence-Based Curriculum (CBC) in response to the inclusiveness of education (REB, 2015). According to Speaks (2012), the development of Assistive Technologies is more advanced in this century, and developers invented different tools to support people with varying types of disabilities. People with ASD also benefited from this revolution.

The inclusive education and ICT in education policies in Rwanda emphasize using different Assistive and Educational Technologies to support equity and quality of education (Rwanda National Council of Persons with Disabilities, 2014) and (Rwanda Ministry of education, 2016). However, there is a gap in the software application in the Rwandan education system, where most of them are in foreign languages and environmental contexts (Ntalindwa et al., 2019a). This situation contributes to the barrier to access

to education in inclusive settings for persons with cognitive disabilities in general and children with ASD in particular (Rwanda National Council of Persons with Disabilities, 2014).

Sciences like mathematics are school subjects built on principles, well organized, and use the typical dialect with well-defined implications at the slightest in its purer shapes, with specific questions. These characteristics make mathematics a subject that is generally simple to get to for individuals with ASD. Baron-cohen & Wheelwright (2007) documented that child with ASD doing mathematical topics perform better than those in other disciplines. A similar study also demonstrated that many children with ASD possess an average mathematical giftedness ability compared to the typically developing children (Chiang & Lin, 2007). However, several studies report that children with ASD face different challenges in an inclusive school environment, such as academic challenges, social isolation, anxiety, and inadequately trained teachers (Fleury et al., 2014; Sevastopoulou,2016; Graham, 2021)

Different intervention models such as interventions, Psychosocial interventions, and Educational interventions support the improvement of the lives of children with ASD (Roberts & Prior, 2006). This study focused on educational interventions to create mobile educational applications for children with ASD in low resource settings. The development of adequate technologies in the Rwandan Context is crucial to support the inclusion of children with ASD in both culture and education. However, the study did not cover the whole competence-based curriculum due to the nature of the research. It focused only on teaching the differentiation of figures of coins and counting money using the coins used in the Rwandan currency system from five to one hundred Rwandan francs.

In practice, I focused on skip counting, which is the method of counting forward by adding the same number each tie to the previous other than one. The Competence-Based Curriculum provides that skip counting by using money in level one of lower primary (P1) and differentiation of money figures in level 3 pre-primary.

1.2. Statement of research problem and motivation

The etiology of ASD is yet to reach conclusive evidence. However, its prevalence is increasing in African countries like in other parts of the world. Sullivan (2012) and Grynszpan et al. (2014) reported that treating children with ASD requires different models mixed with technologies to enhance teaching and learning activities.

Few software applications are available for children with ASD in social communication globally (Baller et al., 2016). However, few of them respond to the needs of children with ASD in sub-Saharan Africa. Gona et al. (2015), Ruparelia et al. (2016), and Abubakar, Ssewanyana, & Newton (2016).

Children with ASD are interested in using digital tools. Their teachers and parents believe that ICTs might improve their learning when they are developed by considering their sociocultural context (Ntalindwa et al., 2019a). However, how to produce such a culturally sensitive digital tool is not yet documented in Rwanda.

Depending on the individual and local limitations in the environment, the interfaces of ICT tools have barriers to e-inclusion, defined as the problem of this thesis. *The problem is how children with ASD can overcome learning obstacles such as Communication Disorders, Behavioral Challenges, and social disorders with personalized digital tools and content*.

The application developed will support children with ASD to learn new skills from the Competence-Based Curriculum of Rwandan Basic Education on two levels. 1) Level three, pre-primary children can differentiate coins used in the Rwandan currency system; 2) level one of lower primary (P1), where children can use arithmetic operations in counting and exchanging money using the coins from 5 to 100 (Rwanda Ministry of Education, 2015).

Although I collected data I used in this study before the COVID-19 pandemic, this mobile application could support the learning of children with ASD during and after the COVID-19 pandemic in remote areas.

1.3. Objectives of the study

1.3.1. General objective

To design and develop a mobile application that improves the learning of children with ASD in Rwanda.

1.3.2. Specific objectives

The specific objectives of this research were to:

1. Investigate what the special educational needs of children with ASD are.
2. Investigate the utilization of the existing Information Communication Technologies to support children with ASD
3. Analyze how to adapt the available digital content to enhance the learning of children with ASD in Rwanda
4. Design and develop a new educational mobile application for a person with ASD in Rwandan Context.
5. Assess the acceptability and efficiency of the developed mobile application.

1.3.3. Research questions

From the research objectives, I formulated the following research questions:

1. What are the special educational needs of children with ASD?
2. How can Information Communication Technologies support the education of children with ASD?
3. How can educational digital content be adapted to support the learning of children with ASD in Rwanda?
4. How to develop a mobile application that suits the Rwandan education Context for children with ASD?
5. How do children with ASD, parents, and teachers perceive the use of the developed mobile application?

1.4. Delimitation

This thesis focused on developing a mobile application to support children with ASD in Rwanda. The goal relates to the education of children with ASD in general, and it was supposed to implement the whole competence-based curriculum of the Rwandan basic education system. Phase I and II focused on exploring the possibility of integrating ICT tools in teaching children with ASD. Phase III focused on developing and

evaluating the mobile application to support learning numeracy skills for children with ASD by using coins used in Rwandan currency. In the third phase, I chose one chapter in the competence-based curriculum.

The mobile application focused only on teaching numeracy (basic mathematics) by counting the coins of the Rwandan currency system. In the early education grades (level 3 pre-primary and level one primary), this content distinguishes coins from 1 to 100 Rwandan Francs based on symbols and representations. Teachers teach two arithmetic operations (addition and subtraction) using examples of coins. The developed mobile application focused only on counting two consecutive currencies from five to one hundred.
The selected chapter represents only one topic in 36 (2.7%) planned content of the syllabus supposed to help children learn basic mathematics at an early age.

Furthermore, while there is an apparent intervention for children with ASD, this thesis does not focus on the elderly. Also, this study excludes persons who do not have access to ICT (NISR, 2019). Finally, this thesis presupposes an interest in ICT for children with ASD that exclude others who do not meet the profile.

1.5. Intended audiences

The intended readers of this thesis are the public and private sector, civil society, educators, and the technology community to ensure the full inclusion of individuals with ASD in the Fourth Industrial Revolution and digitization (ITU, 2020). More specifically, the audiences are persons from 1) formal education (school, universities); 2) informal education context (special centers); and 3) Students and people in the software development field. The third may bring innovation and improvement to the current application. In contrast, others may bring change for the inclusion of children with ASD in the Rwandan education system as well as reduce the stigma against children with ASD.

1.6. Thesis structure

The following sections of this thesis are as follows: 1) Methodology and Overview of phases followed, including philosophical assumptions, trustworthiness/validity, and reliability of the study, 2) Results, 3) Discussion, and 4) Conclusions.

The thesis comprises four phases focusing on different activities that respond to the specific research questions towards the main objective of this study: the development of a mobile application to support the learning of children with ASD in Rwanda.

The first phase (Phase I) responded to the thesis's first two research questions (Q1&Q2). The second phase (Phase II) responded to the third research question (Q3), phase III responded to the fourth research question, and phase IV responded to the fifth research question (Q5).

This thesis presents a narrative literature review and a selection of methods in each phase. The results section summarizes the findings from all phases. The sections of discussion and general conclusions summarize the findings from previous phases and provide recommendations for future studies. Finally, the last section presents a list of references and appendices at the end of this thesis, including copies of research articles published during the study.

The thesis parts (table 1) show the design activities per phase of study and research question.

Table 1. Design activities per phase of the study and research questions

Phase	**Design activities**	**Research questions**
1	Understanding what ASD is and problem explication.	Q1 & Q2
2	I demonstrated the digital content design to support the education of children with ASD.	Q3
3	Design and develop a mobile application.	Q4
4	Demonstrate and evaluate a mobile application.	Q5

Chapter 2. Literature review

This chapter presents the related studies, theories, and concepts as follows: 1) Conceptual framework with the relationship between schools, ICT, and learning, 2) Special educational needs for children with ASD, 3) The use of ICT to support the learning of children with ASD, 4) Digital content to support learning of children with ASD, and 4) Mobile applications for children with ASD.

2.1. Conceptual framework

In this thesis, I selected qualitative research questions, and there is a need to be focused on as a preliminary analysis (Jabareen, 2009). The conceptual framework of inclusive education for children with ASD using ICTs relates to the learning environment, cognitive theories, and ICT. It explains the ontological assumptions "way things are." The epistemological assumptions of "how things are" and "how things work" in an assumed reality and assessing what can be interlinked (Guba & Lincoln, 1994). In this thesis, ICT, Learning, and schools are interconnected concepts. There are many forms of learning, including observation and imitations. Previous researchers documented that observational learning has significant social implications for children with ASD (Taylor & Dequinzio, 2012). The study by Rhiannon (2009) said that some children with ASD are gifted to use information from social interactions in their living environment. Using the theoretical framework of multimodal processing, Bosseler & Massaro (2003) developed a computer-animated tutor, facilitating children with ASD to learn vocabulary and grammar.

For instance, formal education for children with ASD at schools, learning, and ICT are problematic areas requiring attention and communication. In this thesis, formal education focuses on communicating with school leaders, parents, and special centers for children with ASD. However, for children with ASD with a deficit in communication and socialization (American Psychiatric Association, 2013a), ICT could help them learn new skills from selected content by playing with digital gadgets.

Communication includes information, utterance, and understanding; without communication, teaching and learning could not occur (Vaiouli et al., 2015). Several reasons why using senses such as auditory and visual are flourishing. These include the strength of visible speech, the complementarity of auditory and visual vocabulary, and the most delicate integration of these two sources of information (Bosseler & Massaro, 2003).

The study by Ern (2014) documented that digital content should respond to the deficits and social activities of children with ASD, like games, by implementing several methodologies and models to improve the learning of children with ASD in schools (Malley et al., 2014).

Though they have to learn differently, children with ASD can learn all subjects like their peers (Qian & Lipkin, 2011). This learning happens with external factors such as environment, teaching resources, or tools and content. The behavior of persons with ASD is different from one person to another, and strategies to support them in any inclusive social context are different. To achieve this, the developers of ICT applications need to deal with the existing environment where children with ASD live (Amado-Salvatierra et al., 2012).

Children with ASD need to interact with educational systems such as mobile applications and computer-based applications, and the demonstration line is the interface to each design. In a software application, an interface is a program that allows a user to interact with computers in person or over a network(Computer Hope, 2021).

According to Easterbrook (2014), the interface is the actual point at which the system meets its environment. In the current decade, communication between two or more persons can occur face-to-face or via digital gadgets such as computers, smartphones, or tablets. Persons with ASD have a deficit in communication and socialization. However, the brain network actualizes a framework for dialect and communication that ranges from essential paralinguistic social capacities to syntactic (Catani & Bambini, 2014). Hence, awareness of the psychic framework implies a requirement of an interface for perception and understanding of communication that must be comprehensive (Westin, 2017). However, the interface has barriers to digital inclusion, defined as the problem of this thesis: *The problem is how children with ASD can overcome learning obstacles such as Communication Disorders, Behavioral Challenges, and social disorders using ICT and digital content*.

This thesis elucidates examples of digital tools, perceptions of the usage of digital tools, contents, and methodologies of development and evaluation of mobile educational applications for children with ASD.

2.2. Special educational needs for children with ASD

2.2.1. Understanding Autism Spectrum Disorders

Autism Spectrum Disorder is a neurodevelopment disorder that ranges from low to high functioning, characterized by a deficit in social communication, social imagination, and restrictive, repetitive behaviors/interests (American Psychiatric Association, 2013). The most outstanding and fundamental symptoms evident in ASD is an inability to relate to others and delay in language communication (Eyler et al., 2012). Colombo-Dougovito & Block (2019) documented that children with ASD also have different motor skills and delays than other neurotypical children. Young children with ASD may show difficulties with simple interactive play, representing difficulties with social interest and motor imitation. Further complications may occur with imagination; for example, some children with ASD are not afraid of danger. Children with ASD also appear to live in their private world (Chown & Chown, 2016); (American Psychiatric Association, 2013).

Persons with ASD who create critical discourse appear to have contrasts in their communication capacity. In children, prompt and postponed echolalia may proceed to go with essential lessons (Sowden et al., 2013). A person with ASD may have difficulties sustaining conversion and understanding social communication nuances. Children with ASD demonstrate stereotypes and repetitive symptoms such as body rocking, hand flapping or hand watches, and repetitive spinning of objects outside social communication. For other children, nonfunctional schedules are displayed, such as carrying around sacks of little toys, requiring an excellent night tune to be sung sometime recently during sleep time, or the area of specific objects such as furniture, in a room within the child's domestic (Bradley et al., 2016). Individuals with ASD have cognitive deficits such as difficulties with selective attention, auditory processing, executive functioning, and memory (Jodene et al., 2014). Niditch et al. (2012) documented that individuals with ASD do not typically demonstrate deficits in a single domain of cognitive functioning. However, persons with ASD exhibit deficits in regulation of three attention operations 1) Orienting shifting and distributing attention to, 2) between, and 3) across locations of potential importance. According to Ramsey & Ward (2020), these functions help children with ASD apprehend and engage in everyday nonsocial and social situations.

Individual with ASD is generally confused with those with mental retardation. However, children with ASD often demonstrate social responsiveness that is delayed or unusual. Multiple studies documented that the everyday adaptive functioning of the person with ASD is typically more impaired than intellectual functioning (Hill et al., 2015; Klinger, Mussey, & O'Kelley, 2018).

The causes of ASD are not yet known. However, Schwartz & Neri (2012), Brentani et al. (2013), and Murdoch & State (2013) reported the mutation of the same gene could cause the disease. The environmental factors that include exposure to children's chemicals at birth can also cause ASD (Landrigan et al., 2012). Soron (2015), Lauritsen et al. (2005), and Sevastopoulou & Thesis (2016) argued that the prevalence of ASD has increased due to several biopsychosocial and environmental factors.

One in 54 children has ASD in the United States (Centers for Diseases Control and Prevention, 2021). The studies do not report the actual prevalence of ASD in Africa. Still, Olusanya et al. (2018) said that more than 80% of children with a developmental disability live in Low and Middle-Income Countries. They were represented only in about 1% of the research studies in the past decade (Byrne, 2013).

There are three levels of ASD ranging from the mildest to the most severe: 1) ASD level 1: Requiring Support, 2) ASD level 2: Requiring Substantial Support, and 3) ASD level 3: Requiring Very Substantial Support.

Level 1 is the mildest on the spectrum and is commonly known as High Functioning Autism (HFA), previously known as Asperger's (Hahler & Elsabbagh, 2015). People with high functioning ASD have specific social problems such as being aloof and indifferent, socially passive, and active but odd (Scheeren et al., 2020). Persons with high functioning ASD may understand everything spoken by peers but s/he could not get out any word (Autism Research Institute, 2021).

The previous studies by Hardy & LaGasse (2013) and Bharathi et al. (2019) documented that children with the first level of ASD can improve their communication through rhythm and music. This improvement is because hearing is like having a hearing aid with volume control among persons with ASD (Autism Speaks Inc, 2021). Some children with ASD show tactile problems due to the super-sensitivity of their skin (Loscalzo, 2011). Theory of mind (Scheeren et al., 2013) and adaptive skills-based treatment (Linstead et al., 2017) is more fruitful to improve social communication.

Cravalho et al. (2020) found that children with High Functioning Autism can learn vocabulary and comprehension when carefully applied an appropriate teaching intervention. Thus, the children with the first level of ASD can attend the inclusive school and demonstrate good performance like those neurotypical children regardless of anxiety and sensory dysfunction.

The second level of ASD is between the mildest and the most severe. Like those in the first level, level two children have a deficit in communication and attention. The children with level two of ASD can attend class in an inclusive school, but they require more support than the first level.

Level three of Autism is commonly known as Low Functioning Autism (LFA). Persons in this category demonstrate almost the same symptoms as high and middle functioning, like communication, socialization, and bizarre behavior. Still, those symptoms are more severe than others on the spectrum. The term overlaps classic autism, severe autism, or profound autism (Kilmer, 2020; Mayo Foundation for Medical Education and Research, 2021). However, few teachers know the extent of the impacts and the nature of symptoms of ASD, where children are facing multiple challenges in social communication and unique behavioral patterns and need intensive support (Rwanda National Council of Persons with Disabilities, 2014) and (Ruparelia et al., 2016).

2.2.2. Characteristics of ASD that impact learning

The symptoms of ASD impact the learning process in different forms. Therefore, it is crucial to consider that children with ASD have average or above-average intelligence regardless of their difficulties in learning in the same environment as the children with typical development. The behavior of children with ASD is different across the spectrum and is also subject to change through their developmental ages. The common characteristics that impact their learning are: 1) Fixation on specific activities, 2) Language development delay, 3) difficulties with non-verbal communication, and 4) problems with attention.

2.2.2.1. Fixation on Specific Activities

Children with ASD have behavior to fixate their attention on one activity to the point where they tend not to consider their surrounding environment. Different studies documented that this behavior could help children develop competencies in some subjects like mathematics or music (Hardy & LaGasse, 2013; Bharathi et al., 2019). However, fixing a single activity is also a barrier to learning for children with ASD when they are supposed to construct their idea from much content like text or a big picture (Connor, 2016).

2.2.2.2. Language development delays

Verbal communication is the primary tool used in teaching and learning both neurotypical and children with ASD. The typical indicators of children with ASD have delayed development in language communication (Schalick et al., 2012). This delay affects the learning of children with ASD in a neurotypical classroom where education is verbally dependent. Studies reported that the failure to provide early intervention to those children could affect further development in skills (Goddard et al., 2014).

2.2.2.3. Difficulties with nonverbal communication

The deficit in communication is one of the triads of impairments of children with ASD: social communication, social socialization, and stereotyped behavior (Sullivan, 2012). In contrast, most interventional programs focus on practices to overcome verbal communication deficits. The researchers also advise prioritizing the solutions to overcome emotional development and body language like direct eye contact and commonly used body gestures (like moving hands saying hello, or goodbye) (Crowell et al., 2019).

2.2.2.4. Problems with attention

Teaching children with ASD is more challenging due to their deficits in following instructions and paying attention to educators. Children with ASD are more sensitive to distractions from the surrounding environment, such as the colors of clothes of teachers or colleagues, bright lights, sounds, and smells, among others. It is also challenging for educators to provide an environment that accommodates all types of behavior in an inclusive classroom since those children behave differently across the spectrum. The researchers advise educators to be patient and vary strategies to accommodate these children (Neill, 2012).

2.2.3. Learning capabilities among children with ASD

Children with disabilities face challenges when learning in an inclusive environment (Karangwa, 2008). This situation becomes more complicated for children with ASD (Hahler & Elsabbagh, 2015). Like any other child, those children with ASD have an equal right to education and other fundamental rights (Abubakar, Ssewanyana, & Newton, 2016). However, students with ASD face several challenges during

their education in both developed and low and middle-income countries (LMICs) (Simpson & Boer-ott, 2003; Hahler & Elsabbagh, 2015).

Educators and clinicians use different approaches to discover, engage and grow the person's talents with ASD (Sani-Bozkurt et al., 2017). The previous study by Malley et al. (2014) found that the failure of the educational system to meet the needs of children with ASD is due to an insufficient number of schools offering appropriate methods.

Educational models result from some learners with ASD scoring average or high marks in subjects like mathematical knowledge (Baron-cohen & Wheelwright, 2007). Children with ASD also can perform well in scientific domains such as mathematics, physics, or computer science (P. Lewis et al., 2006).

According to Byrne (2013), scientific advancement unveils the potential of children with ASD in different domains. The study of Kamaruzaman & Azahari (2014) documented the potential of children to learn and develop their skills in various disciplines like mathematics.

Despite the high rate of dropouts in schools and their deficit in social communication (Baron-Cohen et al., 2009), studies by Baron-Cohen et al. (2009) demonstrated the existence of the savant syndrome among persons with ASD. The Virginia Department of Education (2011) identified the prevalence of the savant's syndrome in one in 10 (10%) persons with ASD, which may vary from one person to another. This was supported by Treffert (2009), who argued that some persons with ASD can memorize over 6000 books and have extensive knowledge of geography. They can also say all countries of the continent and their capital cities and their presidents. Some studies revealed that some extraordinary creative minds, such as Galileo, Einstein, and Edison, had high-functioning autism (Diener et al., 2014).

The study by Khorrami et al. (2013) reported a tendency among children with ASD to read by decoding before understanding comprehension. Many studies have sought to teach simple mathematic skills (e.g., number matching, counting) (Dixon et al., 2016) by addressing the deficit in communication as a common impairment for children with ASD (Novack et al., 2019).

The focus of children with ASD compromises the sensory onslaught that is going on in the learning environment, which prevents them sustain attention when studying (Kirk et al., 2017). Thus, supporting Learners with ASD could be done by training them in special skills to engage attention rather than seeing their unique abilities as frivolous (Ntalindwa et al., 2019a). This support can be used as a form of expression to channel those abilities more useful (Treffert, 2009). The Sixty-seventh World Health Assembly's

resolution emphasized the comprehensive and coordinated efforts to manage ASD (World Health Organization, 2014).

2.2.4. Educational needs of children with ASD

Many special educational needs are supposed to be met by parents and educators to respond to the difficulties of children with ASD. These unique educational needs could help children with ASD develop optimally and demanding subjects planned in the curriculum (REB, 2015b).

Depending on the level of impairment, some children with ASD can attend the mainstream school settings while others can follow the unique education program (Neill, 2012). Educators could also plan more time and resources for teaching children with ASD.

Previous studies documented that some children can attend many subjects in one school day, while others struggle to adapt to the school environment (Fleury et al., 2014). This statement means educators should also plan the setting that works well for children with ASD and follow it carefully to make the environment enjoyable and cooperative for the subsequent sessions. Teachers succeed in teaching children with ASD when they prepare the children with ASD in advance and verbalize each activity step before teaching and learning activities. An excellent example of this would be: "Today we will learn how to count food. First, we will talk a little more about numbers, after which we will try to write this down together. Is that okay? Once finished, we can go play with the toys." (KidsKonnect, 2021). From this statement, educators could succeed in teaching children with ASD when they repeat the order of the activities in each step and know the interests of children to integrate into the planned lesson.

2.2.5. Early numerical competencies in children with Autism Spectrum

Early numerical skills are essential in the developmental period to play value in later knowledge of mathematics from preschool to higher education. Previous studies by Jimenez & Besaw (2020) reported that understanding the learning process of mathematics could help identify the goals with the tasks to support the learning of children with ASD. The framework of Jordan and Levine (2009) identified five competencies in numerical skills of children at their early developmental age. These are 1) verbal subitizing, 2) counting, 3) Magnitude comparison, 4) Estimation, and 5) arithmetic operation.

2.2.5.1. Verbal subitizing

Subitizing is the capacity to enumerate tiny groups of objects without counting them precisely. Jimenez and Saunders (2019) reported that children could measure small quantities quickly and accurately up to three items without knowing how to count in order. Previous researchers (Reeve & Gray, 2014) documented the importance of children's mathematical skills in their early developmental age. In subitizing, children can count money without knowing the actual value.

In verbal subitizing, the number of things to be enumerated significantly impacts the accuracy, quickness, and confidence with which observers judge the number of objects. The study by Ciccione and Dehaene (2020) reported that when there are more than four items to count, the assessments become less accurate and confident. In addition, response times increase dramatically when the number of items in the display grows above four. (Piffer et al., 2012; Lucero et al., 2020).

2.2.5.2. Counting

Counting is a method of deciding the number of things in a limited set of objects or the measure of a set. The conventional strategy of counting involves increasing a (mental or talked) like: counter by one unit for each component of the group; in a few, arrange to dodge going to the same element more than once; until no unmarked pieces stay; if the counter was to one after the primary protest, the value after going to the ultimate question gives the specified numeric esteem. Le Corre and Carey (2007) documented the off chance that the counter was to one after the primary question. The value after going by the ultimate object gives the required numeric value may be a state that alludes to the method of relegating a number to each component of a limited or interminable set to recognize them uniquely (Schaaf, 2011). Counting encompasses both the procedural and conceptual knowledge required to perform a counting task. Studies by Peklari (2019) revealed that counting is a significant predictor of future mathematics performance. Whereas Conceptual counting knowledge is predictive of untimed mathematical accomplishment, procedural counting knowledge indicates numerical facility. In most cultures throughout the world, learning to count is a significant educational/developmental milestone

2.2.5.3. Magnitude comparison

Children can discriminate between two quantities in magnitude comparison to find the largest or lowest. The number comparison that includes symbolic and non-symbolic contributes to the development of mathematical skills among children with ASD and those with normal developmental abilities. The previous researchers proved that knowing magnitude could play an essential role in children's early development of mathematical skills in the environment that facilitates their learning (Libertus et al., 2013).

2.2.4.4. Estimation

In estimation, children can estimate the position of a number on a line. The estimation includes number space mapping, which is vital for mathematical ability. Studies reported that the judgment of number in line and the estimation of their position accurately correlate with the achievement in subjects that involves mathematics (Fanari et al., 2017).

2.2.5.5. Arithmetic operations

Arithmetical operation assesses the ability to solve simple addition, subtraction, multiplication, and division exercises. The researchers have documented that arithmetic operation could be predictive for later applied problem solving (Kiak et al., 2010). Studies reported those children could understand the addition operation as accumulating certain elements, while subtraction is a separation of the elements.

2.2.5.6. Skip counting

Skip counting is a counting technique by a number that is not 1. Teachers teach counting as a kind of multiplication. In other words, this technique is counting by Twos, Threes, Fours, etc. (MathsIsFun, 2022).

For example, in skip counting by twos, a student can count by adding two to the previous number: 2,4,6,8,10,…

Khan Academy platform provides exercises of skip counting from 2 to 100 with different strategies (Khan Academy, 2019d).

From the Khan Academy platform, there are two types of problems that show up in the exercise:

1. Select those users will see: This problem begins with a specific number and asks users to select the numbers they would know if they were skip-count by hundreds from the given number.
2. Fill in skip-count sequence: This problem has the user skip-count by one hundred from a number, sometimes forwards and sometimes backward.

Skip counting helps students familiarize the patterns in numbers and lays an excellent foundation for numbers sense and learning the multiplication facts (Kristendoyle, 2022). Teaching skip counting, the teacher can use either calculator, play games, questions, use sticky notes with a 100s chart, sing songs, or use manipulatives. Teaching the concept of skip counting for children with ASD requires games and visual objects (Eck van, 2006) because games give learners to explore the idea of numbers, such as counting sequences and computation strategies.

2.2.6. Teaching mathematics to children with ASD

2.2.6.1. Basic principles for teaching mathematics to children with ASD

Teaching mathematics to children with ASD needs to build on principles appropriate to the cognitive level of children with ASD. These principles are 1) concrete-to-abstract, 2) familiarity and 3) generalization.

2.2.6.1.1. Concrete to an abstract principle

The concrete-to-abstract principle is one technique used in education where a teacher starts from the known examples and progresses slowly to more unknown ideas. (Kamina & Iyer, 2009). To achieve this, teachers provide an opportunity for students to use their senses to see, feel, touch, or even smell different objects from their surrounding environment. (Crowell et al., 2019). After exercising their feelings about the things, a teacher can now teach children with ASD how to apply basic mathematical operations like addition or subtraction in playing with these objects. For example, a child can play with five stones and ask a child to bring five bananas. Oliphan (2013) study states that children with ASD are more comfortable and intuitive in learning mathematical skills when the teachers use games to introduce numbers and operations.

2.2.6.1.2. Familiarity principle

Mathematics is in everyday activities, and teachers and parents can integrate mathematical concepts into the daily lives of children with ASD. Using this approach, the children will learn it as one of the parts of their lives. (Connor, 2016). Like typical children, incorporating math concepts in daily life, children with ASD will progressively discover the concepts and use them even before starting the actual lesson. The study of Rovira (2014) proved that children with ASD can learn through the object with which they are familiar. Using objects in the surrounding environment when teaching children with ASD is crucial to improving their performance. This statement further demonstrates that including children with ASD in mainstream school is feasible when the teachers systematically integrate the familiar objects into their subjects.

2.2.6.1.3. Generalization principle

Children with ASD face challenges in adapting to the changes. In a specific condition, children with ASD can be exceptionally good at some content but be confused to demonstrating their knowledge when the environment changes. When it comes to the subject that involves mathematical skills, teachers could make changes to objects applied in the lesson to improve the adaptation of those children. (De Macedo & Ulbricht, 2012). For example, when teaching, adding two and five bananas makes seven bananas, and two and five potatoes make seven. Then a teacher could always encourage children to construct their knowledge by finding examples to make learning more generalizable.

2.2.6.2. Mathematics curriculum for students with ASD

Studies documented that children with ASD easily understand mathematics concepts since it is more methodical and logical. When the teaching activity employs concrete objects, these children can move quickly to the abstract (Tzanakaki et al., 2014). Strengths and weaknesses of learning among children with ASD are more crucial elements to consider when designing a particular curriculum that responds to their needs. The Institute for Remedial Intervention Services (2021) listed strengths and challenges when designing a math curriculum for children with ASD as given in the table.

Table 2. Strength, challenges, and indicators of math skills among children with ASD

Strength	Challenges	Indicators of math skills
1. High visual memory 2. Ability to discriminate between pictures, 3. Ability to coordinate comparable objects and pictures, 4. Ability to distinguish specific visual 5. Scanning speed 6. A look of a couple of seconds is sufficient to see at pictures. 7. Due to photographic memory, record the position of the visual 8. Once recorded, the picture remains until the end of time due to photographic memory 9. Functional association 10. Anything that's practically utilized is caught on way better (e.g., takes after enlightening amid nibble time) 11. Independent in regular exercises like eating and computer recreations. 12. Follow routine 12. Function successfully when the environment is predictable	1. Communication with their peers 2. Difficulty in verbal output 3. Difficulty to produce spontaneous response 4. Difficulty in answering open-ended questions like what did you eat to day? 5. Difficulty in communicating feelings like boredom, disturbed, outrage, and fear, 6. Difficulty in inquiring questions to urge more information	1. Awareness of time (may be the child knows exactly when the session is over) 2. Size (shirt, and shoes) 3. Awareness of days (maybe the child knows Sunday if they go to church) 4. Pick a number a specific number of bananas 5. Brings plates on dinning table 6. Know headings. (Great spatial ability).

Source The Institute for Remedial Intervention Services (2021)

From table 1., children with ASD have more strengths than difficulties which educators need to build on in developing a new curriculum for these children. Mottron (2011) reported that numerous researchers with autism have exceptional knowledge because of their intense focus on a single task. Another researcher found unique mathematical skills among children with ASD who perform well in computer programming tasks (Ribu, 2010). Wei et al. (2013) revealed that children with ASD are more oriented in Sciences, Technology, Engineering, and Mathematics (STEM) subjects than arts and social sciences. The researchers found in the brain of children with ASD, there are unique components activated when solving the mathematical problem, which is different from those with neurotypical development (Asperger & Baron-cohen, 2009; Time4Learning, 2021).

2.2.6.3. Mathematics curriculum for students with ASD in Rwanda

There is no unique standardized curriculum for children with ASD other than including them in the competence-based curriculum (REB, 2015b). The Ministry of Education's policy on children with disabilities and different particular needs has been active since January 2019 (Republic of Rwanda - Ministry of Education, 2019); and (Rwanda National Council of Persons with Disabilities, 2014). Schools request comprehensive rules on successful education and instruction, standard infrastructural offices, assets, proficient teachers, and back administrations. The need for calculated bolster appears to be the essential source of children with ASD's generalized destitute execution in numeracy, proficiency, and comprehension aptitudes (Flores et al., 2013). Despite including children with ASD in mainstream schools in Rwanda, few centers are caring for the children and continuously report difficulties to support the children in an inclusive environment (Ntalindwa et al., 2019a).

2.3. The use of ICT to support the learning of children with ASD

2.3.1. Overview of ICT and ASD

Information communication technologies and modern education techniques can support the education of individuals with specific inabilities by relieving their challenges in different domains (Ploog et al., 2013; Wong et al., 2015; Athbah, 2015). The United Nations (UN) (United Nations, 2019) emphasized utilizing assistive innovation to empower ASD in their communities, and it has been accepted that assistive advances will move forward the learning of children with ASD at school (Ennis-cole & Smith,

2011). Assistive technologies support individuals with ASD by improving their interaction skills (Dee et al., 2006) and self-engagement (Mathewson, 2010). Besides, guaranteeing comprehensive and evenhanded instruction and advancing deep-rooted learning is a portion of the UN's national comprehensive instruction strategy, contributing to accomplishing Feasible Advancement Goal-4 (UNDP, 2015).

ICT can improve the learning of children with ASD in class regardless of insufficient tools developed (Altanis et al., 2013). The utilization of assistive has already been demonstrated to have the potential to move forward the instruction of children with ASD in Rwanda and beyond (Alotaibi, 2016; Soomro & Soomro, 2018).

Despite the criticism towards the inclusion of children with ASD in general education, research has shown the success of the inclusion of children with mental illness in inclusive school settings (R. L. Simpson, 2003), guided by following different strategies and the use of particular methodologies and ICT solutions (Modification & Bay, 2016).
Mintz et al. (2009), Shane et al. (2012), Alcantud et al. (2014), and Allen et al. (2016) have proven the importance of the use of technologies to support children with ASD in education.

However, the use of new technologies in inclusive classroom settings requires teachers' knowledge to contextualize the content of the software application used (De Macedo & Ulbricht, 2012).
Lozano-Martínez et al. (2011) argued that using technological media in teaching a student with ASD is supportive. It requires the teachers to improve their ability to carry out tasks with emotional skills.
The adoption of simulation-based multimedia technologies (W. Chen, 2012) has improved basic computer skills (e.g., word processing and spreadsheet applications) in ordinary Rwandan schools, but not necessarily in inclusive and special schools(Karangwa, 2008).
The report of UNESCO (UNESCO, 2011) showed that ICT plays a significant role to address the problem of dropping out of school in different countries, and the government of Rwanda put the effort from lower to higher education to integrate ICT into other domains (Ministry of Information Technology and Communications, 2018).

2.3.2. The use of a computer for children with ASD

The development of ICT tools like computers has evolved over the last decades to support different activities of human beings. Most computer applications respond to the needs of neurotypical children and other types of disabilities. The applications designed for children with ASD focused on behavior and social deficit and other disorders that are associated with ASD. Researchers like Jyoti & Lahiri (2020) documented that computers are helping the improvement in learning among children with ASD due to their consistency and predictability compared to other tools. Regarding the universal web and mobile accessibility guidelines, the computers are designed to display concrete messages for users with disabilities (De Macedo & Ulbricht, 2012).

Previous studies by Abidoğlu et al. (2017) revealed that the use of computers among children with ASD has the following benefits:

1. Computers give consistency, and convenience, invigorate readiness without undue weight and permit the children to control their learning process.
2. Organized computer programs aid extremely introverted children to overcome their over-incitement selectiveness through honing or adequate experience.
3. Utilizing a voice separator in discourse gives a similar procedure in securing verbal language.
4. Numerous internal-external apparatuses can be adjusted agreeing to the child's improvement (touch screen, joystick, etc.)
5. Computer voice separators make children incapable of creating their discourse aptitudes with mutual communication through a visual translation of the dialect or image frameworks.

Children with ASD can learn from using computers when the software applications installed on them can respond to their level of impairments.

2.3.3. Special Input Devices: Touch Screens and Other Technologies

Tablets and other small devices bring opportunities to learn for children with ASD. These devices can be used in many ways, like requesting services and learning new skills from the planned curriculum.

Using low-cost devices like smartphones is crucial due to their flexibility and portability. The touchscreen layout is designed to be accessible for individuals with learning difficulties like those with ASD because

the easiest way to slide than to type text. Individuals with ASD can improve communication through input devices when the applications meet the environmental context.

The study by Watt (2010) highlights that the children's competencies and awareness of new technologies have continued to increase in the last few decades. The children are now cooperative with the latest technology revolution as they are considered native speakers. Children with ASD easily understand the content with animated images within applications installed on computers and smartphones.

Except for the deficit in communication and loss of focus, research shows that children with ASD are visual learners. They can perform even better than those with neurotypical development (Bartoli & Lassi, 2015). Therefore to assist in teaching children with ASD through ICT technologies, social skills, video modeling, reinforcement, speech, and motor skills are items to consider when selecting an application for smartphones or tablets (Hourcade et al., 2012).

2.3.4. Virtual Reality

The University of Toronto (2021) defines Virtual Reality (VR) as a computer-made environment created with software and presented to users in the form of Three Dimension (3-D) to make users accept and connect the concept with the natural environment. In VR, images that reflect the real world are explored interactively with digital gadgets such as computers, tablets, and smartphones by manipulating the keyboard or moving the mouse and dragging on the screen. For example, the VR application is for shopping goods. By using the application, the children can imitate the operation in their daily life.

Other terms defined by Gupton (2017) groups are Augmented Reality (AR) or Virtual Augmented Reality (VAR) which include digital elements in the live view using devices like the camera on a smartphone. Mixed Reality (MR) or Virtual Augmented Reality (VAR) that combines AR and VR with real-world and digital objects, and Extended Reality (XR), which includes the various technologies that enhance our senses like creating the actual world or simulated worlds.

Assistive technologies such as Virtual Environments (VE), Augmented Reality (AR), and smart glasses have been developed in recent years to improve the collaborative, interactive environment to make children with ASD stay focused (Vahabzadeh et al., 2018; Fraccaro et al.; and Fraccaro et al., 2015).

According to Moore et al. (2010), VR is divided into two categories: 1) The simulation of a natural environment for training and education, and 2) The development of an innovative environment for a game or interactive story. Virtual Modeling Language (VRML) is a computer programming language used to create VRs is Virtual Modelling Language (VRML).

The VR-based mobile applications are used to improve motivation and to learn for children with ASD. Previous studies documented that the VR application for children with ASD results in motivation and improved attention (Ravindran et al., 2019).

Escobedo et al. (2014) revealed that children with ASD are more determined on the VR tasks in the teaching and learning process. In countries like the United States, VR is used in public schools to help children with ASD practice social skills and initiate interaction by asking questions and sharing interests with others. (Escobedo et al., 2012). The same study reported that interactions increased for students with ASD and those with neurotypical development. Chen et al. (2015) documented that VR could improve social interaction among adolescents with ASD when developed to enable them to recognize emotional expression. The same study highlighted that using the AR video in the storytelling could improve the communication of nonverbal students on the spectrum. The researchers also reported that VR could help children with ASD improve their vocabulary skills by using simulations that combine images, videos, and audio. In McMahon et al. (2016), children with ASD can learn a short time frame and show an immediate improvement in new vocabulary. Similar research documented that children with ASD show a considerable improvement in self imagination. (McMahon et al., 2016). The upgraded Google glasses using VR help an individual with ASD to recognize the emotions of others (Escobedo et al., 2014; Goodle, 2021).

2.4. Digital content to support the learning of children with ASD

2.4.1. Overview of digital content

Internet is one of the resources for discovering entertaining activities that teach and excite children with different learning disabilities. Several studies proved that ICT integration in education supports children with ASD and other developmental disabilities in the classroom (Roxana Bassi, 2010; The University of the West of Scotland Paisley Scotland, 2016; MINEDUC, 2018; and (Ntalindwa et al., 2019). Educational websites such as IXL Worldwide (IXL Learning, 2020), (Funbrain Holdings, 2020), and Khan Academy

(Khan Academy, 2019d) have content to support the learning of children with learning disabilities, including dyslexia, dysgraphia, Attention Deficit, and Hyperactivity Disorder (ADHD), and visual-motor deficit.

These websites assist children with learning disabilities in mastering basic skills in reading and math or advanced concepts like calculus (Khan Academy, 2019b).

2.4.2. Design of digital content for children with ASD

2.4.2.1. Edutainment for children with ASD

Children with ASD tend to be visual learners. The digital content designers for children with ASD take advantage of the senses like seeing and hearing by integrating images and videos into the planned content (Ntalindwa et al., 2019a). Wilson et al. (2017) documented that child with ASD who demonstrated verbal difficulties started talking when the teachers used animated videos in their classes. Other studies also revealed that gamified content integrated into the digital content responds to the cognitive deficit of children with ASD (Ern, 2014). The introduction of gamification in the Khan Academy video has proved promising to bring new ways of engaging students with the activities while providing precious data for the teacher (Tenório et al., 2018; and Khan Academy, 2019d). In several studies (Khan Academy, 2019c), (Tenório et al., 2018), and (Morrison & DiSalvo, 2014), the online content in teaching mathematics demonstrated a positive impact in the different learning environments. Online content presented that several specific gaming elements online, such as points or badges in subjects, need practical activities and improve learners' engagement by providing simulation images like earth, sun, and others (Morrison & DiSalvo, 2014).

2.4.2.2. Learning mathematics through edutainment

According to Ferdinandus (2020), Edutainment alludes to utilizing video recreations and amusement for informative purposes, and children with ASD enjoy playing games using digital devices. These highlights give natural interaction, subsequently making a difference in children's centers (Petersen et al., 2014). Studies revealed that children with ASD use most of their time playing games (S. Fletcher-Watson et al., 2016).

Teaching mathematics to children with a deficit in communication like those with ASD is possible when the content is gamified using multimedia technologies (Morfidi et al., 2012; Morfidi et al., 2012; and Tashnim et al., 2017). The findings of Pavlov (2014) and the universal web accessibility fundamentals (WAI, 2019) proposed guidelines to follow when designing ICT-enabled assistive technologies in some intervention areas for children with ASD.

According to Spek et al. (2019) and Ern (2014), gamification of content for the learning of children with ASD brings the opportunities to overcome limitations of accessibility by fostering independence and assisting them in social relationships. Since children with ASD are different in behavior, parents and educators need to contextualize the content of the technological applications.

2.4.2.2. Design principles of digital content for children with ASD

There has been a rapid development of digital content for children with ASD available in the last decades. The internet made learning accessible to children with and without ASD worldwide. The principles of designing digital content refer to the form, content, and devices related to system behavior and inputs (Hussain, Abdullah, Husni, et al., 2016). The same study documented the interface of the digital content for children with behavioral challenges such as ASD should have three elements: 1) form, 2) content, and 3) behavior.

2.4.2.2.1. Form

In this thesis, a form is the interface's physical layout, including fonts, colors, buttons, figures, and labels. The design principles of a form include: 1) simple, without many visual stimuli, to maximize the chance of concentration, comprehension, and learning of the children, 2) the number of pictures should be within the acceptable limit per each page, 3) The screen size of the images should be made very large to make it easier for the users to see the items and to enable them to correctly press/tap each item on the screen without accidentally hitting another icon/button, 4) The icon of the home page should be easily distinguished, and 5) use alternative color than black (Kamaruddin & Sulaiman, 2018).

2.4.2.2.2. Content

In this study, the content combines text, images, audio, and videos that children with and without ASD use to learn. Studies documented that children with ASD can use Picture Exchange Communication System (PECs) to communicate with others and interact with the environment (Vicker, 2022).

The design of digital content for children with ASD respects the following principles: 1) The audio aspects should correspond with the images; 2) It should also be user-friendly and in an appropriate number; 3) To consider the langue to use and avoid bold terms and make it simple as possible; 4) There should be an option for uploading photographs, and 5) There should be a function enabling the pronunciation of the entirely formulated sentence. (Hussain, Abdullah, Husni, et al., 2016).

2.4.2.2.3. Behavior

There is an association between digital content use and aspect of children's development and behavior change (Chassiakos et al., 2016). The behavior of children with ASD changes according to their developmental age and environment (Hill et al., 2015). To design digital content, the study by Hussain, Abdullah, Husni, et al. (2016) recommends images identical to real-life objects facilitate easier recognition and allow children to learn more efficiently and effectively, and e simple navigation buttons from one page to another.

2.4.4. Curriculum and digital content in Rwanda

Rwanda's competence-based curriculum framework emphasizes inclusive education. It has seven key competencies: Literacy, Numeracy, ICT, Citizenship and National identity, Entrepreneurship and Business Development, Science and Technology, and Communication in the official languages. Literacy and numeracy are considered fundamental to accessing learning in other subjects. (MINEDUC, 2018). The content of those subjects is being digitized and uploaded to the Learning Management System of Rwanda Basic Education Board (REB, 2015a).

2.5. The mobile applications for children with ASD

2.5.1. Computer-Based Intervention

The Computer-Based Intervention (CBI) available on mobile devices improves the learning of children with ASD even when used with minimum supervision (Novack et al., 2019). Different studies suggested that electronic devices such as iPads and smartphones enabled with the assistive application effectively teach children with ASD when additional features like audio and videos are provided (Kagohara et al., 2013).

Previous studies by Tanner et al. (2010a), Fairus et al. (2016), and Soomro & Soomro (2018) revealed that mobile application technologies are crucial to improving the learning of persons with ASD. According to Díaz & Barco (2012) and Alcantud et al. (2014), the development of assistive technologies for a person with ASD has increased in the last decade.

2.5.2. Mobile applications interventions

The development and tailor-made design of mobile applications have the immense potential to help the learning competencies of children with ASD in schools (British Columbia. Ministry of Education. Special Programs Branch., 2000).

Previous studies revealed how mobile technologies enhance academic skills, such as word matching and picture perception (Allen et al., 2016) and (Xin & Leonard, 2015). The introduction of the mobile application is one of the most attempted solutions to include persons with ASD in a society where multimedia technologies improve their writing skills and social communication (Omar & Bidin, 2015).

Researchers recommended developing mobile applications to support individuals with ASD (Read et al., 2016) and (The University of the West of Scotland Paisley Scotland, 2016). However, the mobile application should be culture-specific and context-specific (Spikins et al., 2016) by including indigenous features and examples of motivations available in their local context.

Different mobile applications such as iConverse (Disabled World TM, 2020) and SPEAK all! (Purdue University, 2013) have successfully improved the communication ability of children with ASD (Saad Yahya Athbah, 2015). The success of the mobile application designed for the person with ASD happens

when it responds to zones of instructional opportunity, which are central coherence, a theory of mind, and executive function (Rasche et al., 2013). These zones of instruction outline a clear and validated structure of the specific instructional needs of the user where the deficits and impairment associated with ASD affect the user's learning style (Qian & Lipkin, 2011). The interruption in instruction zones reduces the number of new skills translated to memory to make the appropriate decision (American Psychiatric Association, 2013). This information is significant in using mobile applications since they help focus attention on children with ASD (Rasche et al., 2013). The typical interface design of mobile applications may or may not be attainable to all children who can take much time to engage in the proposed activities (Boucenna et al., 2014; Soomro & Soomro, 2018).

The previous studies documented the Participatory Design approach (Douglas Schuler and Akie Namioka, 1993) and (Eaton, 2015) and Agile (Patil et al., 2016) methodologies to use when developing ICT tools to support the learning of children with ASD.

2.5.2. Characteristics of mobile applications for children with ASD

Application designed for children with ASD requires a set of requirements to improve the probability of successful learning (S. Fletcher-Watson et al., 2016). Novack et al. (2019) identified a set of characteristics needed for software interaction and design. Punchoojit & Hongwarittorrn (2017) documented the guidelines for designing a task-centered User Interface (UI).

Mobile applications present different characteristics depending on the intended users. However, an application designed for ASD manifests similar characteristics such as 1) Prevalent use of pictures, 2) Audio recording, 3) Focus on learning traits, and 4) Single learning activity (Voon et al., 2015).

2.5.2.1. Prevalent use of pictures

The application developed for children with ASD uses pictures to communicate words or emotions. Different studies reported that images allow educators to access intentional, social, and task-focused engagement of children with ASD (Omar & Bidin, 2015). The Universal Design for Learning (UDL) recommends using images in the classroom of diverse learners (Evmenova, 2018).

The use of images in teaching children with ASD has the following benefits

a. Images encourage independence

Children with ASD have challenges with socialization with their peers and recognition of social emotions of those suffering from verbal communication. The studies showed that children with ASD improve participation in group projects when the curriculum gives them a chance to explore the content using images (MacLeod et al., 2017). Using images in the teaching and learning of children with ASD improves their knowledge when the educators of individuals with ASD play a role in the art of photography (Charles, 2021).

b. Students gain flexibility in their thinking

Children with ASD face stress and anxiety challenges in an inclusive environment (Paper, 2012). Studies also documented that stress and anxiety occur in the transition of the developmental period of children with ASD (Corbett & Simon, 2014). Children with ASD learn more and engage in related activities that include images used in schools (Ntalindwa et al., 2019a). Other associated studies documented that using images in mobile or web-based applications could reduce stress among children with ASD when these images reflect the real environmental context (Rabba et al., 2020).

c. Students improve their communication skills

Studies reported that visual memory is a zone of quality for children with autism, but the complexity of the stimuli shows up to influence memory work (Qian & Lipkin, 2011). Children with autism could perform coordinated controls on a postponed response visual segregation task (Alexander & Dille, 2018). Studies proved that students with ASD and other learning disabilities are more comfortable with oral presentation than written text (Virginia Department of Education, 2011).

The study of Christopher & Shakila (2012) documented that eye contact may be an exceptionally social, nearly hint, sort of interaction. When the story was described to the children without the pictures, they appeared more occupied and uninterested. When the images were concealed and turned upside down, they seemed more curious and kept up better eye- contact.

Using images and videos in teaching children with ASD improves their communication skills and performs in a different domain (Kim & Lord, 2013).

2.5.2.2. Audio recording

In combination with animated emotions, the audio recording in teaching children with ASD is essential to increase their cognitive level of thinking. Studies relating to the utilization of music to encourage engagement in children with ASD have focused overwhelmingly on the region of social-communicative practices (K. Simpson et al., 2013). Interventions have included utilizing music to extend peer intelligence and extend responsivity and the start and term of social engagement between children with ASD and grown-ups (Finnigan & Starr, 2010). Educators utilized music in mediations to diminish challenging behaviors that may interfere with learning and extend errand engagement. Music has been used effectively with one child with ASD to decrease issue conduct and increment on-task behavior amid upsetting circumstances. Researchers introduced music in an everyday language expression lesson to investigate the engagement of children with ASD in the classroom, and the result was that children with

ASD are more engaged in the school in the lessons that utilize music when compared to others without the utilization of music (Lima & Castro, 2012).

2.5.2.3. Focus on learning traits

Children with ASD present different characteristics, which are strange to educators in mainstream schools. To succeed in teaching children with ASD, educators in special education provide individualized content that responds to the individual learning style (Gunn & Delafield-Butt, 2016).

Students with different learning abilities may face challenges in mastering material without changing the lesson plan or teaching methods. The methods and materials employed outside their learning style result in negative behavior in the classroom (Hulusic & Pistoljevic, 2012). These challenges may happen when the students with ASD are in a more extensive classroom with learners with different disabilities. Therefore, assessing each child with ASD's learning style before preparing an individual learning plan could support the education and success of children with ASD in the academic path and reduce challenging behavior during the learning process.

2.5.2.4. Single learning activity

The mobile application developed for children with ASD tend to focus on a single activity to address a particular deficit. Studies documented that one of the characteristics of the behavior of children with ASD is to focus on a single task. Therefore, the mobile application designer could take this advantage to design tools that respond to individual needs (Tashnim et al., 2017). The studies proved that children with ASD can learn any subject from mobile applications (Allen et al., 2016). Hence it is the role of teachers to select an appropriate tool that responds to the needs of children with ASD in a specific subject.

2.5.3. Principles to design mobile applications for children with ASD

Like other application, designing mobile applications for children with ASD require a set of guidelines. People with disabilities are the primary focus of accessibility. Many accessibility criteria increase everyone's use, particularly in constrained contexts (De Macedo & Ulbricht, 2012). The Web Accessibility

Initiative (Web Accessibility Initiative, 2021) highlighted two critical requirements to design a web or mobile application that supports the inclusion of persons with disabilities. These requirements include:

- Technical requirements ensure the website or mobile application work well with assistive technologies such as screen reader for persons with visual impairments and voice recognition.
- User interaction and visual design address significant barriers for persons with ASD, in which the method of an interface could include understandable instructions and feedback for each action.

The Virginia Department of Education (2011) also recommended the focus areas for interventional interventions that help the developers of mobile educational applications for children with ASD. Dattolo & Luccio (2017), in their review of websites and mobile applications designed for children with ASD, documented a set of requirements to consider when planning to develop a website or a mobile application for children with ASD. Table 2 categorizes these requirements into four categories: 1) Graphical layout, 2) Structure and navigation, 3) User, and 4) Language.

Table 3. Accessibility guidelines for users with ASD

Graphical layout	Structure and navigation	User	Language
1. The standard design and the structure ought to be direct and avoid the substance that occupies the users. 2. The substance ought to be unsurprising and ought to give feedback 3. Pictures should be bounteously utilized in conjunction with the excess representation of information. 4. Pictures ought not to go within the foundation and ought to be sharp. 5. Avoid background sounds, moving content, and squinting pictures. 6. The content ought to go with pictures. Clear, straightforward, and short. 7. Headings and titles ought to be used	1. Navigation should be reliable and comparative on each page/section. 2. The site and each application ought to have a consistent and direct structure to allow users to explore the application. 3. Add route data and route buttons at the top and the bottom of the page.	1. Allow customization. 2. Try to engage the users in the use of the application. 3. Make the interaction with users versatile, considering their interaction history, learning, demands, and needs.	1. The language ought to be exact and straightforward 2. Acronyms and shortened forms, non-literal content, and language ought to not be used.

Source: Accessibility guidelines for users with ASD (Dattolo & Luccio, 2017)

The focus of children with ASD is compromised by the sensory onslaught in the learning environment, preventing them from paying attention when studying (Omar & Bidin, 2015). Therefore, mobile application developers for children with ASD could integrate the indigenous features available in the surrounding environment to stay focused.

Chapter 3. Methodology

This section explains design science and discusses philosophical assumptions, ethics, and data verification. It also presents strategies and methods for data collection and analysis in response to the research questions.

3.1. Philosophical assumptions, design science, and validity and data verification

3.1.1. Philosophical assumptions

In this study, I articulated an interpretative paradigm in five qualitative research questions (Q1, Q2, Q3, Q4, and Q5) to understand how to use and design ICT tools to improve the learning of children with ASD.

According to Lewis (2015), the study required an explication of assumptions regarding 1) ontological, 2) epistemological, 3) axiological, and 4) methodological. From the ontological view, four phases of this study involved teachers, parents, children with ASD, clinicians in Rwanda, and experts in the international field of education, technology, and neuro-developmental disorders. I selected the approaches to data collection based on the study's objective. Epistemologically, literature review, observation, and documents served as the basis of the findings. From an axiology perspective, my values and interests (developing an ICT tool to enable children with ASD) guided me to choose the questions to ask participants throughout the whole process of this study. In this study, I used the interview as a data collection method. My value personal interaction with parents, teachers, and children with ASD contributed to more than anonymous established questions in the interview guide (Saunders et al., 2015).

Methodologically, I mixed the question during the interview depending on the participants' experiences in the fields. The research questions are formulated based on the interest in understanding the use of ICT to support the learning of children with ASD and developing an ICT tool to enable children with ASD. Analysis may also have affected personal experiences, e.g., education, schools, and ICT.

3.1.2. Design science and activities in studies

This thesis focused on developing ICT tools that support the learning of children with ASD in four phases. According to Johannesson, Paul, & Perjons (2014a), Design Science (DS) is "the scientific study and creation of artifacts as they are developed and used by people to solve practical problems of general interest." For illustration, I followed four phases that involved user perceptions of using ICT tools for children with ASD, assessment of the content, the development of an ICT tool that responds to the needs of children with ASD in the Rwandan Environmental Context, and evaluation of the developed mobile application. The Design Science framework used different approaches and methods to respond to research questions and achieve the research goal, reflected in the mixed strategies in four phases of this study.

Design Science builds knowledge in iterations, such as moving back and forth between all the activities of problem explication, requirements definition, development, and evaluation (Johannesson, Paul, Perjons, 2014b). In this study, the process of activities was outlined in four phases as follows:

1. The Use of Information Communication Technologies Among Children with Autism Spectrum Disorders: Descriptive Qualitative Study (Phase I) focused on the initial problem of understanding different perceptions of ICT use among children with ASD and observations of children with ASD when using digital tools. I researched in two months by conducting Focus Group Discussions (FGDs) in different schools and centers caring for children with ASD. This phase aimed to understand current models and methods used when teaching children with ASD and how ICT can address challenges facing children with ASD. I installed two mobile applications on smartphones, laptops, and computers to observe the capabilities of children with ASD to use digital tools. I compared results from mobile applications among children with ASD to children with standard intellectual capacity. The findings of this phase illustrated the initial problem: The use of various low-cost technical devices can aid with teaching and educating children with ASD in Rwanda.

2. Online content as a supporting tool in numeracy learning among children with Autism Spectrum Disorders: A Thematic content analysis study (Phase II). In this phase, I focused on analyzing existing digital content to find out how to support children with ASD through the recreation of

existing content. I selected the content of Khan Academy based on its features that respond to the attention deficit of children with ASD, such as visual, audio, and the introduction of gamification into some content that I saw in the previous phase. I did the thematic content analysis, and the findings of this phase proved the need to create the existing educational tools that respond to the individual needs of children with ASD in society.

3. Develop and evaluate a mobile application to improve numeracy skills among children with autism spectrum disorder: Participatory Design and User testing Study (phase III and IV). This phase results from two previous steps that found ground information that proved the need for the contextualized mobile application for children with ASD in Rwanda. I developed the mobile application through a participatory design approach in which 40 children with ASD, five teachers, and ten parents of children with ASD participated in focus group discussions (FGDs) and usability testing. A narrative literature review was performed to explore existing mobile apps and compare previous studies to design the questions for FGD and facilitate a framework for creating the application. The agile methodology was used to develop the mobile application. The user testing as a formative assessment approach was used to test and evaluate the usability of the initial version of the application to improve its functionalities.

3.1.3. Trustworthiness / Validity and reliability of the study

The validity, reliability of research, and results are the main elements to provide the quality of a research project. According to Hayashi et al. (2019), quantitative studies' validity is more evident than qualitative research studies. In brief, the validity is to ask: - Have I got the right 'thing?'. Denscombe (2019) argued that it is impossible to answer this question in qualitative research. The research questions of the thesis are all qualitative. Credibility (or trustworthiness) is the qualitative equivalent to validity (Denscombe, 2019). In this research, credibility required triangulation, which uses more than one method to collect data on the same topic (Carterb et al.,2014). This thesis used different sources in each phase, e.g., participants, documents, observation, related research, and artifacts.

Phases I-II investigated the context, socio-economic factors, environment context, views of parents, educators, and ASD specialists. It also used observation of children when using digital tools and

analysis of existing content to find ICT solutions to support children with ASD in Rwanda. In the third and fourth phases, the development and evaluation of a mobile application confirmed previous conclusions. E.g., regarding the use of low-cost ICT tools for children with ASD and introduction of indigenous features to recreate or develop digital content to meet the environmental context of children with ASD in Rwanda.

3.2. Research design

Four phases developed in this thesis used case studies as qualitative research designs done in inclusive schools and special centers for children with disabilities. I chose the qualitative method to create in-depth exploration and understanding of a central phenomenon (Creswell, 2017).
The qualitative was chosen over quantitative to explore the views of participants through descriptive (Phase I), thematic content analysis (Phase II), and participatory design and user testing of a mobile application (Phase III and IV). I divided the study into three components by referring to the main phases that are in software application development 1) Requirements and Planning, 2) Design and Implementation, and 3) Testing and evaluation (Adelyar & Norta, 2017).

In the first phase (Phase I), I selected a descriptive qualitative method to understand better teachers' and parents' perceptions of adopting the ICT to support children with ASD. I observed children with ASD using digital gadgets to compare the results with children with standard intellectual capacity. In the first phase, I also used the narrative review of the literature to explore what ASD is and the educational needs of children with ASD. I used the thematic content analysis in the second phase (Phase-II) to examine the current digital content available for children with ASD and understand perceptions from teachers and parents on designing good digital content to deliver adequate support for children with ASD.

In the third phase (Phase-III), I used mixed methodologies: 1) Participatory Design approach to improve the outcomes due to the context-sensitive and future-oriented approach to the design of technological solutions by involving workers and professionals in the design (Douglas Schuler and Akie Namioka, 1993) and (Eaton, 2015); 2) Narrative literature review to compare with existing mobile applications and previous studies (Baker, 2016); 3) Agile methodology which considers customers, developers, stakeholders, and end-

users were used to inspect the application elements at every stage of the development process and make adjustments as per the requirement (Patil et al., 2016).
In the fourth phase (Phase IV), I did user testing as a formative assessment approach (Hartson & Pyla, 2012) in Focus Group Discussions and observation of children using the mobile application to improve its functionalities (Heo et al., 2009; and Borys & Laskowski, 2014).

In this thesis I used a case study method as an empirical research method to investigate the learning capabilities of children with ASD, focusing on the use of digital tools and content within its real-life Context (Teegavarapu et al., 2008). The case studies used in this thesis are 1) descriptive (Phase I), 2) exploratory (Phase II), and 3) explanatory (Phase III-IV).
This thesis applied all phases of research like (1) problem definition, (2) formation of hypothesis, (3) data collection, (4) data analysis, and (5) drawing Conclusions.
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3.3. Setting and Sample

Rwanda operates on a 6-3-3-3 school system: six years for primary school, three years for ordinary level (junior secondary school), three years for advanced level (senior secondary school), and three years for university bachelor's degree. The country has 3,741 pre-primary schools, 3,691 primary schools, and 1,869 secondary schools in general education (Rwanda Ministry of Education, 2022). More than 150 centers in the country are caring for children with disabilities; among them, few centers support children with ASD (Rwanda Ministry of Education, 2019) and (NCPD & NCC, 2016), and they keep the education of children of ASD is still expensive for many families (Ntalindwa et al., 2019a).

The schools and special centers for children with ASD were the settings for this study. I selected schools and centers based on data from the Rwanda National Council for Person with Disabilities (NCPD), the National Council of Children (NCC) (NCPD & NCC, 2016), and the Ministry of Education (Rwanda Ministry of Education, 2021). This study included participants from both rural and urban areas.

The first phase of this study (Phase I) included participants from one province and Kigali city: Groupe Scolaire Jabana (Gasabo District), Heroes Day Care Center (Kicukiro District), Autisme Rwanda (Gasabo) within Kigali city, and the College des Amies de la Paix du Christ Roix (APAX) Janja (Gakenke District)

located in the northern province of Rwanda. In the second phase (Phase II), among six schools from urban areas, only two are in Kigali, the capital of Rwanda: Autisme Rwanda and Groupe Scolaire (GS) Jabana, while the remaining three are from different urban sites in upcountry provinces: HVP Rwamagana (Eastern Province), HVP Nyanza (South Province), Ubumwe Community Center, and APAX Muramba (Western region). College des Amies de la Paix du Christ Roix (APAX) Janja (Northern Province), and College des Amies de la Paix du Christ Roix (APAX) Muramba (western province) are in the rural areas. The third and fourth phases (Phase III) used only Autisme Rwanda (Kigali), which is the center that cares only for children with ASD established in 2014 (Autisme Rwanda, 2020).

3.4. Selection of Participants

I selected the participants using a purposeful random strategy. The specific criteria that are central to the topic of the study were applied. I used the purposeful sampling technique based on the effectiveness of the case study research (Creswell &Chery, 2016). The individuals are selected based on the assumption that they possess knowledge and experience with the phenomenon of interest and thus will be able to provide information that is both detailed (depth) and generalizable (breadth) (Palinkas et al., 2015).

In this research, eligible participants met the following criteria: 1) be an elementary teacher in a class with children with disabilities or mental disorders. 2) Parents with at least one child with ASD, and 3) children are diagnosed with ASD. The children with ordinary abilities participated solely in the study to confirm the observation results in the first phase (Phase I). The gender of the participants did not influence any of the four steps of the study. Teachers and parents were not required to have experience in using ICT in education or using digital devices in teaching activities. However, I had to know about ICT and education. Each phase discussed the details of the selection of participants.

Table 4. Design activities per phase of the study and research questions

Phase	Design activities	Research questions
1	Understanding what ASD is and problem explication.	Q1 & Q2
2	Analyzing the digital content design to support the education of children with ASD.	Q3
3	Design and develop a mobile application.	Q4
4	Demonstrate and evaluate a mobile application.	Q5

3.4.1. Phase I: Understanding what ASD is and problem explication

In this phase, I interviewed participants to determine their views and opinions on the effectiveness and use of ICT in an inclusive classroom setting. Teachers and parents of children with ASD participated in focus group discussions (FGDs). I observed children with ASD using smartphones and computers with cognitive software applications such as Mental Math Expert (Apple, 2019) and Milk Hunt installed (Best Mobile App Awards LLC, 2019). I conducted the FGDs in three randomly selected districts from two different provinces. The study sites included: Groupe Scolaire Jabana (Gasabo District), Heroes Day Care Center (Kicukiro District), Autisme Rwanda within Kigali City, and the College des Amies de la Paix du Christ Roix (APAX) Janja (Gakenke District) located in the northern province of Rwanda. Teachers who participated in this study taught various subjects, including mathematics, ICT, creative performance, geography, English, tailoring, chemistry, history, biology, and Kinyarwanda. Children with ASD and those with ordinary abilities from each school from 5 to 7 years old participated solely in observational sessions, and no questions were asked to them.

Table 5 shows the number of parents and teachers who participated in the Focus Group Discussions and children who participated in the observation sessions.

Table 5. Number of participants in Focus Group Discussion and observation of the first phase of the study

School / Participants	Groupe Scolaire (GS) Jabana	Heroes Day Care Center	Autism center (Autisme Rwanda)	College des Amies de la Paix du Christ Roix (APAX) Janja	Total
Teachers	5	5	5	5	20
Parents	3	3	3	3	12
Students with ASD	4	4	4	4	16
Children with ordinary abilities	3	0	0	3	6
Total	**15**	**12**	**12**	**15**	**54**

Of the participants, there are 20 teachers (N=20), 12 parents (N=12) and 16 children with ASD (N=16), and Six children with ordinary abilities (N=6). Six children with standard intellectual capacity were from two inclusive schools implementing the competence-based curriculum. These schools were the Groupe Scolaire Jabana (N=3) and the College des Amies de la Paix du Christ Roix (APAX) Janja (N=3). Within the parents' group, there were four fathers and eight mothers. All 16 children with ASD and those five with a standard intellectual degree from each school participated solely in observational sessions. The age of children was between five and seven years old. Teachers had experience in teaching children with ASD between two and ten years.

3.4.2. Phase II: Analyzing the design of digital content to support the education of children with ASD

In this phase of the study (Phase II), I recruited 70 participants (N=70), 56 teachers (N=56), and 14 parents (N=14) from seven schools: Five (N=5) from urban and two (N=2) from rural areas.

Among five schools from urban areas, only two are in Kigali, the capital of Rwanda: Autisme Rwanda and Groupe Scolaire (GS) Jabana, while the remaining three are from different urban areas in upcountry

provinces: HVP Rwamagana (Eastern Province), HVP Nyanza (South Province), Ubumwe Community Center, (Western province). College des Amies de la Paix du Christ Roix (APAX) Janja, (Northern Province), APAX Muramba (Western Province) are from the country's rural areas. Within the teacher's group, there were 32 males (N=32) and 24 females (N=24), while in the parents' group, there were six males (N=6) and eight females (N=8). Teachers were teaching Mathematics, Elementary Science and Technologies (EST), Social Sciences, and languages.

I used data from the National Commission of Persons with Disabilities (NCPD) and the ministry of education to select educators (Rwanda Ministry of Education, 2021; and NCPD & NCC, 2016). I recruited the parents from the Rwanda Parent's Initiative on Autism (RPIA, 2020). The parents were not required to have a child enrolled in any school, but s/he might have at least one child with ASD. The age of children was between five and seven years old. Teachers had experience in teaching children with ASD between two and 20 years.

The participants were not required to have experience using ICT in education or digital devices in teaching activities. Table 3 shows the demographic information of the participants in phase II.

Table 6. Sociodemographic characteristics of the teachers in phase II

School	HVP – Rwamagana	HVP - Nyanza	APAX - Janja	APAX - Muramba	Ubumwe Community Center	Autisme Rwanda	GS. Jabana
Gender							
Male	2	2	4	3	2	5	6
Female	6	6	4	5	6	3	2
Age							
Less than 20	1	0	1	2	1	0	0
Between 20 and 25	5	6	5	4	2	3	3
Between 25 and 30	2	1	1	1	1	3	2
Above 30	0	1	1	1	4	2	3
	8	8	8	8	8	8	8
Years of experience							
Less than 5	4	4	5	7	8	8	5
Between 5 and 10	2	3	3	1	0	0	3
Between 10 and 15	1	1	0	0	0	0	0
Above 15	1	0	0	0	0	0	0
	8	8	8	8	8	8	8
Teaching subjects							
Mathematics	5	3	4	6	3	4	3
Science related	1	2	1	1	2	2	2
Social sciences	0	2	1	0	0	1	1
Languages	2	1	2	1	3	1	2

3.4.3. Phase III: Designing and developing a mobile application

Participants in this study phase (Phase III) included children with ASD, teachers, and parents. Five teachers (N=5): two males and three females, were from Autisme Rwanda. Ten parents (N=10) of children with ASD who participated in the design and development of the application were from the Rwanda Parents' Initiative on Autism (RPIA) (RPIA, 2020). The age of children was between five and seven years old. Teachers had experience in teaching children with ASD between two and five years. Teachers' years of experience were between 4 to 15 years teaching in an inclusive school. The parent inclusion of parents in the test and evaluation phase was to have at least one child between 5 and 7 years old.

Table 7 describes 15 participants in the mobile application design and development.

Table 7. The number of participants in the design, development of the mobile application(N=15)

Teachers		**Parents**		**Total**
Males	**Females**	**Males**	**Females**	
2	3	4	6	15

The development of the application followed two steps: (1) User requirement analysis and (2) Design process as recommended by Soomro (2018). Within the design process, I considered also the four fundamentals participatory design principles of human-centered design and application: 1) Ensuring that we solve the core, root issues, not just the problem as presented to us (which is often the symptom, not the cause), 2) Focusing on people, 3) Taking a systems point of view, realizing that most complications result from the interdependencies of the multiple parts, 4) Continually testing and refining our proposals, ensuring they truly meet the needs of the people for whom they are intended (Björling & Rose, 2019).

3.4.3.1. User requirement analysis

The application that I designed for the education of children with ASD needed a set of requirements to improve the probability of successful learning (S. Fletcher-Watson et al., 2016). I used the Agile (Patil et al., 2016) methodology to consider the views of customers, developers, stakeholders, and end-users at every stage of the development process and make adjustments as per the requirement. The FGDs were conducted by involving special education teachers and practitioners in the fields as participants while the children with ASD observed their behavior inside and outside the class.

Information on the software interaction design was gathered from experts around the world who had experience in treating and dealing with children with ASD and individuals with ASD who were successful in their academic careers. This study involved posting questions on the Quora Digest platform (Qura, 2022) and analyzing their replies. I chose to use Quora as my data source because (1) Google Trends data show that it is increasing in popularity against other platforms available globally (Google, 2021); (2) it tries to match questions with experts, and users answer most questions with authority on the content (Paul et al., 2012); and (3) it also offers users the ability to edit the way a question is asked, and thus allows users to connect people with questions they feel the user could answer (Kumar et al., 2018). The information collected from this platform served as complimentary to data gathered from teachers and parents. The profiles and responses from the Quora platform are shared as web links in an appendix- Questions posted on Quora Digest (Phase III).

3.4.3.2. Design Process

As explained in the following equations, I identified a set of characteristics needed for the software interaction from the requirement analysis in the design process.

$U = \{Sn, Cg, Mp\}$ (1)

$Sn = \{Sn_1, \ldots, Sn_n\}$ (2)

$Cg = \{Cg_1, \ldots, Cg_n\}$ (3)

$Mp = \{Mp_1, \ldots, Mp_n\}$ (4)

Where U represents a user (Equation 1), Sn represents the set of the senses (Equation 2), such as eyesight, hearing, and touch; Cg represents cognitive functions, such as memory and attention (Equation 3); and Mp represents a motor function for different parts of the body (Equation 4).

I followed guidelines to create a human-centered User Interface (UI) to design the mobile application, as Punchoojit & Hongwarittorrn (2017) recommended. These recommendations are related to 1) Page composition, 2) Display of information, 3) Control and confirmation, 4) Revealing more information, 5) Lateral access, 6) Navigation, 7) Button, 8) Icon, 9) Information control, and 10) Input mode and selection.

I adapted steps in the task-centered design process and referred to the Universal mobile application accessibility and inclusion proposed by Ballantyne et al. (2018) by making a mobile application more accessible to people with disabilities when they are using mobile phones and other devices.

While designing the mobile application, I followed nine steps: (1) task analysis, (2) choose the representative tasks, (3) find existing interfaces, (4) rough out the design, (5) analyze the user interaction, (6) create a mobile application, (7) test design with users, (8) iterate, and (9) build the design.

3.4.3.2.1. Task Analysis

To design this application, together with parents and teachers, through FGDs, we first agreed on the target audience, as the background of users (i.e., children with ASD) will help the designer to include elements in the design considering their ability.

I developed a mobile application to enable children with ASD to distinguish coins from five to 100 Rwandan Francs based on their symbols and representations. In this process, a software (S) is a set of functionalities (F) operated by the user, which also includes a user interface (I):

$S = \{\{F_1, \ldots, F_n\}, I\}$ (5)

These functionalities are tasks (T) possible to do in the mobile application.

$S = \{\{T_1, \ldots, T_n\}, I\}$ (6)

The mobile application includes a Graphical User Interface (I) which allows users to interact with the system. From equation six (Equation 6), the interface is

$I = \{Uip_1, \ldots, Uip_n\}$ (7)

$Uip = \{\{Cp\}, \{C\}\}$ (8)

Equations 7 and 8 show that an Interface (I) is a set of User Interface Patterns (Uip) which is a group of Graphic User Interface (GUI) interaction styles Cp to solve a particular problem. It is also associated with specific characteristics of users (C).

Each task is associated with a user interface pattern Uip.

$\forall T: Uip$ (9)

Where $\forall T$ represents the universal quantifier, meaning for all tasks, T is associated with a user interface.

From equation nine (Equation 9), the task includes all actions executed by the user.

$T = \{Ac_1, \ldots, Ac_n\}$ (10)

This application's actions are to press, drag, and drop coins into a specific area.

$T = \{Pr\,e\,ss, Drag, Drop\}$ (11)

A child with ASD drags at least one coin of the Rwandan currency system and drops it into a provided space on the right side to get the result. Specific feedback like candy, banana, strawberries, and donuts come immediately after a successful operation. All users with the definite ability (A) exist the user interface patterns.

$(\forall U \cap A) \exists Uip$ (12)

The user interface pattern has coins that the user can drag and drop in the specified place to add up before getting a reward. The use case diagram (Figure 1) illustrates the different tasks to be performed by a user.

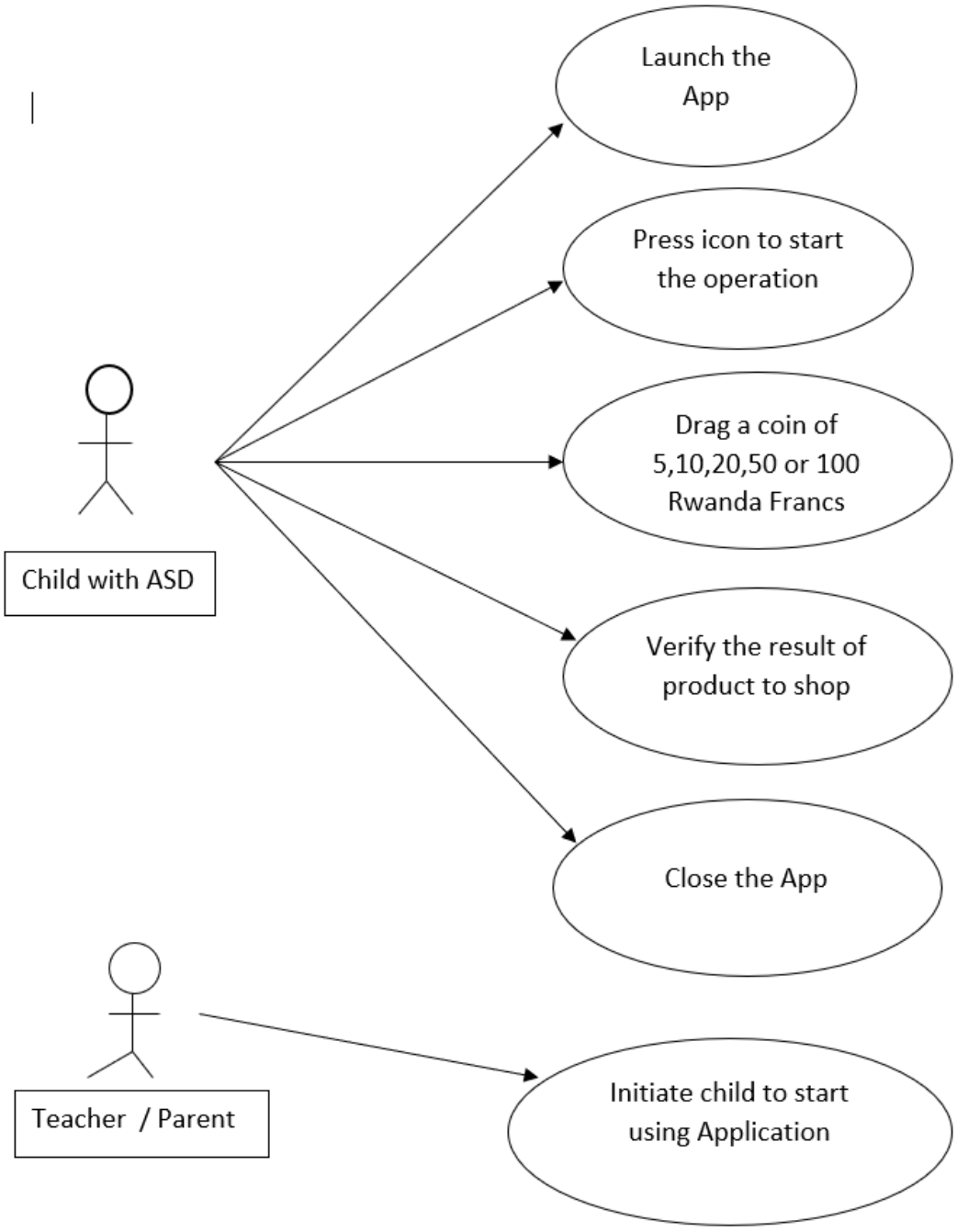

Figure 1. Use case diagram of the mobile educational application for children with ASD

3.4.3.2.2. Choose Representative Tasks

In this step, the mobile app designer analyzed a syllabus of skip counting in the competence-based curriculum (REB, 2015a). Participants suggested numbers and coins represent tasks in this application. Participants suggested numbers and coins represent tasks in this application. The flowchart (figure 2) illustrates the process of learning skip counting through the developed application. From the flowchart (figure 2), the proposed number is given as follows:

$N = \sum(V_0, \dots, V_n)$ (13)

where N is the sum of the expected value of coins and $\sum(V_0, \dots., V_n)$ is the sum of the current value of coins in the target space plus the value of the dropped coin V_n.

$\sum(V_0, \dots, V_n)$ (14)

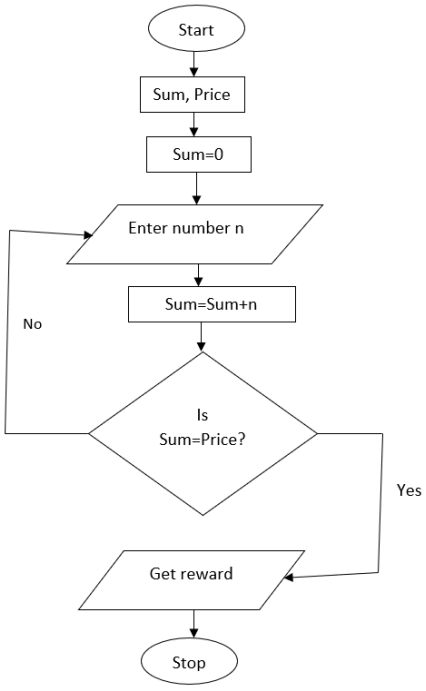

Figure 2. Flowchart of the developed mobile application

3.4.3.2.3. Finding Existing Interfaces

In this step, I identified existing interfaces such as iConverse (Disabled World TM, 2020), SPEAK all! (Purdue University, 2013), and 123 number (Apple Inc, 2019) to build ideas into the system as much as practically possible before making it as a reference to build the actual system. I installed these applications on smartphones and tablets, and I gave them to the children to observe their ability to use these interfaces. The results from this observation were closer to those from our previous study, in which children with ASD were able to use digital gadgets when the apps installed were easy for them to use in the first phase of this study (Ntalindwa et al., 2019b). I used the same methodology of observation and FGDs in the data collection of that study.

This step helped me design an exemplary user interface that depends on how often the users will be using the system compared with how often they will be using mobile applications.

3.4.3.2.4. Rough Out the Design

First, the preliminary (rough) design description is penciled on paper. In this stage, the researchers and education practitioners had in-depth discussions on the features the system should have before building a mobile application so that it can be tested out with the end-users. Figure 3 presents an example of the design that simulates the intended interface.

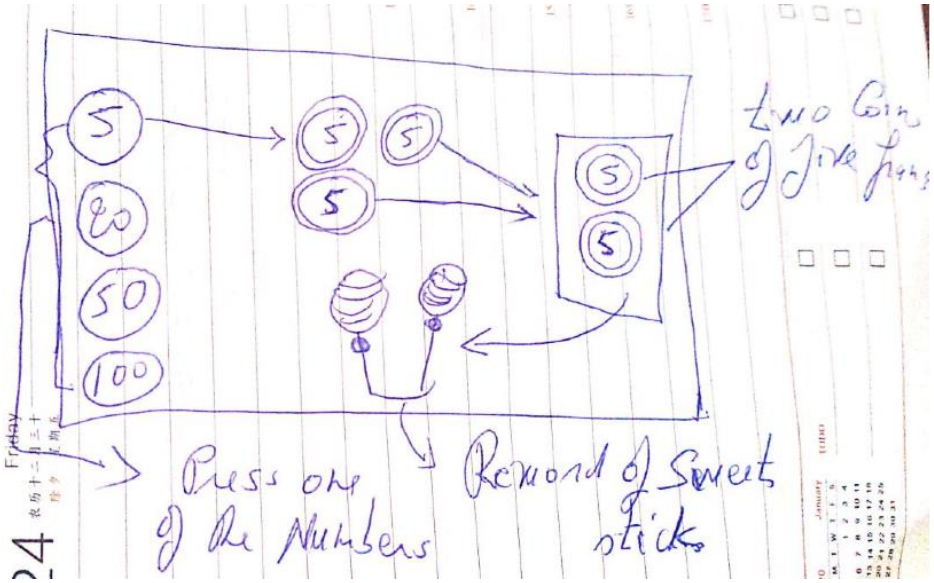

Figure 3. Rough out the design.

As seen in the figure, a child with ASD presses and drags one image of a coin and drops it into the designed space on the right-hand side. The system will count the number of currencies the child puts into the area to present the reward. The child can repeat the same action as much as s/he can.

3.4.3.2.5. Analyze interface of mobile application

Before designing the mock-up, I first analyzed how the users can interact with the interface that has been roughed out while performing specific tasks. At this stage, I identified areas where the users might make mistakes, such as pressing the wrong icon of coins or trying to go back. The analysis of the temporary interface was also supported by results from previous steps and experiences of study participants (Phase I and II).

To use the developed application, children with ASD level 3 will get support from their teachers, parents, or family members who live with them.

3.4.3.2.6. Create a mobile application

This mobile application was designed using Adobe Captivate version 19.0 (Adobe, 2020), the interactive eLearning content authoring tool that has features to design a responsive interface and is compatible with both Android (Android Inc, 2020), the common platform installed in smartphones, and iOS, installed on Apple devices (Apple Inc, 2020). Figure 4) shows the template used to design the mobile application's user interface.

I created this mobile application only to find flaws in the system and ways to improve them in terms of functionality and usability.

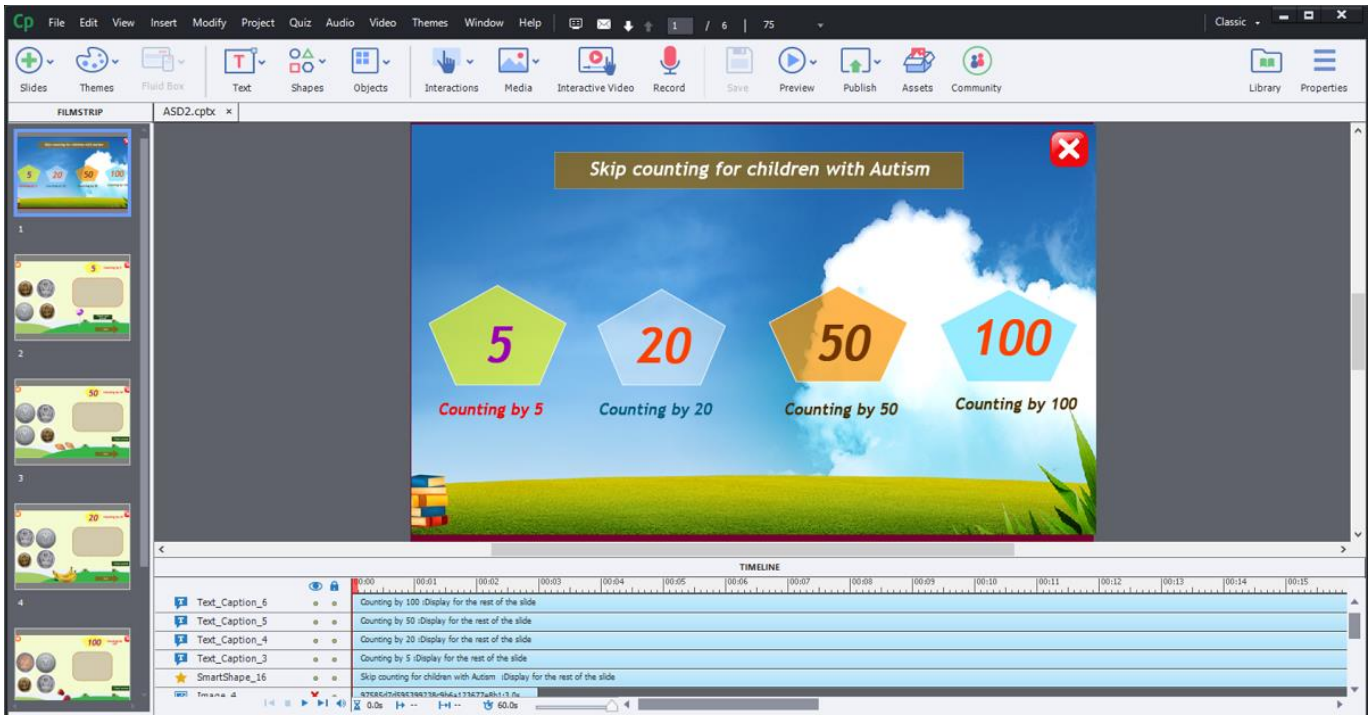

Figure 4. Adobe Captivate interface

3.4.3.2.7. Test Design with Users

Afterward, the mobile application built was tested by chosen users at Autisme Rwanda to bridge the gap that might still exist. This stage helped me improve the system to suit children with ASD in Rwanda. I then analyzed the list of features that may need improvements, such as the number of coins, background colors, and navigation. After testing the interface with the children, FGD was completed with educators at the Autisme Rwanda Center to get more information on the interface design.

The children were identified randomly from the class, regardless of their subject and the economic status of their parents. Gender did not influence children's interaction during the test.

Both teachers and parents helped me in the recruitment of children that tested the app and continuously supported us in monitoring the changes in the behavior of these children. Parents of children who are not in school helped us by monitoring their children when they used the application at their homes during the test period. In this study, I gave Every child a tablet installed on the application. The children used the application for 30 days.

3.4.3.2.8. Iterate

Based on the test phase results, the participants (teachers and parents) reported problems that need to be accounted for, such as changes in the background colors of the application, images, and feedback messages. I re-designed the application to make the recommended changes and reverified it with the participants. I revised the interface two times.

3.4.3.2.9. Build the Design

The final step in the development of this application before it may be commercialized is building the product. I created the application after solving the problems identified in the previous phases of the design process and FGDs. Continuous testing was performed to modify the interface according to the needs of children with ASD, whose behavior may vary from one another.

3.4.4. Phase IV: Demonstrating and evaluating a mobile application

In this phase, I did user testing of the mobile application by exposing the mobile application installed on the tablets to the children with ASD enrolled at Autisme Rwanda and those not registered at any school. The goal of the user testing was to investigate the outcomes of the interaction of children with ASD and the developed mobile application and device (Nielsen Norman Group, 2022). The children with ASD used the mobile application for 30 days. The role of teachers and parents in this phase of evaluation was to monitor and record the progress of children with ASD when using the mobile application.

After the user testing period, I conducted the FGD with teachers and parents who facilitated the testing phase. In the FGD, we discussed how children with ASD interacted with the mobile application.

Teachers and parents examined the application for thirty days and observed children when using the mobile application. They also evaluated the interface of the mobile application by responding to questions proposed following the heuristic principles of usability heuristic such as 1) Visibility of system status, 2) Match between system and the real world, 3) User control and freedom, 4) Consistency and standards, 5) Error prevention, 6) Recognition rather than recall, 7) Flexibility and efficiency of use, 8) Aesthetic and minimalist design (Nielsen Norman Group, 2022).

I excluded 9) help users who recognize, diagnose, and recover from errors, and 10) Help and documentation because of attention deficit among children with ASD, which makes them unable to concentrate on texts (Kirk et al., 2017). I used the same methodology of FGD to collect data from the test of the interface.

Forty children with ASD (N=40): 32 boys and eight girls participated in a test of the developed application. Five children (N=5), four boys and one girl, were not enrolled in schools, and I visited their homes with their parents. Thirty-five (N=35) children: 30 boys and five girls, were from "Autisme Rwanda." The same teachers and parents who participated in the third phase (Phase III) also participated in the Focus Group Discussions to evaluate the efficiency and acceptability of the mobile application. Table 8 describes 55 participants in developing, testing, and evaluating a mobile application.

Table 8. The number of participants in the design, development of the mobile application(N=55)

Participants	**Design and evaluation**	**Development**	**Test**	**Total**
Teacher	5	0	0	5
Parents	10	0	0	10
Children with ASD enrolled in a school	0	0	35	35
Children with ASD not enrolled in school	0	0	5	5
Total	**15**	**0**	**40**	**55**

The age of children was between 5 and 7 years old. Autism Rwanda is not a formal school but a center supporting children with ASD. The center admits children who require special schooling but may proceed to different inclusion levels in mainstream education or local authority special schools (Autisme Rwanda, 2020). Thus, I did not consider the levels of the study in the test and evaluation of the mobile application.

3.5. Data Collection

I used in-depth, semi-structured interviews to collect data from all four phases (Phase I, II, III, & IV) in this study. Focus Group Discussions were conducted in a separate room in each school to provide an environment where participants could give accurate, complete, and sincere answers during the discussion. A series of open questions served as an interview guide during Focus Group Discussions (FGDs), a way to gather people from similar backgrounds or experiences to discuss a specific topic of interest. The interview took face-to-face, lasted longer than one hour, and was audio recorded. In the third and fourth phases (Phase III-IV), I visited children with ASD who were not in school at their homes, and discussions with their parents took place.

In the first phase (Phase I), I chose the software applications to support the education of children with ASD, such as *Mental Math Expert* (Apple, 2019) and *Milk Hunt* (Best Mobile App Awards LLC, 2019). The

software applications were randomly selected from the Internet and installed on laptops and smartphones to test their usability by children with ASD and those with the standard intellectual capacity to observe and compare their ability to use these digital devices.

In the second phase (Phase II), I selected the online content of early counting mathematics of Khan Academy (Khan Academy, 2019b) based on its audiovisual features, which can aid children with ASD.

In the third phase (Phase III), I posted questions on the Quora digest forum (Quora Digest, 2021), a community-driven social platform for questions and answers.

I chose to use Quora as our data source because 1) Google trend data shows that it is increasing in popularity against other platforms globally (Google, 2021). 2) It tries to match questions with experts who can answer questions with authority on the content (Paul et al., 2012), and 3) It also offers users the ability to edit questions to allow users to connect people with questions they feel the user could answer (Kumar et al., 2018). The information collected from this platform served as a supplement to data gathered from teachers and parents. The profiles and responses from the Quora platform are at the end of the shared manuscript of the third phase (see Paper III. appendix 4a). I observed children with ASD using the developed mobile application in the fourth phase (Phase IV). During the Focus Group Discussions (FGDs), I mixed questions purposively to make participants more engaged in conversation in each phase (Phase I-IV). The sample of pre-defined questions used in semi-structured interviews is at the end of each paper produced in each phase in the appendices of this thesis.

3.6. Data Analysis procedures

The interviews and results from the observational sessions were analyzed and transcribed using Word. I developed a coding scheme with codes serving as groups of teachers, parents, and children with ASD to clean the data considering their knowledge, experiences, and perspectives. I refer to teachers, parents, and children using the following notation: T1 refers to teacher 1, P1 refers to parent 1, C1 refers to child 1, and so on in all phases (Phase I-IV).

In the study's second phase, the inductive, descriptive thematic analysis of the FGDs transcripts followed several steps (Caulfield, 2019). These steps are (1) Familiarization, (2) Coding, (3) Generating themes, (4) Reviewing themes, (5) Defining and naming themes, and (6) Writing up. Firstly, transcripts were read and re-read to establish familiarity with the data. Then the initial codes that captured features of interest and

importance to the research questions were identified. I developed a coding framework by collating initial codes to create candidate codes that meaningfully described the overall patterns of participant responses in the data. Selected participants reviewed transcripts to ensure that the coding framework captured participant responses. Then, the transcripts were coded line-by-line to collate all instances of patterns identified in the data. Finally, candidate codes were then collapsed to produce higher-order themes that were then read for patterns of similarity and divergence within and across each theme.

In the third and fourth phases of the study (Phase III-IV), I analyzed interviews following the guideline of the Qualitative Narrative Analysis (QNA) method (Sudhahar et al., 2011).

Data management in all phases (Phase I-IV) was supported using the qualitative software program NVivo (QSR International Pty Ltd. V.9) (QSR International, 2020). Participants' demographic data were analyzed using SPSS-23 (IBM, 2021). Descriptive statistics were used to summarize these data. The data from the interviews are kept in a secret place at the physical drive.

3.7. Ethical considerations

There are four areas to consider when conducting research that involves the Autism community: 1) Pre-study considerations; 2) Recruitment of participants; 3) Study visit considerations; and 4) Post-study considerations (Gowen et al., 2020).

3.7.1. Pre-Study considerations

The participants of this research are from the autism community. Following the recommendations of preventing the possibility of personal research (Gowen et al., 2020), I first identified schools and centers to be involved in the study. Then I applied for ethical clearance from the collegial research ethical committee of the University of Rwanda – College of Education. I informed schools and centers of the interest in the study and future contributions of findings. I and Autisme Rwanda signed an agreement of collaboration before starting the design, development, and evaluation of a mobile application. Before beginning the research, I got an ethical clearance certificate from the University of Rwanda – College of Education and a letter of collaboration from Autism Rwanda.

3.7.2. Recruitment of participants

In the recruitment of participants, I sent the introduction letter informing them why the research was taking place and explaining the methods and procedures to follow when conducting the research. I used this approach to reduce the stress and anxiety that may happen when induced by unexpected activities during the study. The participants were informed about the number of teachers, parents, and children with ASD to participate in the research. I sent a sample of questions to guide the focus group discussions and the consent form signed by participants in each phase.

3.7.3. Study visit

The managers of schools and centers and I discussed and agreed on the venue before data collection to prevent anxiety and stress (Disorder et al., 2015). In this study, all participants agreed to meet far from the rooms where children with ASD stay. Managers of schools and centers also clearly guided me to reach the venue with one participant member to prevent the deviation.

3.7.4. Post-study

After each research activity, participants and I discussed the way of communication after the research projects. After research, a full briefing is provided, including information on the investigation, what will happen to the findings, and when they can expect to hear about the study's outcomes. Participants have access to published papers, and they will also have rights to the completed thesis.

Chapter 4. Results

This study investigated the feasibility of designing a mobile educational application for children with ASD that support their inclusion in the Rwandan Competence-Based Curriculum (CBC). The purpose of the qualitative case study was to explore how to adapt the ICT in the teaching and learning of children with ASD in inclusive settings. The findings of this research identified five themes which are formulated based on the research questions: 1) Special educational needs for children with ASD, 2) How to use Information Communication Technologies to support the education of children with ASD, 3) Educational digital content to support the learning of children with ASD, 4) Development of a mobile educational application for children with ASD, and 5) Acceptability and efficiency of a developed mobile application.

4.1. Special educational needs for children with ASD

Research question 1: What special educational needs are for children with ASD?

4.1.1. Educational needs for children with ASD

Children with ASD need exceptional support to respond to their interests and learning abilities. Children with ASD face challenges, and there is a need to provide appropriate resources that help them learn.

Of eight selected schools, five (5/8, 62.5%) use the Individualized Education Plan (IEP), a written document that outlines a child's education. To develop the IEP, parents, teachers, and schools' administration sit together to analyze the needs of each child registered in a school. The IEP outline includes 1) The child's particular education plan (goals for the school year), 2) Services needed to help the child meet those goals, and 3) A method for evaluating the student's progress.

The parents who participated in this study demonstrated the efficiency of the IEP developed together with educators to contribute to their children's education after classroom time. Teachers reported that children with ASD are different from each other in a class, and they use various techniques to support them in the class.

Teachers reported that children with ASD are hypersensitive to the environment. They provide accommodations to make them focus, such as reducing light in the class and putting images that attract the children in the course.

Children with ASD get easily distracted by things that other typical children ignore. Parents and teachers reported that the usual distraction of these children includes 1) whispered conversations, 2) classmates asking teachers for help, 3) children running, screaming, and playing outside of the classroom windows, and 4) intercom announcement.

To prevent the distraction of children with ASD, the classroom of these children is in an isolated space, and there are rooms where children can use the different objects for their occupations.

Children with ASD face verbal challenges at an early age, which becomes more critical at school. Two schools that participated in the study reported having a speech therapist who helps children to develop verbal communication at school.

Teaching children with ASD is a multidisciplinary work involving educators, parents, and health professionals. Understanding and commitment of all sectors to educate children with ASD could improve their lives.

4.1.2. Methods and techniques used when teaching children with ASD

Teaching children with ASD requires different strategies to ensure that every child receives support. Teachers reported strategies to use, such as 1) creating an environment that is not over stimulating, 2) creating a structured environment with a predictable routine, 3) giving few choices, 4) Select repetitive motions when working on projects, 5) Maintaining voice low and clear when teaching, 6) Limit physical contact, 7) Allow students to stand instead of sitting around a table for a class demonstration, 8) Encourage and promote one to one interactions with students to promote social skills, 9) Eliminate stress, and 10) For visual learners, be sure to use signs and pictures, such as the pictures and videos.

In teaching children with ASD, teachers could provide personalized content to aid their learning based on each child's individual needs. However, there is a standard methodology that teachers apply to all children. For example, when asked about methods to help pupils get to grips with mathematics, teachers reported that games are the best approach to stay focused and engage in the classroom.

Teachers from five schools (5/8, 62.5) also reported they use Applied Behavior Analysis (ABA) model by offering different rewards to make students stay focused. Of 56 teachers, eight (8/56, 14%) reported that children with ASD need instant motivation, like giving them different objects they most like available in the school environment.

Only two (2/8, 25%) use Relationship Development Intervention (RDI) to help children interact positively with other typical children in eight schools. They learn these skills through play guided by teachers. In the implementation of RDI, a teacher selects a social game to play with children, and the activity is repeated many times.

Children with ASD are visual learners. The use of images and videos brings the freedom of children to work on the given task by imitating what they see. Parents and teachers also reported that games could enable them to socialize with others and support others in enhancing teamwork in inclusive class settings. Most teachers reported providing personalized content and creating a conducive environment that allows learner interaction could help discover the learning abilities of children with ASD and develop their inner talents.

4.1.3. Teaching and Learning Numeracy for Children With ASD

This theme elucidates models and techniques to support learning numeracy for children with ASD. Teachers used different strategies and tools available in the surrounding environment to motivate learners when teaching new numeracy skills. A common statement from teachers says:

> *Learners with Autism need rewards like giving them a pen or a toy to encourage them to study. We use available tools like pens or rulers to motivate them to learn.*

This succeeded when the teachers considered the needs of each child, as they are different across the spectrum. This is supported by an international expert who replied to the question posted on a public forum:

> *You must consider the needs of each child, as everybody on the spectrum is different. Some people on the Autism Spectrum might find it challenging to do simple math problems, while others may find complicated math problems too easy. Some may need more help with the X and Y values, while others may need more help counting money.*

This statement suggests that individuals with ASD do not learn the same way, and thus the methods for teaching them need to be different. In the public forum, a person with Asperger syndrome said

> *The first flaw in your question is that you assume we all learn the same. We don't. However, if you take the approach that all individuals have different learning styles and try to incorporate that into your app, you might find success.*

Children with ASD struggle to receive information outside their preferred style, which leads to classroom behavior changes. Teachers in inclusive schools reported insufficient resources to support the individual learning style with ASD. They suggested modifications to the curriculum and considered the behavior of each child with ASD in the class.

Changes in methodologies and curriculum modification by integrating ICT in all subjects could help teachers develop the skills of children with ASD in their classes.

4.1.4. Material realities used to improve the learning of children with ASD

This theme shows that the education of children with ASD involves using different objects to contextualize in connection to the school's physical environment to understand better the content of the subject they are learning. When asked about the things used in teaching children with ASD, 40 (71%) teachers responded that they use real examples of objects available in schools to replace the models in the curriculum syllabus. Teachers in inclusive schools reported that contextualization of content helps children understand the topic planned in the curriculum like other typical development children.

All teachers (100%) reported that educational videos are alternative to support insentient learning among children with ASD when they are out of classes.

For children with ASD, videos that simulate the real world are more motivating and make children focus on one aspect of skills at a time to learn skills.

4.1.5. Awareness of the existence of ASD among children in schools and community

The presence of ASD is not well known in the schools and Rwandan community. Of 56 teachers, who participated in the second phase of this study, only 12 (21%) knew the essential characteristics of children with ASD. Parents reported knowing the ASD in their children after three years.

This lack of information results in different misunderstandings of children's behavior with ASD in families. One parent said:

> "*I did not know that my child has a problem with ASD before. But after consulting one of the medical doctors, I was informed that this problem existed for a long time ago*."

Parents also reported a lack of awareness of ASD as a factor that supported the stigmatization of their children with ASD among different families, and it also seemed to encourage them
to drop out of school.

> *My family failed to accept my daughter's behavior and the cost of caring for her. They always ask where I got her, and I am afraid of her future when I will not be alive. But I believe that with the help of ICT, like Television broadcasts and Radio talks, they can change their beliefs over time.* [A mother of an ASD daughter]

A lack of materials, qualified teachers, awareness, and teachers' motivation was a significant challenge to including children with ASD in the Rwandan education system.

Being a spectrum, ASD is manifested differently from low to high functioning, and all children with ASD are not the same. This difference makes educators confuse children with ASD with other cognitive disabilities.

> "*It is challenging for me to confirm that the child has ASD because those children are always different from one another.*" (a joint statement from teachers).

Increased qualified medical personnel in all hospitals with professional diagnostic tools and a strong collaboration between education and health sectors could raise awareness of children with ASD in schools and prepare personalized learning materials.

4.1.6. Acceptability of children with ASD in an inclusive classroom and community

The teachers also reported the difficulties of teaching children with ASD in the same classroom as those without cognitive disabilities. The behavior of children with ASD is the factor that brings problems to accepting children with ASD in all schools.

> "*It is not easy to include children with ASD in the same classroom because they have very challenging behavior. For example, if you are teaching, they stand up, flap their hands, and even can speak loudly. And they do not focus on what you are teaching*" (a teacher from Muramba).

However, some participants reported positive possibilities of accepting children with ASD despite the challenging behavior in all schools.

> "*These children can be included in all schools if there are more staff trained in the education of children with ASD and enough personalized teaching material*." (a teacher from HVP Gatagara).

Personalized teaching material and the availability of trained educators for children with ASD can support the inclusion of children in mainstream schools. The educational materials are more effective if teachers integrate ICT systematically into teaching and learning activities.

4.1.7. Preferred Areas of Learning for Autism Spectrum Disorder Students

In response to the question of students' interests with ASD, teachers said that the students aged between 5 and 7 years were interested in subjects that involved vision and hearing. They noted that many students with ASD liked the subjects that involved drawing and creative performance (e.g., singing and dancing), while a few of them had unknown interests. This was supported by a teacher at Groupe Scolaire Jabana who said:

> *Those children most like geometry in my class, but when I teach algebra, they do not follow; I sometimes find them drawing the faces of their colleagues and teachers. They can also see some objects that other children consider as having standard intellectual capacity are not interested.*

Parents and teachers also reported no difference in the age group and gender interest in a specific subject except for the additional support offered from one school to another and families.

From my observations, students who participated in the observational session demonstrated different individual capabilities, such as drawing the objects they saw, reproducing specific images, and memorizing songs and voices compared to their peers with typical development.

4.1.8. Areas of Interest Outside the Classroom

Parents reported their children liked drawing objects they saw around and imitating the sounds and voices of animals and people. The children demonstrate a deficit in socialization with others in their families, but they were seen engaging in different activities. Another father of children with ASD said:

> *I have never seen my son talking about his interests or engaging in activities I gave him. It took me a long time to observe him, and I surprisingly saw him get engaged in different activities while I thought he could not do anything.*

This testimony was also supported by a Teacher at APAX Janja, who said:

> *When I was doing my academic research, I met one man diagnosed as having Autism in Kigali who can imitate most of the voices of animals like dogs, cows, birds, lions, and others. If digital tools like Television are available to young children, they can imitate what they watch.*

The parents also said that their children could perform some house activities independently. From observations in the workshop room, children with ASD demonstrated a good skill level in tailoring sweaters and performing other creative activities.

4.1.9. Future Opportunities and Challenges in Rwanda

Students' disruptive behavior in the inclusive classroom may be a barrier to the effective implementation of the proposed competence-based curriculum. This was supported by teachers who said:

Children's behavior is very challenging, and it is not easy to teach them to others regardless of the government's policy emphasizing their inclusion in schools. It will only happen if two or three teachers in one classroom support them.

In this study, most teachers in the schools and centers suggested that the presence of two teachers in an inclusive classroom could help overcome the challenging behaviors of children with ASD.

Parents also reported a lack of awareness of ASD as a factor that supported the stigmatization of their autistic children among different families, and it also seemed to encourage them to drop out of the schools.

My family failed to accept my daughter's behavior and the cost of caring for her. They always ask where I got her, and I am afraid of her future when I will not be alive. But I believe that with the help of ICT like Television broadcasts and Radio talks, they can change their beliefs over time. [A mother of an ASD daughter]

In addition, the participants also said that a combination of a lack of materials, qualified teachers, awareness, and teachers' motivation was a significant challenge to including children with ASD into the Rwandan education system.

4.2. How to use ICTs to support the education of children with ASD

Research question 2: How can Information Communication Technologies support the education of children with ASD?

4.2.1. The use of ICT for the education of children with ASD

Teachers who used software applications (e.g., Matchit and Number Run) installed on computers and tablets to keep teaching children with ASD in the class reported that ICT could improve teaching and learning activities for children with ASD in inclusive settings. Observation of children with ASD when

using cognitive software applications (Mental Math Expert and Milk Hunt) was promising to enhance their learning.

Participants reported that cognitive software applications positively affect the education of children with ASD, and children like to use digital devices like computers and smartphones to play games and draw images in and outside the class.

Parents reported Software Applications designed for children with ASD and videos are essential to help students pay attention as most children with ASD enjoy watching the video. When children with ASD were left watching, they focused and imitated what they saw through the media. The analysis of coded data showed that children wanted to use digital devices when the installed applications met their individual needs.

Providing ICT tools like computers with specialized software applications for educators to use in their instruction can help them be more efficient. As most teachers supported during the interview, this provision is especially evident when emphasizing the use of images and videos and how children might learn from them.

4.2.2. Existing augmentative facilities for learning

The coded data for the interview revealed that few schools had a computer or tablet with special software applications for a person with ASD, such as games like *Matchit* (Puzzle King AB, 2019) and *NumberRun* (Number Run, 2021). The schools used these applications to help children with ASD develop their visual perception skills, cognitive skills such as categorization, language skills such as naming objects, colors, and numeracy skills such as counting in order. The schools reported getting the application from external institutional partners and research from the Internet.

Schools and parents struggle to support children with ASD due to a lack of appropriate funding. To address these challenges, Rwandan financial leadership in education encouraged promoting facilities and increasing the capacity of ICT at the school level. However, technological innovations such as educational software applications and videos need to be culturally relevant to support students with ASD and improve their attention when studying. A teacher from APAX-Janja said:

Special Software Applications and videos are essential to help students pay attention as most of my students with ASD enjoy watching the video. When left alone watching, they are more focused and finally imitate what they have seen through media.

Teachers also reported the use of video to allow them to improve the skills and behavior of individual children. For example, video can help children with ASD learn to walk when transitioning. The children also can imitate the activity they saw from actors in the video, such as drawing, asking permission, and socializing with others, such as greetings.

Besides the difficulties of ICT tools, schools and centers have educational barriers related to a lack of qualified staff that can support students with ASD and facility limitations, including classrooms, dormitories, and teaching materials that are not adapted. Thus, participants recommended increasing facilities to support the education of children with ASD.

4.2.3. Current patterns of use of ICT in education

The teachers from the four schools reported that only a few of them had a computer or tablet with special software applications for a person with ASD, such as games like Matchit and Number Run that work on basic mathematics skills. Participants thought that cognitive software applications could have a positive effect on the education of a person with Autism, with one of the interviewed teachers saying:

> *I find that students with ASD and related disabilities are more interested in using mobile telephones and tablets, which we are using to improve their communication at the school. They can search the application from the tablet and start using it.* (a teacher from the Autism Center in Rwanda)

Despite these positive intentions, teachers reported difficulties in using new technologies with children with ASD. Teachers at Heroes Day Care Center said:

> *We do here that we try all means to get some tools to support our children. Still, all of them are in English or French, which is a new language and difficult to learn as they have difficulty communicating in our local language.*

More teachers and parents suggested increasing ICT tools with specific software applications installed and training in teaching and caring for children with ASD in an inclusive environment.

Cost-effective assistive technology devices would help improve teaching and learning activities for children with ASD in inclusive settings. Introducing the teaching approach using ICT in inclusive schools could improve the quality of education for all children regardless of their learning style.

4.2.4. Integration of Information and Communications Technology into Educational Programs

Parents stated that their children liked to use digital devices and recommended access to particular ICT tools. One father of a child with ASD said:

> *My son is very good at playing games on my smartphone, and he is the one who usually opens a TV for me and forces me to watch a channel of cartoons. If the government provides ICT tools for children like mine at school, it will be better.*

Teachers and parents thought that integrating ICT and providing cost-effective ICT devices like smartphones and computers would be helpful. A teacher from APAX Janja said:

> *Suppose we can provide the low-cost tablet or smartphone with unique applications for each of the children customized with their interests and provide the teaching with that. In that case, I am confident that they will be more successful in their specific domains.*

This statement was supported by teachers who used ICT tools to keep teaching their children in the class, with all of them saying that ICT could improve both teaching and learning activities for children with ASD in inclusive settings.

4.3. Educational digital content to support the learning of children with ASD

> *Research question 3: How can educational digital content be adapted to support the learning of children with ASD in Rwanda?*

The second phase (Phase II) of the study mainly answered the research question, which aimed to analyze digital content to improve the learning of children with ASD. This theme explores the design of the content of the Khan Academy website to engage children with ASD in their learning.

4.3.1. The design of educational digital content

All teachers (100%) appreciated the content categorization on the course page. Children's cognitive level categorization supports education in Rwanda, starting from preschool to higher education. This possibility brings a positive impact when teaching children with ASD early.

The parents reported that most of their children could not follow the formal education system and recommended using the examples and images available in their families when designing a web interface for children with ASD.

The contextualization of learners by creating an intellectual need for information and skills could help children with ASD learn through practice to prevent them from losing attention. In addition, the visual and hearing senses developed in children with ASD could help the designers of digital content take these advantages to enable them to learn.

4.3.2. Availability of educational digital content

The availability of digital content helps support the education of learners with ASD. The educational videos hosted on YouTube channels are accessible where there is Internet connectivity. The content users can download the video content from YouTube and use them offline. This option is more supportive of schools that have low Internet connectivity.

Among teachers, 16 (29%) who participated in the study's second phase reported barriers to accessing online content due to poor Internet connectivity. Participants recommended the increase of bandwidth of the Internet they get regardless of the possibility of downloading the video and playing offline.

> "*as you can see, it is not possible to play YouTube videos in this area; I encourage you to do advocacy for us to get high-speed Internet in the rural area as we see in cities of Rwanda; however, if there is a possibility to download the video and play it offline can support our education system*."
> [statement of eight teachers from Janja and Muramba]

Different initiatives of the Government of Rwanda addressed some challenges to improve the Internet service in the rural area, especially in education service.

"*But from the beginning of this year, the Rwanda Education Board (REB) informed us that it is going to provide the Fourth Generation (4G) modems which we will be using to access the material from its website*." [one teacher from APAX Janja]

Teachers reported that the availability of the web interface is a driving factor that could lead to the adaptation of its content in the education system in Rwanda.
In the second phase of this study, 56 teachers and 14 parents also recommended developing digital content accessible offline using the mobile application.

4.3.3. Quality content of an educational multimedia

YouTube is a video-sharing platform used by many online education websites to provide educational content to different users. Professionals from other domains create the videos, and some of them are published under a Creative Commons license to allow users to adapt or recreate them. In this study, participants suggested content recreation meet the Rwandan context by responding to the content planned in the competence based curriculum and engage the community in the development and recreation of content.

All 56 teachers (100%) of the study's second phase reported that the educational digital content could support children with ASD when designers adapt the content to the local context.

Teachers and parents argued that the translation of the content into the local language could bring a positive impact not only on the learning of children with ASD but also on other non-disabled children who are interested in using educational digital content.

Participants recommended the recreation and translation of content into the local language to help learn children who are not registered in schools and to increase literacy and numeracy among children with ASD. This strategy is crucial because, in the second phase of the study, 13 in 14 parents (93%) do not know English, and 42 in 56 teachers (75%) have difficulties using English.

The translation and recreation of content adapted for the local context can be an excellent approach to integrating ICT into the education system and improving children's learning with different cognitively disabled children in Rwanda.

4.3.4. The opportunity of using the translated and recreated content in and outside the class

This theme elucidates the opportunities to use the recreated and translated content to upgrade the current education system to international standards. All 56 teachers and 14 parents reported that Khan Academy's content could help teach basic mathematics to children with ASD because of the availability of interactive videos in the educational content.

Among the parents' group, 13 in 14 parents reported the usefulness of the content to make their children be engaged when they are at home. The parents said:

> "*We found this content more helpful as it contains many educative videos. However, it will be much better if translated and recreated content meets our environmental context*."

Teaching children with ASD in the local language can bring more advantages than using a foreign language, as most of them present a deficit in communication. In addition, the translation and adaptation of international content can bring new opportunities to all children to learn the same content prepared by globally recognized experts in different fields.

Using recreated and translated content is an opportunity to upgrade the current education system to international standards. Most participants suggested adapting the digital content to the current education system.

> "*From my observation, this content is well prepared by professionals especially teaching basic mathematics to children who are mostly interested in the interactive videos. I suggest we start trying to adapt this content to our teaching methods to meet the international standards*". (HVP Gatagara).

Another teacher said:

"*I wish to start translating the content myself because I find this can help me to develop the skills of my students from early class*." (APAX Janja)

Teaching children with ASD in the local language can bring more advantages than using a foreign language, as most of them present a deficit in communication. Hence, the parents who participated in the study welcomed technology-enhanced content in teaching children with ASD.

4.3.5. The relevance of the digital content in the Rwandan education system

When answering how digital content can support the education of children with ASD, teachers reported that digital content of educational material is essential by preventing cognitive overload and providing the content to inform everyone. All teachers said:

"The digital content has many advantages to use because we can access educational material anytime we want. It will also be helpful if children and parents can also have such access."

However, ICT adoption in education needs strategies and financial investment to get positive results. These strategies include training educators in digital content in teaching and learning and improving the infrastructure.

"*In our schools in the rural area, it is impossible to adapt this content because of the limited availability of the Internet. I suggest having an offline content play on our existing computers without depending on the Internet*". [16 teachers from APAX Janja and Muramba]

However, this technology is not a perfect solution as some schools still report the lack of digital devices to use the content offline.

"*Apart from Internet issues, I also find the problem of digital tools such as projectors, and computers to use when teaching children with ASD in Rwandan System*" [statement of 56 from all schools].

Participants suggested the mixture of digital content and traditional learning to enable the children to learn despite the insufficiency of digital gadgets.

From Focus Group Discussions, participants suggested further works on the online content and interfaced for teaching children with ASD. A joint statement from participants says:

> "*I suggest also having some other kind of websites like YouTube channel where we can subscribe and post our comments to the created content and get a notification of new content available.*" [a teacher from Ubumwe Community Center]

The participants recommended the subscription to the recreated content to improve the accessibility of new resources. The improvement of educational content, adapted to the classroom context, is more efficient if the content development constantly includes teachers of a specific subject.

4.3.6. Enhancement of the accessibility and quality of the content

From Focus Group Discussions, 65 (93%) participants suggested further work on online teaching children with ASD.

Teachers criticized the early math content (Khan Academy, 2019b) that I used in data collection to contextualize exercise. The narration voice included in the videos is also not well understood by teachers. Teachers and parents suggested the recreation of the content by using examples that children meet in their everyday life. Figure 2 shows the interface of early math counting I used in the data collection of the third phase.

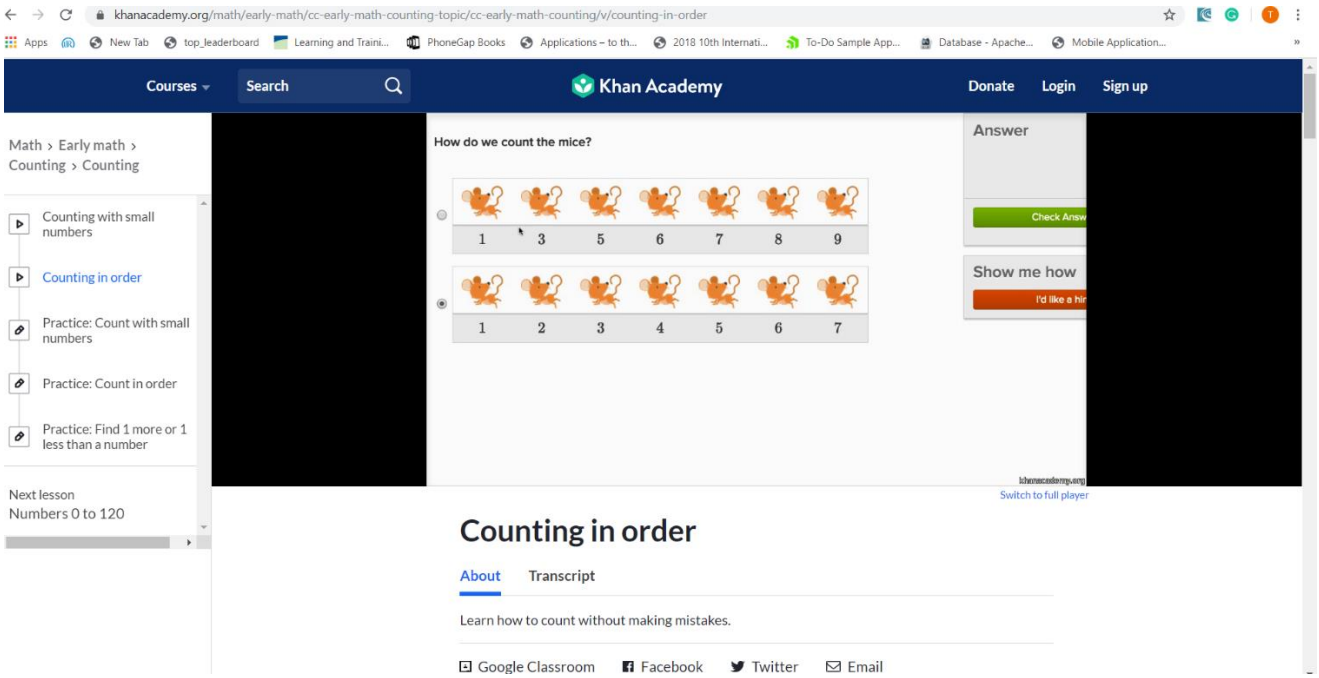

Figure 5. Interface early math counting (Khan Academy, 2019c)

Teachers suggested the recreation of the content of this lesson to meet the Rwandan teaching environment to provide personalized material to improve the learning of children with ASD in an inclusive environment. Participants also recommended the subscription to the recreated content to improve its availability.

4.4. Development of a mobile educational application for children with ASD in the Rwandan Context

Research question 4: How can mobile applications be developed to suit the Rwandan education Context of children with ASD?

This theme emerged from the exercise of developing a mobile application that responds to the need of children with ASD to improve their learning. It explains the approach to follow when planning and developing a mobile application for children with ASD.

4.4.1. Planning the development of mobile application

In planning the development of an application that helps children with ASD, the involved collaborators sat together. They examined the behavior of children with ASD in different conditions.

The equations (1,2,1 and 4) show that to design an interface for children with ASD, I considered 1) the senses of the children like vision, hearing, and tactile, 2) the cognitive level of a child to perform a given task, and 3) the ability to exercise motor functions to perform a task.

A list of users' requirements (Table 10) was collected from participants when planning mobile application development.

Table 9. List of user's requirements

Requirements / Difficulties	Requirements	Methods in gathering requirements
Senses (Sn)	1) Voice: There must be a voice associated with each action. 2) Use clear images of coins of Rwandan currency, 3) Number of pictures of coins less or equal to five, 4) The size of icons/coins must be big enough to enable the precisions of children when dragging to the right place, 5) Ignore the background sound.	Group Interviews, observation, literature review, and open online discussion.
Cognitive functions (Cg)	1) Use of soft sound that can attract children to use the app, 2) Use direct feedback of an image of the product children like, such as doughnuts, bananas, and candy, 3) Reduce background colors that can distract children. Better to use one background image known to children, 4) Use a clear image that tells the user to return to the home screen or close the application.	Group Interviews, observation, literature review, and open online discussion.
Motor function (Mp)	1) The user interface needs to be responsive to devices with high resolutions, such as tablets, 2) Allow the user to repeat actions till the dragged object reaches the target, 3) Choose the application to be in a landscape position.	Group Interviews, observation, and literature review.

Equations 1, 2, 3, and 5 were also supported by a typical response from the global practitioners. They replied to the questions posted on the forum that the app design should take advantage of the interaction strengths by making the accessibility limited to skill instruction and improving information processing by being both engaging and enjoyable. The participants also suggested removing the product's price from the application to prevent confusion in using knowledge on the market in which the price keeps changing.

4.4.2. Designing the interface for children with ASD

In the findings of this study, the participants suggested three points to consider when designing the interface for children with ASD. (1) Graphic design guidelines, (2) User interface design, and (3) Success recognition and messages.

4.4.2.1. Graphic design guidelines

The developed application enables children with ASD to distinguish coins from five to 100 Rwandan Francs based on symbols and representations.

To design the graphical interface, I followed the recommendations of Hussain et al. (2016), who suggested the interface, the number of pictures, size of the screen, icons, colors, and content to prevent the distraction of children when using mobile applications. Two main menus make graphic interfaces: (1) Home and (2) Exit. The application's design flow (Figure 3) illustrates the application's structure that facilitates users to navigate through the mobile application.

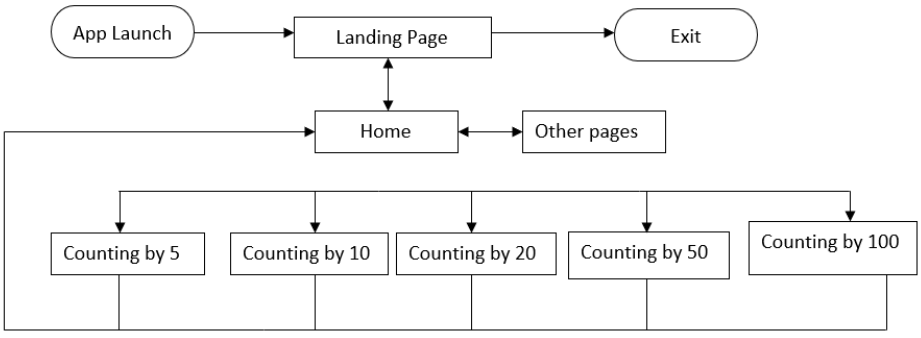

Figure 6. Design flow of the application

Figure 3 shows that the home menu is the starting point when the app is open, while the exit icon is used only to close it. Equation 5 defined a software app as a set of functions associated with a user interface. The developed mobile app's interface elements are the home menu, exit, and images that illustrate numbers to count. Equation 6 substituted the functionalities with tasks that users are expected to do within a software app via an interface. In this app, a child with ASD presses one of the figures to start counting numbers.

Equation 7 shows that an interface (*I*) is a set of user interface patterns (*Uip*) facilitating users' interaction with the system. From the home menu, a user can navigate through the system by touching 1 out of 5 icons: (1) counting by 5, (2) counting by 10, (3) counting by 20, (4) counting by 50, and (5) counting by 100. Equation 8 shows that a child with ASD who presents different characteristics presses one of these icons to start counting to achieve a particular goal.

Equation 9 demonstrates that a user counts Rwandan francs coins (bnr, 2020) that correspond to the number they heard from the voice (Equations 1-4).

To perform a task presented in Equations 10 and 11, a child with ASD drag at least one coin to a provided space to get feedback (e.g., candy, banana, strawberries, and others). The feedback for each action is the interfaces proposed in Equation 12.

4.4.2.2. User interface design

Equation (7) shows that an Interface is a set of User Interface Patterns that facilitate users interacting with the system. A user can navigate the system from the home menu by touching one of five icons. (1) counting by five, (2) counting by 10, (3) counting by 20, (4) counting by 50, and (5) counting by 100. Equation (8) shows that a child with ASD who manifests different characteristics presses icons to start counting to achieve a specific goal.

Equation nine (Equation 9) expresses that under each submenu, a user counts Rwandan francs coins that correspond to the number they heard from the voice presented in the equations (1,2,3 and 4).

To perform a task presented in equations (10 and 11), a child with ASD drags at least one coin of the Rwandan currency system to a provided space to get the result. Specific feedback like candy, bananas, strawberries, and others. The feedbacks of each action are interfaces proposed in equation (12).

After launching the application by pressing the icon of the desktop of the device, such as a smartphone or tablet, the landing page shows all categories of skip counting numbers using the example of coins of Rwandan currency. The home page does not contain images of money to prevent the distraction of children, as recommended in equation (3). The landing page of the application (Figure 4) shows the design of the application's landing page, which offers four options where a user can press one of them to start doing the operation (Equations 5 & 6).

Figure 7. The landing page of the application

Other pages come after pressing one icon from the landing page, as indicated in equation (9). Each task is associated with a specific user interface (Equation 6). The interface contains a set of coins of the Rwandan currency system: five francs, ten francs, twenty francs, fifty francs, and one hundred francs; (BNR, 2020). The child drags a certain number of coins to the destination place to get a reward. Counting by five interfaces (figures 7) and the interface of counting by five after dragging one coin of five francs (figure 8) are samples of the pages of counting by five before and after an operation. A child identifies coins of five francs and drags them into the box on the right side. Then after a successful procedure, s/he is given a reward of candy (Equations 10 and 11).

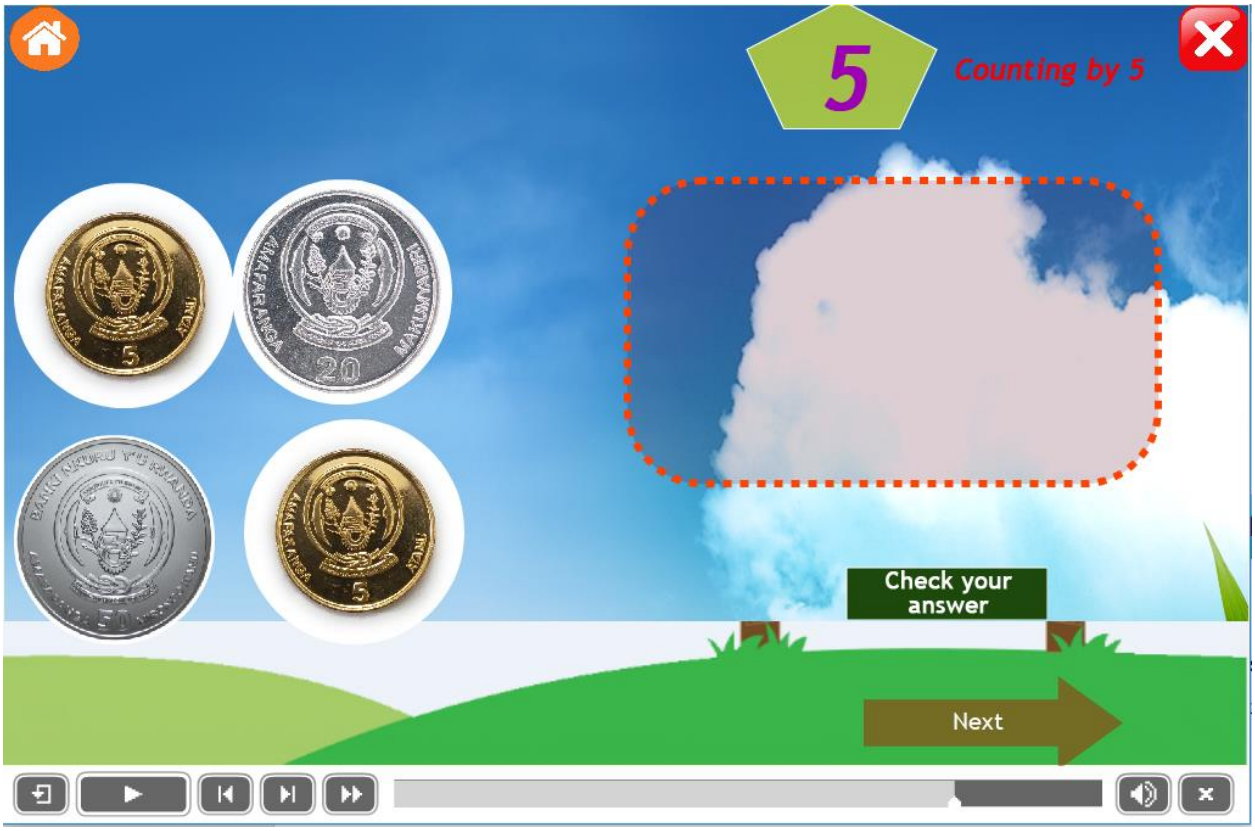

Figure 8. Counting by five interfaces

4.4.2.3. Success recognition and messages

This application's actions are to press, drag, and drop coins into a specific area (Equation 11). Equation (13) shows that the current value is 0, and it will be adding the value of the dropped coins in its value as presented in equation (14). The flowchart (Figure 2) illustrates learning skip counting through the developed application.

Given the example of counting by five, the value of the equation (14) is:

$$N = V_0 + V_1 + \ldots + V_n$$

$$V_0 = 0, V_1 = 5, V_2 = 5$$

$$N = 0 + 5 + 5$$

$$N = 10$$

From figure 8, a child drags and drops coins of 5 francs to get candy in the space on the right side.

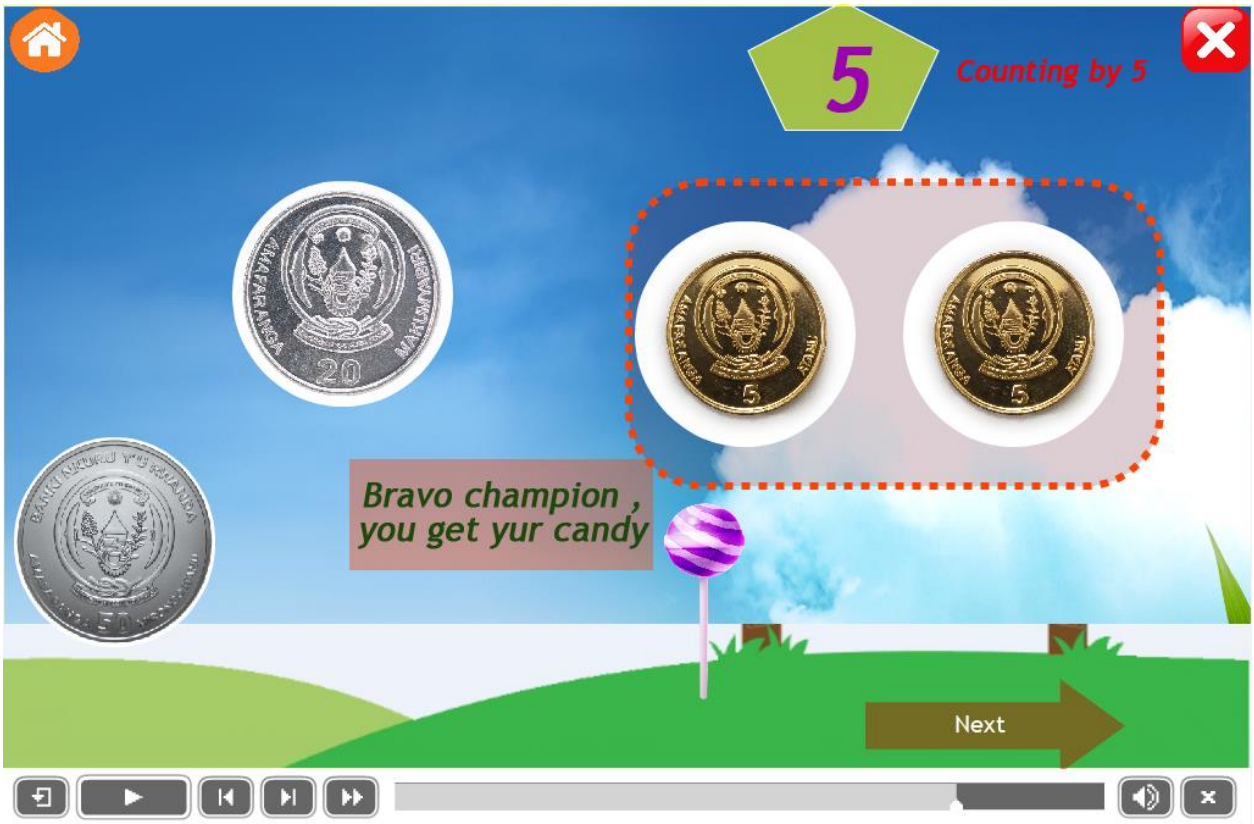

Figure 9. The interface of counting by five after dragging one coin of five francs

Figure 9 shows the gift of candy offered to a child after the operation's success. The child with ASD has an image, text, and audio (Equation 9).

Participants recommended awarding a special gift to a child at every operation step to encourage children with ASD. This mobile application provides different rewards available in the surrounding environment, such as doughnuts, bananas, and candies.

Figures (10,11, and 12) are samples of messages and products after the successful operation.

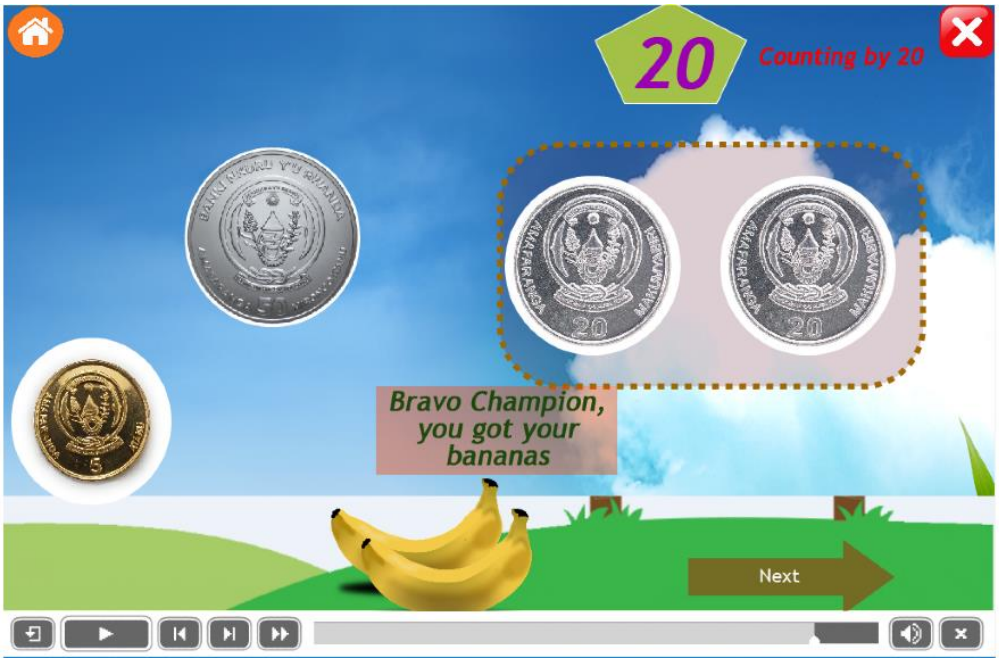

Figure 10. The reward of bananas after dragging 2 coins of 20 francs

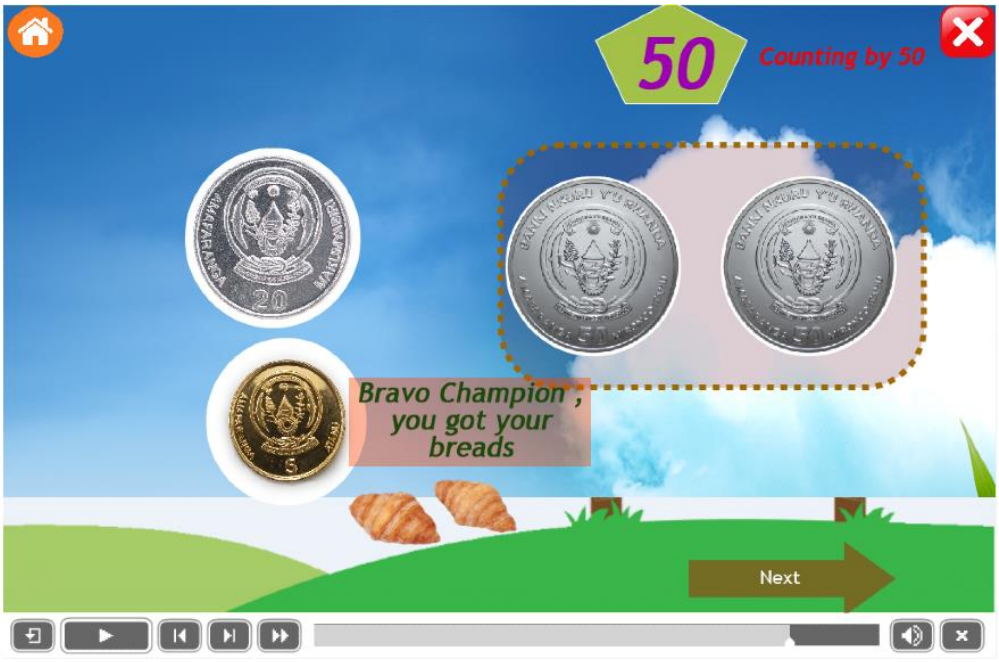

Figure 11. The reward of doughnuts after dragging 2 coins of 50 francs.

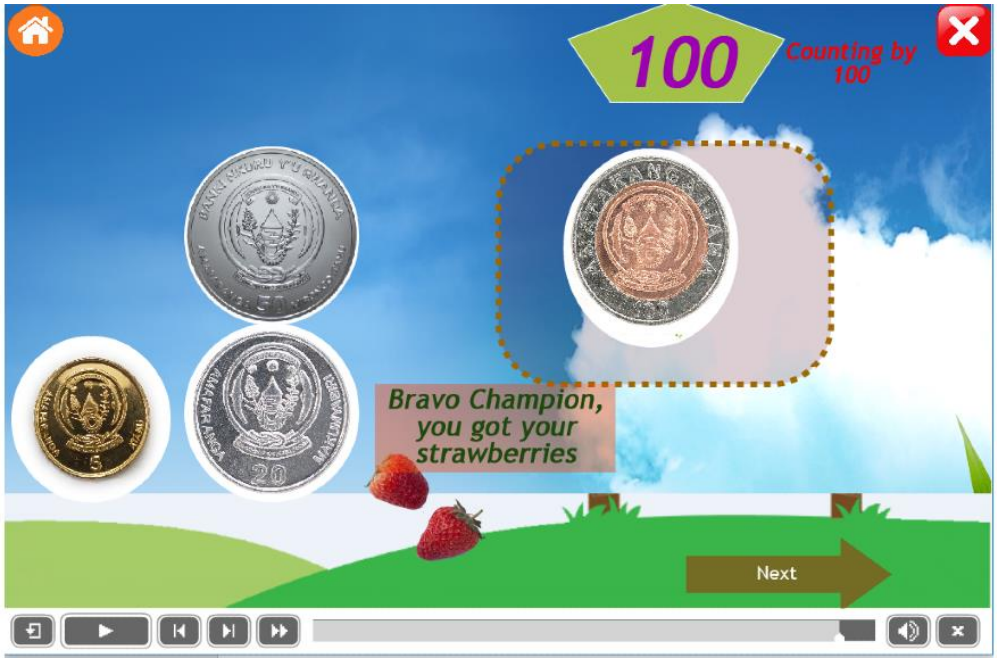

Figure 12. The reward of strawberries after dragging two coins of 100 francs.

4.5. Testing Mobile Application

4.5.1. Usability testing

This theme demonstrates the result of testing the developed mobile application. A total of 35 children in the Autisme Rwanda tested the application, which the teachers in the center monitored. I visited Five children who are not in the center at their homes. Table 10 presents the number of participants who participated in the test of a mobile application.

Findings from the test showed that it is crucial to customize the application in different forms but with the same goal to cater to each child's behavior.

The development of apps for children with ASD is a long process to accompany an individual in his/her life. Therefore, it is crucial to permanently change the content and format of the app to respond to each child's behavior with ASD. These changes have also supported a parent from the Quora forum who said

> *My son loves very intense, bright colors. But that doesn't mean everyone on the spectrum would. They are all individuals.*

While some users reported suggestions, many found the app promising to improve the learning of children with ASD in Rwanda. This was supported by a parent who said,

> *I can see that by using this application, my kid will gradually increase their knowledge in counting money, and I hope it will help him to use that knowledge in society even though he is not enrolled in the school.*

Using ICT tools, children with ASD learn more skills, which they can employ in their daily lives without being at school.

Children using the mobile application showed more interest in continuing to use the app. They are familiar with the images of coins used in the app, which are similar to the ones they use in their families. This was supported by one parent who said,

> *My son was very interested in using this application because he always sees the coins we use at home. I believe within the time, my child will be able to count money.*

Children with ASD can learn counting from the electronic device when the app is contextualized with the environment.

4.5.2. User Testing

4.5.2.1. Visibility of the system status

I tested how children with ASD are informed about the application for user testing. The application provides feedback on every user's action by sound and message. The motivation messages are displayed at every successful operation. The images (9,10,11, and 12) are examples of feedback offered to the children. These images serve to keep children with ASD informed of the current status and allow them to steer interaction in the right direction without wasting effort. These indicators communicate that the system is working and

reduce uncertainty, preventing users from tapping the same button multiple times because they weren't sure if the first time worked.

4.5.2.2. Match between system and the real world

The mobile application I developed uses coins that are available in Rwanda. I also included the voice as narration to guide the children when using the application at each step. Figure 13 is one of interfaces of the application. It shows coins of 100, five, and ten. The voice of counting by ten is automatically played and the child with ASD can drag on a coin to the right side.

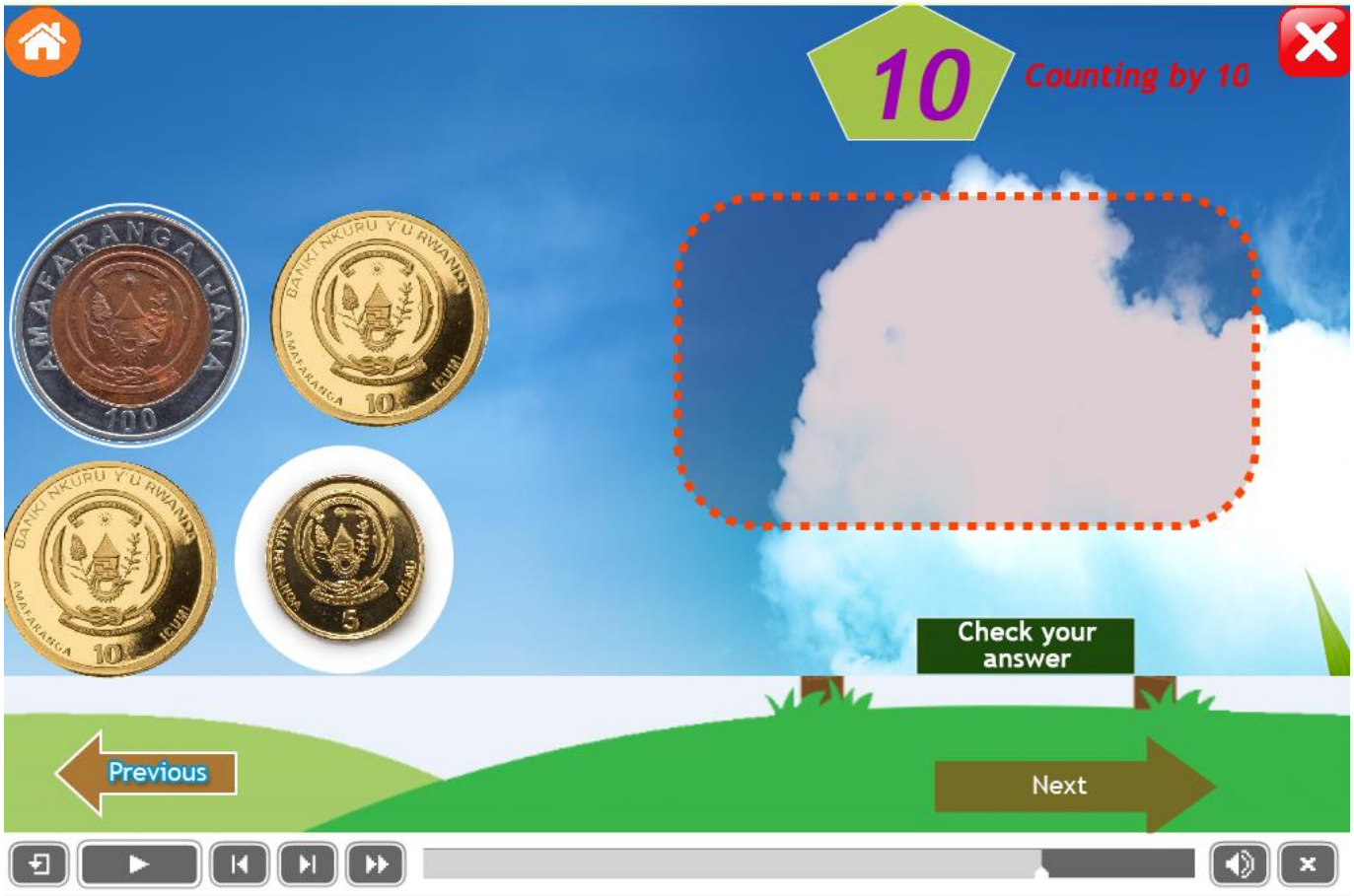

Figure 13. Counting by 10

After successfully dragging on a coin of ten, the sound is played, asking them to add another coin of ten. The image (figure 14) shows the success of dragging a coin of ten francs.

Figure 14. The success of dragging one coin of ten

After adding the second coin of ten, the application display the message of congratulations, and the voice is automatically played. The motivational image of the product also is shown.

Figure 15. The success of dragging two coins of ten

With the failure to pull the proposed coins, the voice is played to inform a user to try again. The participant recommended replacing the English with Kinyarwanda to help more children and facilitated parents to guide them.

4.5.2.3. User control and freedom

The third heuristic states that users can choose system functions by mistakes and will need to leave the function or go back. In this application, there is a back button at each interface that a child with ASD can press to the previous state.

The interface also has an exit icon which they can use to close the application. The Home icon is used to go to the first interface of the application.

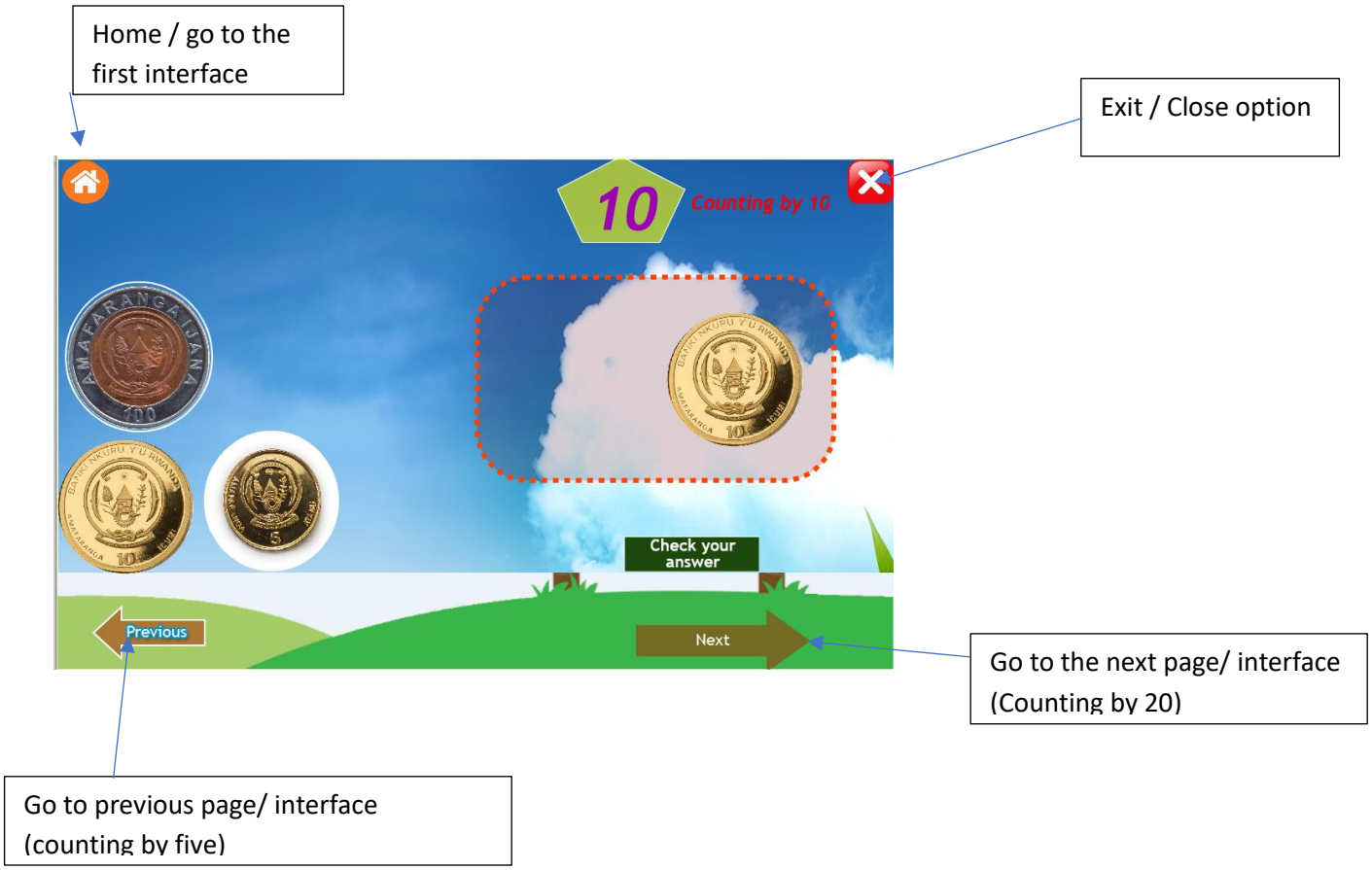

Figure 16. example of use control and freedom

4.5.2.4. Consistency and standards

I developed the mobile application using simple terms of currency and numbers used in the Rwandan curriculum in terms of consistency. As I mentioned in an earlier section of the methodology, we tested the application twice with participants (teachers and parents). Initially, we identified features to include in the application and illustrated the actions and operations on the paper (Figure 3). This application's functions are to press, drag and drop coins into a specific area (Equation 11), and it appears on every page of the application.

In addition to coins and narration voice, the use of home and exit icons that are more familiar to mobile application users is also reported to positively impact the usage of the application by children with ASD. The results from observation showed that children with ASD are not confused when they navigate the application. The parents who participated in the study reported that the interface is easy for their children and suggested using the Kinyarwanda language to improve the children with verbal communication difficulties.

4.5.2.5. Error prevention

In the design and deployment of the mobile application, together with parents and teachers, I tested the interface two times to verify and remove some possible errors that may occur when using the application. For 30 days, the children used the mobile application, and teachers and parent reported no error they found when using it. Of 10 parents, eight (8/10, 80%) recommended improving the quality of the voice used. The quality of voice used in the application is from the device I used in recording (smart phone, Techno Cammon 11) (Techno Mobile, 2022).

The high quality of the recorder would improve the quality of the voice and reduce the challenges of hearing and improve the verbal communication of children with ASD; hence apply the knowledge from the application in the community.

4.5.2.6. Recognition rather than recall

Children with ASD face a cognitive challenges like attention deficit and stereotyped behavior. I referred to motor function, sense, and cognitive abilities in the mobile application design, as I mentioned in equations 1 to 4. Children with ASD are familiar with the images of coins I used in the mobile application. The parents reported that children with ASD can recall the pictures and associated actions in the mobile application. Teachers also said the children with ASD were able to use the mobile application with very minimum support. The parents and teachers also reported that the application can not only support the children with ASD and that the typical children can benefit from the content of the application. From these findings, the mobile application will support the inclusion of children with ASD in mainstream schools when it includes all content planned in the curriculum.

4.5.2.7. Flexibility and efficiency of use

The flexibility of the application includes shortcuts to help users go to any step without following all processes from the beginning to the end.

The first interface of the application allows a student to go to any application page. The image (figure 17) shows the options of counting on the first page of the application.

Figure 17. The first page of the first interface

From any interface, a user (child with ASD) can eight go to the previous page, to the next page, or go to the first interface of the application. Teachers and parents reported that using the application did not take much experience using mobile applications for children with ASD. the children only needed the time to initiate the device and application. Within that time, they demonstrated the ability to use it themselves.

4.5.2.8. Aesthetic and minimalist design Observation

Regarding astatic and minimalist design, I tested the interface for children with ASD and discussed the mobile application with the parents and teachers. In the FGDs, I identified the number of icons to be on the interface, background colours, and operations to perform. I used the blue sky as the background colour of the application base on findings from the focus group discussions and observations where participants reported the blue sky to be more attractive.

Ten teachers reported that children with ASD are visual learners, and the selection of images to use in the application could be a form of attracting them to learn new skills behind. After the interface revision following the suggestions from teachers and parents, children with ASD were more attracted to continue using the mobile application to explore more features.

The size of the images of coins was relatively at the same scale as the existing ones used in the Rwandan currency system as I took the photograph of the coins and only removed the unnecessary background. In the observation sessions, children with ASD demonstrated the ability to hit the coin's image without failure, as recommended in equation 4. The participants from Quora digest suggested a continuous revision of interfaces, mainly background colors, because children with ASD change the colors they like by their developmental age. For example, a child can like blue more at seven years old but at 12 likes black.

4.6. Acceptability and efficiency of a mobile application

4.6.1. Strength of the developed application against the existing

This theme proved the positive effect on children with ASD in Rwanda through the developed mobile application. The result from the observation of children with ASD using SPEAK all! (Purdue University, 2013) showed that it is difficult to adapt the existing interface to children with ASD from a different context from what they are living.

When asked how children with ASD benefit from learning from the ICT tools developed in the foreign language and context, most participants responded that it is challenging to know new content in the foreign language.

More teachers and parents believe in improving the learning of children with ASD when they use the mobile application developed concerning the Rwandan environment. A statement from parents supports this:

> *"This application will positively impact the learning of our children because the coins used in the application are those we use in our daily lives."*

Despite this optimistic statement, participants suggested using the local language to have the application version. Children with ASD have difficulties in verbal communication. It is crucial to use their mother tongue language to learn new skills.

The incorporation of features available in the living environment of children with ASD and strong collaboration between teachers, parents, and application developers can improve the quality of software applications developed in response to the needs of children with ASD in Rwanda.

4.6.2. Behavioral Maintenance and Relapse Prevention

Children with ASD tend to lose focus when communicating with others. This challenge mostly happens due to distraction, commonly noted in these children in an inclusive environment. The instant motivational feedback when a child completes the operation makes them focus on using the app.

This argument is supported by an autism consultant who replied to a question posed on the Quora forum:

> *Just because they might not look at you does not mean they are not paying attention or focusing. Their ability to focus is compromised by the sensory onslaught that is going on in the room.*

The participants also suggested considering different factors such as noise level in the room, smells, and movement that can make children with ASD lose their focus. These factors can also be associated with the health conditions as reported by the same consultant.

> *Some autistic people have difficulty with interception and understanding messages from their bodies. The child might have a headache, earache, stomachache, etc. but not be able to let you know. Or, this might be a constant state for them, again, making it harder to focus.*

The parents who participated in the study suggested giving time to the children when they were not following the instructions.

> *The children with ASD generally do not follow all the instructions we are giving them. Still, we are surprised to see them practicing what we expected them to do when they followed the instructions, and we hope that ICT can help improve their skills.*
> [A statement from 10 parents who participated in the third and fourth phases of the study]

The provision of mobile educational apps that provide instant feedback at every step can help children with ASD stay focused and gradually improve their skills in different subjects.

4.6.3. Data Protection for Users

Privacy of information about users of mobile apps remains critical among participants.

The participants suggested not to expose any information about children with ASD. This information includes their images and information about their families. The school management also supported this policy, which prohibited using children's photographs within the app.

Parents suggested disabling the camera when children are using the mobile app and preventing the app from taking any other information from children.

> *Usually, in the community, there is a misunderstanding of the cause of ASD. We accept our children, but we don't want to share their images outside unless they are at school.* [A statement from 10 parents who participated in the third and fourth phases of the study]

This argument is also supported by a teacher who said,

> *When I was doing my academic research, one parent told me that many people are coming to visit him to do marketing of his child for business purposes. Now I cannot allow anyone to take a picture of my child.*

Although the use of ICT suggests improving the learning ability of children with ASD, some features such as pervasive monitoring, facial recognition, biometrics, and blanket data retention practices are not recommended in educational apps for children with ASD (Rucz & Kloosterboer, 2020).

4.6.4. Social Implications

This theme illustrates the social benefits and challenges of using the mobile app. Children with ASD have limited social communication skills, a significant barrier to learning. Thus, the participants expected the mobile app to improve the social relationship between children with ASD and the community.

I believe that the continuous use of mobile applications designed by considering this environment can also make children cope with the environment like shopping, bringing some products and others. [A father of a child with ASD]

Children with ASD can benefit from the practical knowledge of using money, thereby improving their relationship and communication with economic dealers.

However, some participants also reported adverse effects of using a mobile app for children with ASD that can affect their lives. They suggested a time limit to restrict children's continuous use of the app, allowing them to learn from other average persons while not solely depending on the app for learning.

Using the mobile application is helpful to our children; however, allowing them to learn only from the application can make them addicted to technology. [A statement from teachers]

Thus, mixing the technology with traditional educational interventions for children with ASD can positively impact the lives of these children and improve their social living with the community.

4.6.5. Possibilities to integrate the mobile application into the existing curriculum

Teachers who participated in this study said that children with ASD enjoyed using digital devices with features like audio and visual. Participants recommended providing digital devices in the class with content related to the intended learning outcomes.

"The ICT can bring a positive impact in class, but it is better to select applications that can respond to the planned objective." (a statement from 5 teachers who participated in the third phase of the study).

The results from the test of the developed application were promising to support teaching and learning mathematics syllabus in a competence-based curriculum.

"I found the improvement of children with ASD in learning after using this application. However, it takes much time to learn from it compared to normal students."

During the FGDs, teachers reported that learning a new subject for children with ASD takes longer than typical students, and they suggested extra time to the time planned in the curriculum.

Parents' responses proved that learning basic mathematics outside the classroom is possible when teachers use the ICT enabled with assistive technologies.

> *"my kid is now trying to count money after using this mobile application. But it took time to learn it; it requires more time to expose the child to the application and play with it."* (Mother of child with ASD)

Participants recommended changes in the curriculum structure and ICT integration in every syllabus section to include children with ASD in education.

> *"An autistic child can learn anything that a neurotypical child can. The challenge is in the different approach to teaching, and the learning environment is accepting of and accommodating their needs."*(Response from Adult diagnosed on the autism spectrum from Quora forum)

The adaption of content for the children with ASD is possible when the teacher reduces the text in teaching, and the ICT with audio-visual features is empowered.

4.6.6. Challenges in Rwanda

Changes in behavior and feelings among children with ASD may be a barrier to developing ICT tools enabled with assistive technologies in Rwanda. The response from the Quora forum about the colors the children with ASD like indicates that their color preference changes with their age.

> *That's totally up to the child. Many of them don't show any particular indication of liking specific colors. When my autistic son was young, he wanted orange, but he wore nothing but black after seven. He's 36 years old and still wears nothing but black. Occasionally we can talk him into charcoal, but it doesn't last long.*

Teachers who participated in this study suggested a continuous change in the app depending on a child's behavior.

The developed application can be helpful when children have a common preference. As we see, it will succeed if the system designer can continually update it depending on the changes in our children's behavior. [A statement from 5 teachers who participated in the third phase of the study]

Developing a mobile app for children with ASD requires continuous iteration in the design process. However, the insufficient number of ICT technicians and qualified teachers available to participate in the design and development of a mobile app that responds to the needs of children with ASD remains a challenge in Rwanda.

Participants also reported difficulties accessing the app because it can only be used on tablets or smartphones. This technology makes the mobile app inaccessible for children from families with less privileged backgrounds. The participants recommend the provision of low-cost devices to families with low income.

4.6.7. Focus on Future

The last theme is identifying the views and recommendations from participants when planning and developing mobile apps for children with ASD. The findings of this study suggested the importance of developing a family-centered process that requires parents to support their children. In this study, most teachers suggested a collaboration between software developers to create apps that respond to the needs of the children.

As we see, the application's design for these children is a long process. We suggest building a good collaboration with application developers to make sure that the application can respond to the needs of the children.[A statement from 5 teachers who participated in the third phase of the study]

Developing a software app involves collaboration with stakeholders in every step of development. However, if the users are persons with mental disorders such as ASD, this requires strong participation of persons who live with them. Teachers also recommend developing a mobile app for the whole competency-based curriculum.

The parents reported using the mobile app to support children's transition from childhood to adult life if the developers continuously updated according to children's level and the changes in their behavior.

> *The behavior of our children is changed over time. We suggest a continuous change in application to accompany the children in their development till adulthood.*
> [A statement from 10 parents who participated in the third phase of the study]

Using digital technologies supports the social inclusion of children with ASD when these tools are systematically updated and meet the environmental context. Succeeding in developing and utilizing mobile apps for children with ASD requires a strong collaboration between educators, parents, and the digital technology industries.

Chapter 5. Discussion

This qualitative case study aimed to examine the possibilities of developing a mobile educational application for children with Autism Spectrum Disorders in the Rwandan context.

This chapter discusses significant findings related to the literature on ASD, education, and ICT to improve the learning of children with ASD and what methodologies to follow when developing a culture-specific mobile application for children with ASD. Also included is a discussion on the connection between this study and motivation studies. The chapter concludes with a discussion of the study's limitations and areas for future research.

This chapter contains discussion and future research possibilities to help answer the research questions:

1. What are the special educational needs of children with ASD?
2. How can Information Communication Technologies support the education of persons with ASD?
3. How can educational digital content be adapted to support the learning of children with ASD in Rwanda?
4. How to develop a mobile application that suits the Rwandan education Context for children with ASD?
5. How do children with ASD, parents, and teachers perceive the use of the developed mobile application?

This study revealed the possibilities of developing a mobile application to support children with ASD in Rwanda's competence-based curriculum. ICT was acceptable among both teachers and parents of children with Autism. The themes developed in the four phases of the study (Phase I, II, III, IV) show that integrating digital content recreated and mobile applications designed to meet the individual needs of children with ASD is an excellent approach to improving children's learning. The triangulation of the findings demonstrated that the participants in the study thought that ICT could improve the education of children with ASD in class regardless of the problem of an insufficient number of tools developed. The learning improvement of children with ASD could occur when the technology is developed by referring to the current environmental context.

Scientists thought that there was no cure for ASD. Still, educational interventions, theories, and practices are approaches to improving the lives of children with ASD (Odom et al., 2012). The researchers acknowledged using motivation tools as a practical approach for working with children with ASD (Virginia Department of Education, 2011)and (Bou, 2016). However, the multidimensional constraints of culturally valid and acceptable educational curricula, inadequate training for teachers, and lack of strategies for teachers to improve their methodologies when they are teaching in inclusive classroom settings is still a barrier to the education of children with ASD (Ghavifekr et al., 2016) and (Hampton et al., 2019).

Teachers who participated in this study reported using available motivational objects to make children stay focused in the class. Grandin & D (2002) documented a study that lists teaching tips for children with ASD; among them, a direct motivational reward motivates a child after the activity's success.

The inclusive curriculum, which aims to improve access and successful participation in a person with disabilities, can positively impact when teachers integrate ICT within teaching and learning practices (Guenaga, Mechaca, Romero, & Eguluz, 2012). However, studies also proved that it is challenging to follow formal curriculum design when teaching children with ASD (Virginia Department of Education, 2011). Different strategies (Kamoga, 2016) include the development of teachers' competencies in teaching children with ASD before enrolling them into mainstream schools, followed by the improvement of infrastructure such as assistive technologies enabled to facilitate these children's learning (Fage et al., 2018).

To support previous research (Hume et al., 2009), the parents who participated in the FGDs stated that their children with ASD were motivated to engage in different activities at home, and the role of parents and teachers should be to guide and supervise rather than to compel them to work on a task.

The use of ICT has previously proven to have the potential to improve the education of children with ASD in Rwanda and beyond, as supported by multiple studies (Alotaibi, 2016; Soomro & Soomro, 2018). Despite the importance of ICT in supporting the education sector, the lack of facilities is a significant challenge in enhancing the learning of students with autism in mainstream schools (Hart et al., 2010).

These findings supported previous studies (Tanner et al., 2010b; Omar & Bidin, 2015; Alhajeri et al., 2016) and the educators' recommendations who participated in this study. Children with ASD perform better when an emphasis is made on the augmentation of digital technologies, cognitive software applications, and the senses of children with ASD (i.e., hearing and vision) (Vaiouli et al., 2015; Hong et al., 2016). The observational findings indicated an improvement in the ability of the child participants to use cognitive software applications installed on the computers and smartphones provided to them.

To support previous research by Hume et al. (2009), the parents who participated in the FGDs stated that their children with ASD were motivated to engage in different activities at home, and the role of parents and teachers should be to guide and supervise rather than to compel them to work on a task. The interviewed teachers suggested improving the competency-based curriculum by focusing on mental disorders such as ASD, as supported by varying studies (Mcconnell, 2017). The parents and teachers also reported that some children were not attending school due to stigmatization. However, the findings of this study suggest that increasing awareness of ASD by using varying means, including ICT, could help overcome the stigma against people with ASD that has been associated with social and cultural issues (Dyches et al., 2004). This study is supported by Ehsan et al. (2018), who found a lack of contextualized studies on ASD in less developed countries while the number of people with ASD continues to increase.

Computer-assisted educational content is developing fast in different domains (Sue Fletcher-Watson, 2014). Teaching basic numeracy to children with a deficit in communication like those with ASD is possible when the content is gamified using multimedia technologies (Tenório et al., 2018). Teachers who participated in this study reported using games when teaching different subjects in class. Educational videos are essential to improve the learning of children with ASD (Jodene et al., 2014; Chatzopoulos et al., 2017). After watching the footage used in this study (Khan Academy, 2019a), teachers reported integrating recreated Khan Academy content can bring the possibility of including learners with ASD in an inclusive classroom (Malley et al., 2014).

In the third phase of this study, the evaluated content is on the YouTube platform (Kong et al., 2019), which has content delivered in an educational institution. The studies by Baker et al. (2012) reported that integrating multimedia content improves the learning of different subjects (The University of the West of Scotland Paisley Scotland, 2016). Participants in this study suggested the recreation of the Khan Academy content to meet the school's environmental context.

This research suggested computerizing the existing methodologies and the contents to adapt to an individualized context. Educational software for children with ASD must respond to each interest and developmental needs (Malley et al., 2014). Tashnim et al. (2017) also reported that the computer interface must be more interactive to facilitate children with ASD learning. The use of assistive technologies has previously proven to have the potential to improve the education of children with ASD in Rwanda and beyond (Alotaibi, 2016).

Despite the importance of ICT in supporting the education sector, the lack of facilities is a significant challenge in enhancing students' learning with autism in mainstream schools (Tanner et al., 2010b), (Alhajeri et al., 2016) and (Omar & Bidin, 2015).

The study by Vaiouli et al. (2015), Amber Simpson (2016), and Hong et al. (2016) reported that children with ASD perform better when an emphasis is on the augmentation of digital technologies. These cognitive software applications respond to the senses of children with ASD (e.g., hearing and vision). Our observational findings indicated an improvement in the ability of the child participants to use cognitive software applications installed on the computers and smartphones provided to them.

Educational videos are essential to improve the learning of children with ASD (Treffert, 2009) and (Simsek & Allsopp, 2016). Teachers reported the integration of Khan Academy could bring the possibility to include learners with ASD in an inclusive classroom when the content they re-create meets a particular context (Simsek & Allsopp, 2016). The integration of multimedia content can increase the accessibility of children with ASD to education (Ntalindwa et al., 2019). A similar study by Brame (2016) highlighted the importance of videos to enhance teaching and learning in an inclusive classroom. This teaching is possible when the educators are aware of the presence of children with ASD in the schools, the use of adapted methodologies that help learners to stay focused (Steyn & Couteur, 2003), and the increases the acceptability of these children into mainstream schools (Disorder et al., 2015).

Learners with ASD expect to benefit from mobile applications when their features meet the physical environment in which the children live. Song et al. (2010) researched communication applications and found success in assisting communication difficulties through ICT tools. The exposure of children with ASD to digital tools can bring positive effects (Aresti-Bartolome & Garcia-Zapirain, 2014). However, children with ASD are engaged when they play with digital devices (Ntalindwa et al., 2019a). The behavior is likely to be sustained if the reinforcement emphasizes immediate and affective outcomes (Conoyer et al., 2015). The developed application in this research offers different products as reinforcements after the success of the counting operation. However, parents and teachers are encouraged to supervise children with ASD to solve challenging behavior upon removing the digital device.

This study revealed the role of the autism community in conducting research related to ASD (Gowen et al., 2020), and the result collected from Quora digest (Quora Digest, 2021) suggested a continuation in changes

of features of the mobile application to adapt to the behavior of children with ASD within their development. The study of Buteau-poulin et al. (2020) recommended the regular update of information related to special education of children with disabilities available online. Children with ASD are among vulnerable children in different societies. It is crucial to respect the data protection of mobile application users (United Nations Democracy Fund, 2014).

The translation of the findings of this study into practice is helpful for educators and future research to address a barrier to education for children with ASD by focusing on their functional abilities rather than a deficit model based on students' diagnoses of particular interest. Enabling children with ASD to learn mathematics contributes to eliminating all causes and obstacles that can lead to disparity in education, be it by gender, disability, geographical or social group, which is one of the Rwanda Education Sector objectives (REB, 2015a).

I carried out this study before the crisis of the COVID-19 pandemic in Rwanda (WHO, 2020). However, participants' results demonstrate that the online content could help educate children with ASD during and after the COVID-19 crisis. The study by Stenhoff et al. (2020) documented the possibilities to support children with ASD through distance education during the period of schools closures. The availability of digital content for learners with ASD is also crucial to keep remote learning in response to the COVID-19 measures of prevention (Michalak Nikki, 2020).

In this study, I intended to find an ICT solution that can support the current competence-based curriculum of primary education in the Rwandan education system.

This study has the following strengths: (1) It reflects the experiences of teachers and parents who are in service to support children with ASD, (2) Researchers have experiences in the field of education, Information Technology, special education, and ASD, and (3) Children with ASD participated in the test of mobile application, and parent and teachers contributed to the improvement of the developed application.

The rationale was that teachers could adapt to different new methods and innovative tools to improve teaching and learning. In this study I selected content like skip counting, which can help children with ASD improve mathematical skills used in real life (Lozano-Martínez et al., 2011).

However, this study explores only one topic in 36 (2.7%) planned syllabus content, which is supposed to help children learn basic numeracy early.

In future studies, all content responding to the existing syllabus should be explored and allow more time for participants to test the interface and provide much of their views. The impact evaluation of the developed application will also focus on the subsequent study.

A longitudinal usability study of the interface may help uncover long-term advantages and disadvantages that teachers may experience and adapt to the curriculum changes that first-time experiences cannot. Another potential solution is developing personalized ICT solutions for an individual with ASD that responds to their educational and societal needs. In addition to other research (Abubakar, Ssewanyana, de Vries, et al., 2016) and (Grynszpan, Weiss, Perez-Diaz, et al., 2014), this study recommends further exploration into Low and Middle-Income Countries (LMICs) like Sub-Saharan Africa.

Chapter 6. Conclusions

6.1. Introduction

The objective of this study was to contribute to the design and development of a mobile application that improves the learning of children with ASD in Rwanda. To this end, I adopted an interpretative paradigm and multiple case studies in four phases. It has been argued mobile applications can support the education of children with ASD when they respond to the individual needs within a given subject in the curriculum. I have also argued throughout this work that ICT has promisingly paved its way into the field of teaching and treating children with ASD. The community plays a vital role in the planning, developing, and evaluation of a mobile application for children with ASD. This study aimed to create a user-friendly, practical mobile application that responds to the needs of children with ASD and eliminates the barriers to learning basic mathematical skills.

This chapter concludes the research effort by analyzing how each chapter has contributed to addressing the research questions. The next section continues with contributions and their implication to the existing knowledge. The final section discusses the limitation of the study and includes an overview of opportunities for further research.

6.2. Overview of the research

1. In chapter 1, the thesis examined the nature of the background to the problem, statement of the research problem and motivation, general and specific objective, research questions, delimitation, intended audience, and the structure of the thesis. It has found the present status of the problem of children with ASD at inclusive schools and the contributions of ICT to address the barriers to their education. I formulated the research questions with the reference to the specific research objectives.
2. Chapter 2 discussed the general literature review that documented studies related to the research objectives and research questions. This chapter includes 1) a conceptual framework, 2) special educational needs for children with ASD, 3) the use of ICT to support the education of children with ASD, 4) digital content to support the learning of children with ASD, and 5) The mobile applications for children with ASD. the literature review revealed the learning capabilities of children with ASD in an inclusive environment. Special educational needs, and methods to follow when developing

mobile applications. The literature review of this study also highlighted different models and strategies to use when teaching children with different levels of deficits associated with ASD. From the literature, I found that many existing ICT interventions are developed without the full participation of communities of persons with ASD and this failed to respond to the actual zone of instructions of children with ASD from different environmental contexts.

3. In chapter 3, I elaborated on the methodologies that I followed to achieve the research objective. This chapter has the following sections: 1) philosophical assumptions, 2) research design, 3) setting and sample, 4) selection of participants, 5) data collection, 6) data analysis and 7) ethical consideration. In this chapter, I documented that I used an interpretative research paradigm in all four phases of the study. Literature review, teachers, parents, and children with ASD were the sources of the information in the study. By creating the artifact to overcome learning obstacles, this thesis focused on developing ICT tools that support the learning of children with ASD in four phases. I used qualitative descriptive, thematic content analysis, and participatory design to respond to the proposed research questions. I used qualitative descriptive studies to draw from naturalistic inquiry, which purports a commitment to studying something in its natural state to the extent that is possible within the context of the research arena. Thus, there was no pre-selection of study variables, no manipulation of variables, and no prior commitment to any one theoretical view of a target phenomenon. I used agile methodology to develop mobile applications that respond to the needs of children with ASD that were identified in the first two phases (I-II). Using agile methodology, teachers, parents, and children with ASD participated in the research project from the planning, development, and testing. This resulted from multiple iterations of the application at each phase. Purposeful case studies were used in four phases of the study conducted in inclusive schools, special centers for children with disabilities, and communities. The case studies used in this thesis are 1) Descriptive (Phase I), 2) Exploratory (Phase II), and 3) Explanatory (Phase III-IV). The schools and special centers that have children with ASD were the settings for this study. The population used in this research is from four provinces and Kigali city. Parents are recruited from Rwanda Parents' Initiative on Autism (RPIA). I used in-depth, semi-structured interviews in FGDs for the data collection, and observed children with ASD when using mobile applications. I also used the Quora digest forum (Quora, 2021) to collect data from the international community. I used the user testing method to test and evaluate the efficiency of the mobile application. With the respect to

ethics, I got an ethical clearance from the collegial research ethical committee, and a letter of consent was signed by participants before they participate in the study. All data collected are kept confidential at the physical drive and participants have rights to published papers, thesis, and developed applications.

4. In chapter 4, I presented the results from four phases of the study. The first phase of the study revealed that ICT can support the education of children with ASD when they respond to individual needs within a given subject in the curriculum. I have argued throughout this work that the ICT has promisingly paved its way into the field of teaching and treating children with ASD. in the second phase, it was found that the existing digital platform can be adapted to teaching and learning children with ASD when they are translated and recreated to respond to specific environmental context. The third and fourth phases demonstrated the role of the community in the planning, developing, and evaluation of a mobile application for children with ASD. This study aimed to create a user-friendly, practical mobile application that responds to the needs of children with ASD and eliminates the barriers to learning basic mathematical skills.

5. In chapter 5 I elaborated a discussion on the findings and existing literature to help answer the research questions. The findings of this study revealed the capabilities to integrate ICT in the education of children with ASD and were supported by previous studies. I also highlighted the strength and limitations of the study.

6.3. Revisiting the research questions formulated in Chapter 1

To break down the problem of *how children with ASD can overcome learning obstacles such as Communication Disorders, Behavioral Challenges, and social disorders with personalized digital tools and content,* I formulated the following questions in chapter 1:

1. What are the special educational needs of children with ASD?
2. How can Information Communication Technologies support the education of persons with ASD?

3. How can educational digital content be adapted to support the learning of children with ASD in Rwanda?

4. How to develop a mobile application that suits the Rwandan education Context for children with ASD?

5. How do children with ASD, parents, and teachers perceive the use of the developed mobile application?

6.3.1. What are the special educational needs of children with ASD?

This research question was addressed throughout the thesis but with particular emphasis in the first phase of the study. This was done by using a narrative review of existing literature that documented what is ASD, the levels of ASD, are characteristics, the behavior of children with ASD, and models applied to support children with ASD. I also responded to the question through face-to-face focus group discussions with parents of children with ASD, and their teachers, and observed the behavior of those children.

6.3.2. How can Information Communication Technologies support the education of persons with ASD?

This research question was also addressed in the whole thesis, but specifically in the first phase of the study. It was responded to through the literature review that documented the role of ICT to support the education of children with ASD. I also visited schools and centers that have children with ASD to discuss with teachers and parents to understand their perceptions of using ICT in the education of children with ASD. I also installed mobile applications on smartphones and laptops to observe their capacity to use digital gadgets.

6.3.3. How can educational digital content be adapted to support the learning of children with ASD in Rwanda?

This research question was also addressed in the whole thesis, but specifically in the second phase of the study. The researchers used focus group discussions (FGDs) to collect the data for the second phase of the study. I selected online content from Khan Academy, which focused on early counting mathematics, based on its audiovisual features, as these can aid learning for children with ASD. I projected the selected

educational video on a screen, and the participants discussed the design layout and possible modifications to adapt it to the education of children with ASD in the Rwandan context.

I followed six steps of thematic content analysis recommended by Caulfield (2019) and Nowell et al., (2017): (1) familiarization, (2) coding, (3) generating themes, (4) reviewing themes, (5) defining and naming themes, and (6) writing up. I used conceptual reliability to ensure the validity and reliability of the data at every step of the analysis of the coded data by involving 18 teachers and 6 parents in coding and reviewing data.

6.3.4. How to develop a mobile application that suits the Rwandan education Context for children with ASD?

This research question was formulated based on the main objective of this study: *To design and develop a mobile application that improves the learning of children with ASD in Rwanda*. It was answered specifically in the third phase of the study. I used a participatory design approach to design a human-centered mobile application to support the learning of mathematical skills of children with ASD. this phase involved teachers, parents, and children with ASD in all steps of the development of a mobile application.

6.3.5. How do children with ASD, parents, and teachers perceive the use of the developed mobile application?

This question was addressed by conducting a qualitative usability tasting of the developed mobile application in the fourth phase of the study. In the usability-testing session, teachers and parents were facilitators who guided and observed children with ASD when they use the mobile application. After 30 days of using the mobile application, I conducted a Focus Group Discussion (FGD) with parents and teachers to understand their perceptions of using the developed mobile application among children with ASD. After a Focus Group Discussion, I also observed children with ASD using mobile applications to verify and confirm the results. The results revealed that the applications are promising to improve the learning of children with ASD in the implementation of the competence-based curriculum of Rwandan basic education.

6.4. Research contributions

This section focuses on the contributions of this study. the section is divided into three subsections focusing on contribution to theory, methodology, and practice.

6.4.1. Theoretical contributions

Theory and empirical findings contribute to the understanding of the role of ICT in teaching children with ASD and the role of the community to develop digital content and mobile applications in the global context. This study also contributes to the understanding of the problem to overcome the communication barrier of children with ASD to access educational content in Rwanda and used ICT-related initiatives. From the literature review, I found that most of the mobile applications that are developed to support children with ASD were developed with low participation of parents and educators to elaborate the set of features that respond to the behavior of children with ASD. I have documented that ASD is caused by biopsychosocial factors and the environmental context influence the behavior of children with ASD.

The formula which defines the user as a set of senses, cognitive, and motor functioning (equation 1) could guide future researchers to contextualize the digital content and develop new mobile applications that respond to the psychosocial environment of children with ASD.

Although some studies have been done on how ICT can support children with ASD in developing countries (Stuckey & Domingues-Montanari, 2017), (Zamrodah, 2016), and (Kumm et al., 2022). There is a lack of good-quality publications from sub-Saharan Africa and other low-income countries about teaching children with ASD using ICT. There is no other study conducted in Rwanda on how to use ICT to improve the education of children with ASD in the implementation of the competence-based curriculum. This study will help researchers with existing theories and methods to improve the lives of children with ASD in different domains.

6.4.2. Methodological contributions

The main methodological contribution of this research is a combination of three purposeful case studies 1) Descriptive (Phase I), 2) Exploratory (Phase II), and 3) Explanatory (Phase III-IV). The local flow of the

phases of the study (Understanding, Demonstration, Design and development, and evaluation) may also contribute to the methods. Another methodological contribution lies in the experience gained through the application of the case study strategy and an interpretive approach and techniques applied for data collection. This experience may be useful for other studies on the adoption and use of ICT-related tools to support the education of children with ASD in the context of developing countries.

Finally, a methodological contribution relates to the appropriateness of applying theoretical concepts and theories developed in other contexts. The applicability of some research theories and models developed in other developed countries to studies in the context of a developing country has been questioned owing to the differences that exist in social and cultural settings. The successful use of these theories in this study contributes to providing examples of the interpretation of case studies from developing countries like Rwanda.

6.4.3. Practical contributions

The practical contribution is the detailed insight provided in the four phases of the study. the purposeful case studies reveal that ICT can support the learning of children with ASD when the tool responds to their deficits. This implies that for effective implementation, emphasis should be placed on the role of the community in planning and selecting tools that respond to the specific behavior of children with ASD. This will support the inclusion of children with ASD in competence-based curriculum or Rwanda basic education.

The case studies also revealed that teachers need to be aware of the existence of children with ASD in classrooms and acquire new skills to support them in an inclusive environment. Another practical contribution is the framework of analyzing the process of adoption, development, and use of ICT tools to understand development in a specific context. The contribution of this research is to understand, based on philosophical assumptions how to ICT can be adapted to implement the competence-based curriculum specifically the inclusion of children with ASD. To this end, the due process used in this thesis can be used as a practical tool.

6.5. Limitations and recommendations for further research

In this study, four major limitations have implications for further studies. The first limitation is that the developed mobile application focused only on counting two consecutive currencies from five to one hundred. The selected chapter represents only one topic in 36 (2.7%) planned content of the syllabus supposed to help children learn basic mathematics at an early age. The second is that, while there is an apparent intervention for children with ASD, this thesis does not focus on the elderly. Third, this study excludes persons who do not have access to ICT (NISR, 2019). The final limitation is that this thesis presupposes an interest in ICT for children with ASD that exclude others who do not meet the profile.

The qualitative data analysis revealed that changes in methodologies, provision of educational resources, and empowering skills of ICT are used in teaching and supporting learners with ASD in an inclusive environment. The study also documented that the contextualization of existing digital content is a perfect solution when it meets the actual context of the domain. However, to succeed in using ICT in teaching children with ASD, the developers of mobile applications could include features available in the surrounding environment and provide a continuous change in the application across the development age of these children. The findings also revealed the need for changes in policies, modifications of the existing competence-based curriculum, and an increase of qualified teachers to facilitate the inclusion of children with ASD.

Considering this field of research is new in the least developed countries, this study recommends further exploration of educational methodologies and the development of ICT tools that respond to the needs of children with ASD. This study may be the starting point for future studies that facilitate the successful integration of individuals with autism into the society of Rwanda by utilizing different digital tools to ensure their participation in various learning and economic activities. Future studies may also focus on developing ICT tools for children with ASD to implement the whole competence-based curriculum of Rwandan primary education. This study underscores the need for more ICT tools to be developed in response to the needs of children with ASD.

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Turnitin antiplagiarism check declaration.

I, Ntalindwa Theoneste (Student Reg. number: 217302238), am a student registered for the Ph.D. program in the year 20016/2017. I hereby declare the following:

- I am aware that plagiarism (the use of someone else's work without their permission and/or without acknowledging the original source) is wrong.
- I confirm that ALL the work submitted for assessment for the above course is my own unaided work except where I have explicitly indicated otherwise.
- I have followed the required conventions in referencing the thoughts and ideas of others.
- I understand that the University of Rwanda may take disciplinary action against me if there is a belief that this is not my own unaided work or that I have failed to acknowledge the source of the ideas or words in my writing.

Signature:  Date: _**14**th **December** 2021

Appendices

List of published papers

1. Ntalindwa T, Soron TR, Nduwingoma M, Karangwa. E. and White. R. (2019). The Use of Information Communication Technologies Among Children With Autism Spectrum Disorders: Descriptive Qualitative Study. *JMIR Pediatrics and Parenting*, *2*, 1–8. https://doi.org/10.2196/12176

2. Ntalindwa T, Nduwingoma M, Karangwa E, Rashid Soron T, Uworwabayeho A, Uwineza A (2021). Development of a Mobile App to Improve Numeracy Skills of Children With Autism Spectrum Disorder: Participatory Design and Usability Study. JMIR Pediatr Parent 2019;2(2):e12176. https://doi.org/*10.2196/21471*

3. Ntalindwa T, Nduwingoma M, Uworwabayeho A, Nyirahabimana P, Karangwa E, Rashid Soron T, Westin T, Karunaratne T, Hansson H Adapting the Use of Digital Content to Improve the Learning of Numeracy Among Children With Autism Spectrum Disorder in Rwanda: Thematic Content Analysis Study JMIR Serious Games 2022;10(2):e28276.

   http://dx.doi.org/10.2196/28276

Research ethical clearance (Phase I-IV)

UNIVERSITY of RWANDA

COLLEGE OF EDUCATION

RESEARCH AND INNOVATION UNIT

Rukara, 27th May, 2019
Ref: 01/P-CE/635./EN/gi/2019

TO WHOM IT MAY CONCERN

I am pleased to you Mr. Theoneste Ntalindwa, a citizen of Rwanda, who is currently an employee of the University of Rwanda-College of Education as E-learning Officer and a doctoral student of the School of Education at the University of Rwanda-College of Education. As a PhD by research student, he is conducting a research entitled: "**Developing educational mobile application for persons with Autism Spectrum Disorders in Rwanda**". His research will involve both children with Autism Spectrum Disorders (ASD) and their parents recruited respectively from schools and centers of children with special needs education and association of parents of children with ASD.

Mr. Ntalindwa's research project passed through an internal collegial ethical process. Thus, the University of Rwanda-College of Education: Directorate of research and Innovation confirms that this research adheres to ethical standards and principles. Therefore, we kindly request you to accord him your cooperation to enable his research to be successful.

Your permission for him to conduct the study will be highly appreciated.

Yours sincerely,

UNIVERSITY OF RWANDA - COLLEGE OF EDUCATION - CE

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Cc:

- The Principal, UR-CE
- Dean, School of Education
- Dr Mathias Nduwingoma

Informed Consent Form for teachers/Parents (Phase I)

Informed Consent Form for teachers/Parents

This informed consent form is for teachers of children participating in the research study titled: "Use of Information Communication Technologies among children with Autism Spectrum Disorders; A descriptive qualitative study."

The study is conducted by ThéonesteNtalindwa (Ph.D. candidate at University of Rwanda, Rwanda), Nduwingoma Mathias, Karangwa Evariste, and Tanjir Rashid Soron (Neuro-Developmental Disabilities Protection Trust, Bangladesh).

This Informed Consent Form has two parts:

Information Sheet (to share information about the study with you)

Certificate of Consent (for signatures if you agree that your child may participate)

Part 1: Information Sheet Introduction

We are researching to enable people with Autism Spectrum Disorders to be included in the basic education system in Rwanda. In short, the study is about finding out how it can be helpful to support teaching and learning in Rwandan primary education schools.

Our research will be an open discussion about the ICT to improve the teaching and learning of children with ASD. The focus group discussion will take place at the school address.

To do this, we ask you as a teacher/parent for permission. After reading about the study below, and if you agree, the next thing we will do is ask you for their agreement before the session.

There may be some words that you do not understand. In that case, please feel free to either contact us via e-mail or the principal at the school, who can send us all your questions via e-mail so we can answer them before you sign the certificate of consent.

Voluntary participation

You do not have to agree that you can participate in the study. You can choose to say no, and any services you receive at the school will not change. We know that the decision can be difficult. You can ask as many questions as you like, and we take the time to answer them via the school manager. You do not have to answer any questions or participate in the focus group discussion if you feel uncomfortable doing so.

Procedure

The study will be done at the <<Name of the school>>>. You will participate in one session of about one hour and a half in focus group discussion. The interviews will be recorded.

The questions that are likely to be asked during the focus group discussion will be related to the main research question: How helpful is ICT to support children's education with ASD learning in Rwanda?

Benefits

There will be no immediate and direct benefit to you or your school. Still, your participation is likely to help us find out more about how the ICT can be made more accessible and support the inclusion of person with neuro-developmental disabilities like ASD in the education system with other normal students. We hope that the results will help the integration of ICT in your teaching profession and enabling your child to perform like others at the school as well as improving communication between you and your children.

Reimbursements

You will not be provided with any payment to take part in the research. However, the findings of research will be available to you for free.

Confidentiality

We as researchers will not share information about you. However, because something out of the ordinary is being done through research in your community, it will draw attention. If you participate, you may be asked questions by other people in the community. We cannot guarantee confidentiality, but it is our belief that the nature of the research question is not very sensitive or personal.

Sharing of Research Findings

We will share what we have learnt with the participants and the principal. Nothing that your child will tell us during the sessions will be attributed to him/her by name. A written report will also be given to the participants, which they can share with their community. We will also publish the results in order that other interested people may learn from our research.

Right to refuse or withdraw

You may choose not to participate in this study. Choosing to participate or not will not affect either your own future at the school in any way. You still have all the benefits that would otherwise be available at this school. You stop participating in the discussion at any time that you wish without either of you losing any of your rights.

Who to Contact

If you have any questions you may ask them now or later, even after the study. If you wish to ask questions, you may contact either the principal or ThéonesteNtalindwa, ntatheos@yahoo.co.uk, Telephone: 0788884594. Mathias Nduwingomandumathias2001@yahoo.com, Telephone: 0788897814. EvaristeKarwangakarangwa81@ymail.com, Telephone: 0785489767.

Part 2: Certificate of Consent

I as a teacher have been asked to give consent to participate in this research study, which will involve observation and a brief interview. I have read the foregoing information, or it has been read to me. I have had the opportunity to ask questions about it and any questions that I have asked to have been answered to my satisfaction. I consent voluntarily to participate in this study.

Print Name ofTeacher

Signature ofTeacher

Date_____ Day/Month/Year

Interview guide and Characteristics of a Person with Autism Spectrum Disorder (Phase I)

1. Characteristics of a Person with Autism Spectrum Disorder

Autism is characterized by marked difficulties in behavior, social interaction, communication and sensory sensitivities.

Behavioral

People on the spectrum may exhibit unusual behavior due to the difficulties they have responding to their environment. These behaviors may include:

unusually intense or focusedinterests

Stereotyped and repetitive body movements such as hand flapping and spinning

repetitiveuseofobjectssuchasrepeatedlyswitchinglightsonandofforlininguptoys.

insistence on sticking to routines such travelling the same route home each day and doing things in exactly the same order everytime

sensory sensitivities including avoidance of everyday sounds and textures such ashair dryers, vacuum cleaners andsand

Social interaction

Their difficulties with social interaction may manifest in the following ways:

Limited use and understanding of non-verbal communication such as eye gaze, facial expression and gesture.

Difficulties forming and sustaining friendships

Lack of seeking to share enjoyment, interests and activities with other people

Difficulties with social and emotional responsiveness

Communication

Therearesomepeoplewithautismwho speak fluently,others who are speech impaired to varying degrees and others still, who are unable to speak at all. Impaired communication is characterized by:

delayed language development

difficulties initiating and sustaining conversations

stereotyped and repetitive use of language such as repeating phrases from television

Interview guide questions for teachers.

As I come from describing the characteristics of children with ASD, do think you have some children in yourclass?

I am conducting research into basic education. Inn which level you you areteachning?

Which subject are youteaching?

Which subject your students with ASD likemost?

What are the interests of children with ASD inclass?

My research interest is ICT to support education of children with ASD inschools. Do you have some ICT gadget to support your teachingactivities?

Do you have any special tool designed only to help those learners withASD?

Do the students have access to ICTtools?

Which topics the learners mostlylike?

Do you think ICT can improve performance in thesetopics?

How ICT can be used to teach thesechildren?

What do see as the biggest obstacle to your learners with ASD developing theirinterests?

In your teaching, what do you suggest that can improve your teachingactivity?

What is your message to the government regarding education of children withASD?

Questions for parents

As I come from describing the characteristics of children with ASD, do think you have some children in your class?

How did find the school for your children the ASD is not known by every school?

Did you know about Autism

How your children behave out of the schools

Do you have any digital tool at your home such as TV, smartphone, Radio, etc.?

How often you children use those tools

What are behavior changes you see from the students after using digital tool?

What the interest of those children who do not have access to the smartphone?

Did you see you children engaged in some activities a thome?

How do you think ICT can contribute to educate your children?

What are difficulties you observe the children face when they are using ICT tools?

In which area should we emphasize whewn selecting ICT tools for thesechildren?

What do you see as the biggest obstacle to your children with ASD developing his interests?

What is your message to the government regarding education of children withASD?

What is your message to theeducators?

What is your message to the family of children withASD?

Interview guide questions for school managers

As I come from describing the characteristics of children with ASD, do think you have some children in yourclass?

I am conducting research into basic education. Are you teaching in whichlevels?

Are your class inclusive? This means all students with and without ASD are in the same class.

Which subject your students with ASD like most?

What are the interest of children with ASD in schoolactivities?

My research interest is ICT to support education of children with ASD inschools. Do you use ICT as a tool in your teachingactivities?

Do you have any special ICT designed only to help those learners withASD?

Do the students have access to ICTtools?

What are facilities you have at thisschool?

Which topics the learners mostlylike?

Do you think ICT can improve performance in thesetopics?

How ICT can be used to teach thesechildren?

What do see as the biggest obstacle to your learners with ASD developing theirinterests?

How the policy of inclusion in education is implemented at yourschool?

What is your message to the government regarding education of children withASD?

Informed Consent Form for teachers (Phase II)

This informed consent form is for teachers of children participating in the research study titled: ***"****Digital content as a supporting tool in the learning of numeracy among children with Autism Spectrum Disorders in Rwanda: A Thematic content analysis study"*

The study is conducted by Théoneste Ntalindwa (PhD candidate at University of Rwanda, Rwanda), Nduwingoma Mathias, Karangwa Evariste, Alphonse Uworwabayeho (University of Rwanda, Rwanda), Thomas Westin, Henric Hasson and Thashmee Karunaratne (University of Stokholm, Sweeden) and Tanjir Rashid Soron (Neuro Developmental Disabilities Protection Trust, Bangladesh).

This Informed Consent Form has two parts:

- Information Sheet (to share information about the study with you)
- Certificate of Consent (for signatures if you agree that your child may participate)

Part 1: Information Sheet

Introduction

We are doing research to enable people with Autism Spectrum Disorders to be included in basic education system in Rwanda. In short, the study is about finding out how the content, interface and process of Khan Academy can be useful to support teaching basic mathematics in Rwandan primary schools.

In our research, we need to observe teachers teaching basic mathematics, exploring their lesson plan and teachers guides. The focus group discussion will also take place.

To do this we ask you as a teacher for permission. After reading about the study below, and if you agree, then the next thing we will do is ask you for their agreement as well, before the session.

There may be some words that you do not understand. In that case, please feel free to either contact us via e-mail or the principal at the school, who can send us all your questions via e-mail so we can answer it before you sign the certificate of consent.

Voluntary participation

You do not have to agree that you can participate in the study. You can choose to say no and any services that you receive at the school will not change. We know that the decision can be difficult. You can ask as many questions as you like, and we take the time to answer them via the principal. You do not have to answer any question or take part in the observation if you feel uncomfortable doing so.

Procedure

The study will be done at the << school>>. You will participate in one session of about 15 minutes in focus group discussion. The interviews will be recorded.

The questions that are likely to be asked during the focus group discussion will be related to the main research question: How useful is Khan Academy content, process and platform for supporting children with ASD learning in Rwanda?

Benefits

There will be no immediate and direct benefit to you or your school, but your participation is likely to help us find out more about how the content of Khan Academy can be made more accessible and support inclusion of person with neuro-developmental disabilities like ASD in education system with others normal students. We hope that the results will help integration of ICT in your teaching profession and enabling your child to perform like others at the school as well as improving communication between you and your pupils.

Reimbursements

You will not be provided with any payment to take part in the research. However, the interface for teaching basic mathematics will be made available for free.

Confidentiality

We as researchers will not share information about you. However, because something out of the ordinary is being done through research in your community, it will draw attention. If you participate, you may be asked questions by other people in the community. We cannot guarantee confidentiality, but it is our belief that the nature of the research question is not very sensitive or personal.

Sharing of Research Findings

We will share what we have learnt with the participants and the principal. Nothing that your child will tell us during the sessions will be attributed to him/her by name. A written report will also be given to the participants, which they can share with their community. We will also publish the results in order that other interested people may learn from our research.

Right to refuse or withdraw

You may choose not to participate in this study. Choosing to participate or not will not affect either your own future at the school in any way. You still have all the benefits that would otherwise be available at this school. You stop participating in the observation at any time that you wish without either of you losing any of your rights.

Who to Contact

If you have any questions you may ask them now or later, even after the study. If you wish to ask questions, you may contact either the principal or Théoneste Ntalindwa, ntatheos@yahoo.co.uk , Telephone: 0788884594. Mathias Nduwingoma ndumathias2001@yahoo.com, Telephone: 0788897814. Evariste Karwanga karangwa81@ymail.com, Telephone: 0785489767.

Part 2: Certificate of Consent

I as a teacher have been asked to give consent to participate in this research study, which will involve observation and a brief interview. I have read the foregoing information, or it has been read to me. I have had the opportunity to ask questions about it and any questions that I have asked to have been answered to my satisfaction. I consent voluntarily to participate in this study.

Print Name of Teacher _____

Signature of Teacher_____

Date _____

Day/Month/Year

Interview guide question for primary teachers (Phase II)

We are working on the study to support teaching math to children with Autism in schools.

Do you have some children with Autism in your school?

Describe your teaching method – how would it help pupils get to grips with maths?

How do you plan to use technology in a typical maths lesson?

How would you boost a pupil's attention when you are teaching math?

We are evaluating the interface of Khan Academy to support teaching numeracy children with Autism.

Let us watch the short course from Khan Academy teaching basic counting.

https://www.khanacademy.org/math/early-math/cc-early-math-counting-topic/cc-early-math-counting/v/counting-in-order

How do you find this interface to help learning of children with cognitive disabilities like those who have Autism?

As I introduced, the goal this research is to translate the content of Khan Academy in Kinyarwanda language to increase the accessibility of digital content to person with disabilities.

What are your suggestions to be done on the interface to meet the Rwandan context?

What are challenges you find to be addressed before using this interface?

If the content is translated into Kinyarwanda, what are elements can be included in the interface to help children with Autism to stay focus.

Teaching children with Autism in class we need reward actions for them. How do you reward the children in class to encourage them in their learning?

To close this discussion, do you have any other comments or suggestions that may contribute to this study?

Sample Form for Observers' Notes at Focus Groups (Phase II)

FOCUS GROUP DATA CAPTURE PRO-FORMA				
Study Title:	Digital content as a supporting tool in the learning of numeracy among children with autism spectrum disorders in Rwanda: A Thematic content analysis stud			
Date:				
Moderator Name:				
Name of school / center				
No. Participants:				
Start Time:				
End Time:				
Participant Demographics: ***enter column headings as appropriate***				
Gender	Number	Job		
Male				
Females				

Discussion Question 1	
Do you have some children with Autism in your class?	Time
1. I did not know that my kid has Autism before he got diagnosis from a medical Doctor. 2. In our class is not easy to confirm whether one child has autism because we confuse it with other learning disabilities, 3. *It is not easy to include children with ASD in the same classroom because those children have very challenging behavior. For example, if you are teaching and when you ask them to respond to the questions, those children refuse to respond*"	5 min

Discussion Question 2	
Describe your teaching method – how would it help pupils get to grips with math?	Time
1. When a child does come activity, s/he can tell you any other activity he/she wish to perform. For example, here, a child can accomplish to fabric the cap, and then he/ she insist to be allowed to make a calf for example. We allow him/her what s/he wishes to do even though s/he is	5 min

not able to make it. We have seen that, if we deny it, the learner's happiness and courage disappear! 2. *One of the methods we use is the introduction of games on each topic we are teaching. This makes children stay focus and be engaged in the class because they always enjoy games".* 3. *Students are given a task to cut pieces of clothes. All students can't make it well at the same time. There is a time when one among the best performers ask the teacher to go and help those who failed to do the task. That time we allow that so that they can go on at the same level. That kind of teamwork also makes the children happy.*	
Discussion Question 3	
How do you plan to use technology in a typical math lesson?	Time
1. *In the evening we use the projector screen to play some educational videos and cartoons that bring children together and we see improvement after a given time.* 2. *Like children with other disabilities like vision or hearing impairment have different tools that enable them to learn in class, I also wish the availability of tools that may bring children with ASD to stay focused when they are in the class.* 3. We find that digital games can help children with Autism to learn. However, most of tools we use are in foreign language which are hard to learn for those children.	5 min
Discussion Question 4	
How would you boost a pupil's attention when you are teaching math?	Time
1. *In such a case we use the real examples of objects which are found in our region to replace the examples provided in the book. This strategy helps children to better understand the topic we are teaching.* 2.	5 min
Discussion Question 5	
We are evaluating the interface of Khan Academy to support teaching numeracy children with Autism. Let us watch the short course from Khan Academy teaching basic counting. https://www.khanacademy.org/math/early-math/cc-early-math-counting-topic/cc-early-math-counting/v/counting-in-order	5 min

The video is played three times	
Discussion Question 6	
How do you find this interface to help learning of children with cognitive disabilities like those who have **ASD**?	5 min
1. *This page is well organized as it indicates easy categories of learners where you can get the content by grade because it is not in the same way we teach first or second grade.* 2.	5 min
Discussion Question 7	
As I introduced, the goal this research is to translate the content of Khan Academy in Kinyarwanda language to increase the accessibility of digital content to person with disabilities. What are your suggestions to be done on the interface to meet the Rwandan context?	Time
1. *Because most of our children are not able to follow the formal education system, it would be better to use the examples and images that are found in our families.* 2. *I find the educational content can be supportive in the learning of children with Autism, but there are some changes to be made to adapt this content to our local context.*	5 min
Discussion Question 8	
What are challenges you find to be addressed before using this interface?	
1. *As you can see, it is not possible to play YouTube videos in this area, I encourage to do advocacy for us to get high-speed Internet in the rural area as we see in cities of Rwanda; however, if there is a possibility to download the video and play it offline can support our education system.*	
Discussion Question 9	
If the content is translated into Kinyarwanda, what are elements can be included in the interface to help children with Autism to stay focus.	Time
1. *When the content will be translated into the local language together with examples found in our environment, it will be helpful to all children including those considered to have normal intellectual capacity.*	5 min
Discussion Question 10	
Teaching children with Autism in class we need reward actions for them. How do you reward the children in class to encourage them in their learning?	Time
1. *As we said, learners with Autism need rewards like giving him a pen or a toy to encourage them to study, here, teachers don't have various*	5 min

tangible rewards to offer. While teaching, the student with ASD can accomplish the given task in a good way." 2. *In our class we use object that are available such as pen, and books as a reward to motivate children with Autism.*	
Additional Comments and Reflections	
1. *When the content will be translated into the local language together with examples found in our environment, it will be helpful to all children including those considered to have normal intellectual capacity.* 2. *Availability of offline content will be also supportive to teach children with Autism in and outside the class.* 3. *Participation of educators in the design and development of digital content for children with Autism can improve the quality of education for children with Autism.*	5 min

Informed Consent Form for teachers and parents (Phase III-IV)

This informed consent form is for teachers of children participating in the research study titled: "Development of a mobile application to improve numeracy skills of children with Autism Spectrum Disorders in Rwanda"

The study is conducted by Théoneste Ntalindwa, Nduwingoma Mathias, Karangwa Evariste, Alphonse Uworwabayeho, Annette Uwineza (University of Rwanda, Rwanda), and Tanjir Rashid Soron (Neuro Developmental Disabilities Protection Trust, Bangladesh).

This Informed Consent Form has two parts:

Information Sheet (to share information about the study with you)

Certificate of Consent (for signatures if you agree that your child may participate)

Part 1: Information Sheet

Introduction

We are doing research to enable people with Autism Spectrum Disorders to be included in basic education system in Rwanda. In short, this study aiming at design, development and evaluation of a mobile application to improve learning basic mathematics for children with Autism in Rwanda.

In our research, we need to work with teachers and parents in the design and evalution of the mobile application. We will work with children with ASD in testing of how they can use the developed application.

To do this we ask you as a teacher / parent for permission. After reading about the study below, and if you agree, then the next thing we will do is ask you for their agreement as well, before the session.

There may be some words that you do not understand. In that case, please feel free to either contact us via e-mail or the principal at the school, who can send us all your questions via e-mail so we can answer it before you sign the certificate of consent.

Voluntary participation

You do not have to agree that you can participate in the study. You can choose to say no and any services that you receive at the school will not change. We know that the decision can be difficult. You can ask as many questions as you like, and we take the time to answer them via the principal. You do not have to answer any question or take part in the observation if you feel uncomfortable doing so.

Procedure

The study will be done at the Autisme Rwanda. You will participate in one or more sessions session of about 30 minutes in focus group discussion. The interviews will be recorded.

The questions that are likely to be asked during the focus group discussion will be related to the main research question: Is it possible to design a mobile application that helps children with ASD to learn skip counting using coins used in Rwandan currency?

Benefits

There will be no immediate and direct benefit to you or your school, but your participation is likely to help us find out more about how to develop a mobile application to be made more accessible and support inclusion of person with neuro-developmental disabilities like ASD in education system with others normal students. We hope that the results will help integration of ICT in your teaching profession and enabling your child to perform like others at the school as well as improving communication between you and your pupils.

Reimbursements

You will not be provided with any payment to take part in the research. However, the mobile application will be made available for free.

Confidentiality

We as researchers will not share information about you. However, because something out of the ordinary is being done through research in your community, it will draw attention. If you participate, you may be asked questions by other people in the community. We cannot guarantee confidentiality, but it is our belief that the nature of the research question is not very sensitive or personal.

Sharing of Research Findings

We will share what we have learnt with the participants and the principal. Nothing that your child will tell us during the sessions will be attributed to him/her by name. A written report will also be given to the participants, which they can share with their community. We will also publish the results in order that other interested people may learn from our research.

Right to refuse or withdraw

You may choose not to participate in this study. Choosing to participate or not will not affect either your own future at the school in any way. You still have all the benefits that would otherwise be available at this school. You stop participating in the observation at any time that you wish without either of you losing any of your rights.

Who to Contact

If you have any questions you may ask them now or later, even after the study. If you wish to ask questions, you may contact either the principal or Théoneste Ntalindwa, ntatheos@yahoo.co.uk , Telephone: 0788884594. Mathias Nduwingoma ndumathias2001@yahoo.com, Telephone: 0788897814. Evariste Karwanga karangwa81@ymail.com, Telephone: 0785489767.

Interview guide for teachers and parents (Phase III-IV)

Describe your teaching method – how would it help pupils get to grips with Maths?

How do you plan to use technology in a typical Maths lesson?

How would you boost a pupil's attention when you are teaching math?

How do you find this interface to help the learning of children with cognitive disabilities like those who have Autism?

As I introduced, the goal of this research is to develop a mobile application to enable children with ASD to learn from the apps.

What are your suggestions to be done on the interface to meet the Rwandan Context?

What are the challenges you find to be addressed before using this interface?

What are elements can be included in the interface to help children with Autism to stay focus?

Teaching children with Autism in class we need reward actions for them. How do you reward the children in a class to encourage them in their learning?

What do you suggest focusing on in the future?

To close this discussion, do you have any other comments or suggestions that may contribute to this study?

Questions posted on Quora Digest (Phase III)

Question 1: What colors do children with autism-like the most when using a mobile application?

(https://www.quora.com/What-colors-do-children-with-autism-like-the-most-when-using-a-mobile-application)

Question 2: What are technical design of mobile app for person with Autism? **https://www.quora.com/unanswered/What-are-technical-design-of-mobile-app-for-person-with-Autism**

Question 3: What are the key elements to consider when designing a mobile app to teach numeracy to children with autism?

https://www.quora.com/What-are-the-key-elements-to-consider-when-designing-a-mobile-app-to-teach-numeracy-to-children-with-autism

Question 4: What are the key points to consider when teaching numeracy to children with autism to make them focus?

https://www.quora.com/What-are-the-key-elements-to-consider-when-designing-a-mobile-app-to-teach-numeracy-to-children-with-autism

Question 5: Can a child with autism study numeracy?

https://www.quora.com/Can-a-child-with-autism-study-numeracy

Letter of Collaboration (Phase I-IV)

autismerwanda@gmail.com/https://www.facebook.com/ www.autismerwanda.org

+250781521973,+ 250 782 414 220, +33677188974 Rosine Duquesne Kamagaju, Fondatrice

LETTER OF COLLABORATION

The purpose of this agreement is to define the reception conditions in the Autism Rwanda center and Théoneste Ntalindwa.

RECEPTION CENTER

NAME: AUTISM RWANDA

Represented by: ROSINE DUQUESNE KAMAGAJU

as General Manager

Address: KG 836 N ° 1 GISOZI

Telephone: +2507824141220

INTERN

Last Name and first name: Théoneste Ntalindwa

Date and place of birth: 08/17/1984 / Gicumbi

Nationality: Rwandan

Address: Kigali City - Gasabo-Jabana

EDUCATIONAL INSTITUTION OR TRAINING ORGANIZATION

NAME: University of Rwanda - College of Education

Represented by: Prof. George K. Njoroge

as: Principal

Address: principal.ce@ur.ac.rw

EDUCATION AND TRAINING

Nature of studies or training: Autism and management of autistic children

Duration: 4 years

Degree prepared or qualification sought: Doctorate / PhD

Level reached (year of Bachelor, Master ...): Bachelors of Computer Sciences with Education, Kigali Institute of Education (KIE), 2009. Master of Science in Information Technolgy (MSc.IT), Univerity of Madras India, 2012

STUDY OBJECTIVES

The aim of the work is to ensure the practical application of the student's theoretical knowledge.

The student's missions within the center are as follows: Autism and understanding the appropriate care for persons with Autism within Autisme Rwanda

The educational objectives are:

- Develop a computer application to help learning for children with autism.

- Evaluation of the use of the application by children with autism

- Do advanced research to develop the intervention for children with Autism

Name, first name and position of the person in charge of the internship follow-up in the company:

Rosine Duquesne Kamagaju, Founder

STUDIES CARRIED OUT

The duration of study is (10) months. It takes place from (November 2019) to (September 2020). It will take place (place) (in case of multiple places, specify each of them and the corresponding dates)

EVALUATION

At the end of research:

- Theoneste Ntalindwa is required to provide the Autism Rwanda center with a research report, a copy of which is communicated to the reception center.

- Théoneste Ntalindwa is required to mention in his research book the collaboration of Autism Rwanda in his research as well as the name of the legal representative.

SIGNATURES

Legal representative of the Autisme Rwanda signature and stamp

14.07.2020

Théoneste Ntalindwa
signature