EXPLORING TEACHERS' MOTIVATION TO USE DIGITAL TECHNOLOGY IN MATH EDUCATION

Augmented Reality Educational Environments.

Submited By

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Master of Science in Information Systems (Option: Internet Technology)

May, 2024

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A dissertation submitted in partial fulfilment of the requirements
for the degree of Master of Science in Information Systems
(Option: Internet Technology)
In the College of Science and Technology

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May, 2024

ACKNOWLEDGEMENTS

I express my heartfelt gratitude to the Almighty God for the gift of life and the spirit of hard work that sustained me throughout my master's program.

I extend my deepest appreciation to my family for their unwavering support, including financial, moral, and spiritual assistance, which played a crucial role during this journey.

A special acknowledgement goes to the lecturers at the University of Rwanda, College of Science and Technology, whose imparted knowledge laid the foundation for the completion of my master's thesis.

I am deeply grateful to the University of Agder and the University of Rwanda for offering me the extraordinary opportunity to participate in the exchange program, made possible through the EQIP PROJECT funding. Joining this program has been an immensely enriching experience, providing me with invaluable exposure to cutting-edge technologies such as Virtual and Augmented Reality. It was my first encounter with these innovations, and I am truly appreciative of the chance to acquire new skills and knowledge in this field. Additionally, this journey marked my maiden voyage through the skies, an unforgettable experience. I extend heartfelt appreciation to the welcoming individuals I encountered in Norway, whose kindness left a lasting impression on me. This opportunity has not only broadened my horizons but has also fostered personal growth and enriched my academic journey in profound ways.

I am truly honored and fortunate to have received encouragement and guidance from my academic supervisors throughout the thesis-writing process. Their support helped me choose an engaging topic and navigate the complexities of my research.

I also want to express my sincere thanks to my fellow students, whose collaborative spirit made the learning experience an interesting and rewarding adventure.

I extend my heartfelt gratitude to the participants who generously contributed to the data collection process. Their willingness to collaborate not only made the learning experience engaging but also provided essential data for addressing my research questions and challenges. Their valuable input has been instrumental in shaping the outcomes of this study, and I am deeply appreciative of their participation and support throughout the research journey.

ABSTRACT

Motivating teachers is pivotal for enhancing the quality of education within any educational system, as their motivation significantly influences students' learning experiences. Unfortunately, many teachers face challenges in maintaining high levels of motivation, prompting the need to explore the intrinsic factors that contribute to or hinder motivation in their teaching careers. This study aims to investigate teachers' intrinsic motivation to utilize digital educational technology for teaching mathematics and uncover the factors influencing their motivation. Additionally, the research assesses the user experience with an augmented reality geometry application prototype in the teaching process.

The study employs the design science research methodology, where innovative artifacts are created to address research questions and contribute new knowledge. Following a human-centered design approach with three iterations, each subjected to usability testing, the study focuses on secondary school teachers in Kamonyi District, Rwanda, utilizing a purposive sampling method. The research utilized the People Activity Context and Technology, Technology Acceptance Model, and Technology Pedagogy and Content Knowledge frameworks, aimed at guiding organizations in designing interactive systems that prioritize user needs, foster satisfaction, and enrich the overall user experience. The literature review enhances understanding of motivation, pedagogy, and digital visualization tools in education. Data were collected through documents review, survey questionnaires, observation, and interviews, with qualitative data analyzed using thematic analysis and NVIVO software.

Study findings indicate that some teachers exhibit the capability to select suitable educational technologies that effectively enhance engagement among educators and students during learning periods. Furthermore, teachers demonstrate proficiency in employing various technology-based pedagogical approaches in their teaching activities. All teachers express a willingness to undergo regular training on digital teaching methods to become familiar with the contextual use of educational technology. The study underscores the importance of an autonomy-supportive motivation style that respects individual autonomy, competence, and a sense of relatedness, contributing to increased intrinsic motivation.

Keywords: motivation, pedagogy, augmented reality, educational technology,visualization tools, and mathematics education.

ABBREVIATIONS

AR	Augmented Reality
VR	Virtual Reality
1D	One Dimension
2D	Two Dimension
3D	Three Dimension
RQ1	Research Question One
RQ2	Research Question Two
RQ3	Research Question Three
UI	User Interface
UX	User Experience
SUS	System Usability Scale
CBC	Competence Based Curriculum
APPs	Applications
SDT	Self-Determination Theory
PACT	People Activity Context Technology
HMD	Head Mounted Display
MATH	Mathematics
GPS	Global Positioning System
SDKs	Software Development Kits
TAM	Technology Acceptance Model
PU	Perceived Usefulness
PEU	Perceived Ease of Use
TLAs	Teaching Learning Activities
HCI	Human Computer Interaction
NUI	Natural User Interface
ELT	Experiential Learning Theory
TPACK	Technological Pedagogical Content Knowledge

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Chapter 1

INTRODUCTION

A teacher's motivation can be a dynamic and ever-changing aspect of the workplace. At times, individuals may be hired with a high level of intrinsic motivation, accepting their new roles with enthusiasm and energy while others start their jobs with little or no intrinsic motivation. However, over time, various factors can contribute to weakening this motivation[39]. According to self-determination theory[24], motivation can be categorized into two distinct types: intrinsic motivation and extrinsic motivation. These two forms of motivation are characterized by their own unique causal factors and traits. Drawing from goal-setting and self-efficacy theories, they explain the relationship between goals, expectations, self-efficacy, and performance[63][3]. Thus, the extent and how these elements are put into practice may influence individual emotions, ultimately shaping competencies at a particular level. These competencies have the potential to either diminish or enhance intrinsic motivation[63][16]. Integration of visualization tools in education will help teachers adapt different teaching styles or methods that are in line with students' learning styles and interests [72]. This will help to visualize one, two, or three-dimensional concepts very well in learning mathematics[66].

1.1 Background of the Study

A comprehensive understanding of motivation is essential before exploring intrinsic motivation, the relevant motivational styles, and the factors that characterize demotivated teachers.
According to Self-Determination Theory (SDT)[25], motivation refers to the reasons or driving forces behind an individual's choices, actions, and behaviors. Therefore, motivation concerns such things as activity, energy, direction, and persistence.[26][16]. Some researchers consider motivation as an integral aspect of emotion processing, while others define motivation as the driving forces behind people's behavior[96].In the context of teaching, motivation is a set of attitudes and values that are encouraged and owned by the teacher and can influence students' attitudes toward achieving specific tasks through the learning objectives[43]. In Rwanda, as well as globally, mathematics education often involves students learning through the manipulation of images, symbols, and objects[12]. Visual tools play a pivotal role in doing so and enhancing the engagement of both teachers and students in mathematics instruction[35], leading to improved understanding, heightened motivation, enhanced performance, and ultimately, more effective outcomes. Among these tools, augmented reality (AR) application software stands out as a solution that can significantly contribute to achieving these outcomes[7][11]. To this end, researcher will undertake the development of a prototype augmented reality application tailored specifically for mathematics education.

1.1.1 Motivation

Motivating teachers is crucial for enhancing the quality of education within any educational system, as their motivation and behavior significantly impact students' learning experiences[33]. Factors such as the absence of context, demotivators, and lacking teacher behaviors have been identified as strong influences of early course motivation. However, the introduction of information and communication technology has presented new solutions to these challenges and demotivating factors faced by teachers in their teaching practices[33] . The adoption of augmented reality technology has yielded numerous positive outcomes, including improved attention, satisfaction, motivation, critical thinking, levels of confidence, learning interest, creativity, acquisition of new science vocabulary, positive emotional responses, better results, appreciation, fun experiences, enjoyment, effort, retention of knowledge, perception, collaboration, group learning, as well as enhanced immersion and engagement for both teachers and learners[7]. Ultimately, these outcomes contribute to an overall improvement in performance within educational settings.

1.1.2 The Goals of the Study

This research aims to explore factors contributing to teacher demotivation in delivering effective instruction and to evaluate the influence of educational technology visualization tools on teachers' intrinsic motivation. The objectives include a thorough examination of motivational concepts through an extensive literature review, an assessment of teachers' autonomy and competence in utilizing digital educational technology for mathematics instruction, an exploration of the enjoyment levels experienced by teachers while using digital education.

1.2 Autonomy-Supportive and Controlled Motivation Style

Autonomy-supportive and controlled motivation styles are concepts often associated with self-determination theory, a widely recognized motivation theory developed by Deci and Ryan[25]. These styles describe different ways in which individuals can be motivated[16].

1.2.1 Autonomy-Supportive Motivation

In an autonomy-supportive motivation style, the emphasis is on cultivating individuals' intrinsic motivation by providing them with choices, autonomy, and opportunities to make decisions. This approach aims to satisfy the basic psychological need for autonomy[16]. Key characteristics of an autonomy-supportive motivation style include:

- Respect for autonomy: This style respects individuals' preferences, values, and goals, allowing them to make decisions that align with their interests and values.
- Positive feedback increases intrinsic motivation because it enhances perceived competency.
- Effective communication in performance evaluation increases intrinsic motivation and develops the teacher's mindfulness.

1.2.2 Controlled Motivation

In a controlled motivation style, individuals are motivated primarily by external factors, pressures, or rewards. This style is associated with a lack of autonomy and can lead to lower levels of satisfaction and well-being. Key characteristics of controlled motivation include:

- External rewards or punishments: Individuals may engage in activities primarily to gain rewards or avoid punishments rather than because they find the activities inherently meaningful or enjoyable.
- Lack of autonomy: Controlled motivation often involves a feeling of obligation, where individuals feel forced to act in certain ways[16].

Controlled motivation can be effective in the short term but is less likely to lead to long-term commitment and satisfaction because it doesn't tap into intrinsic motivation or the individual's own sense of autonomy.

1.3 PACT Framework

PACT is a framework designed to help organizations understand the requirements for designing an interactive system that puts people first, supporting their needs and enhancing their enjoyment.The core emphasis of this framework is that individuals utilize technologies to engage in activities within specific contexts[89] .This human-centered approach prioritizes what people want to do rather than focusing solely on what the technology or applications can do.

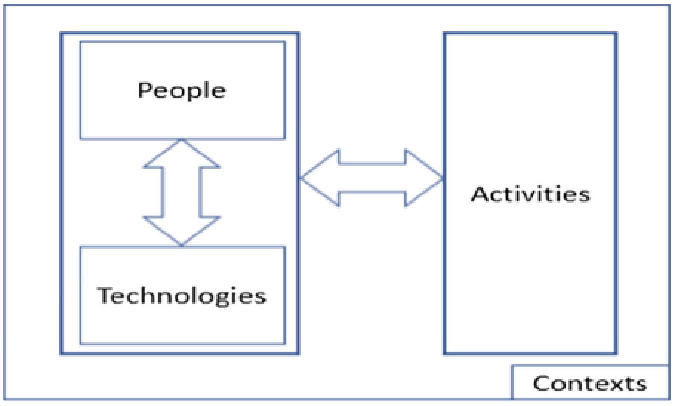


Figure 1.1: Interactive System Design Requirements Framework[89]

A scenario below can provide deeper insights into the concepts of intrinsic motivation by using the PACT analysis framework.

o Ms. Smith, a high school mathematics teacher, has always been passionate about math courses. She genuinely loves teaching her students and helping them develop a deep appreciation for course content. While teaching mathematics in the classroom, she combined a blend of technology, utilizing tools such as the iPad, PowerPoint slides, interactive whiteboard,SimReal, and GeoGebra to enhance the learning experience[66] [15]. She finds joy in seeing her students grow intellectually and emotionally through the study of content or handling challenging math questions.

• The PACT framework (which stands for People, Activities, Context, and Technologies) can be utilized to analyze the scenario involving Ms. Smith, the high school mathematics teacher, in the following way:

People identify the people involved in the scenario and these are:
1. Ms.Smith (the teacher).
2. High school students (the learners).
By analyzing their roles, perspectives, and characteristics : Ms.Smith is passionate about teaching and has a deep appreciation for the math course. She is dedicated to helping her students grow intellectually and emotionally. The students are the recipients of Ms.Smith's teaching and support.

Activities taking place in the scenario are:
1. Teaching mathematics to high school students.
2. Fostering a deep appreciation for the course content.
3. Helping students handle challenging math questions.
4. Observing and facilitating the intellectual and emotional growth of her students.
By considering the methods and strategies Ms.Smith may use to accomplish these activities through effective teaching techniques, creating a positive and engaging learning environment, providing additional support and guidance when students face challenges, discussing learner's emotional states like anxiety and boredom, forming student's groups to facilitate them collaborate together and so on.

Context analysis the contextual factors that influence the scenario:
1. High school setting.
2. The subject is Mathematics.
3. Ms. Smith's passion and dedication play a significant role.
4. The students' receptivity and motivation to learn mathematics.
5. The curriculum and educational standards in place.
By considering external factors that may impact the teaching and learning process, the following can be considered: School policies and resources, socioeconomic backgrounds of students, school

environmental and social factors. On another hand consider these internal factors that may impact the teaching and learning process: Individual personal belief, emotional state(e.g. anger, anxiety,happiness),personal competency and so on .

Technologies aspect evaluate the role of technologies in this scenario:
1 Ms.Smith may utilize various teaching technologies, such as GeoGebra, digital resources,or online platforms.
2. Technology can aid in delivering lessons effectively and engaging students in math-related activities.

By using the PACT framework, you can gain a comprehensive understanding of Ms. Smith's role as a teacher, the activities she engages in, the context in which she operates, and the potential role of technology in her teaching. This analysis can help identify areas for improvement, alignment with educational goals, and strategies for enhancing the teaching and learning experience.

According to the above-mentioned PACT analysis, intrinsic motivation behavior is engaged in for the person's own sake and for the pleasure and satisfaction derived from their performance [16][40]. From the above example, a mastery goal orientation can promote positive emotions and sustain motivation, whereas a performance-avoidance goal orientation can promote negative emotions and poor motivation[47][96]Smith has a mastery performance-oriented goal.

The following strategies have been suggested to improve motivation among teachers in coping with the factors that could decrease motivation. Three basic psychological needs should be met, where a person is free of anxiety and does not feel a demand or pressure to respond in a particular way (e.g. "should" or "ought")[16][26]. These needs include:

• Autonomy where individuals experiencing a sense of agency and having choices that determine their own behavior[26].

• Relatedness: Involves an individual experiencing a sense of connection to and support from others[26].

• Competency: The need for competence involves an individual experiencing a sense of self-efficacy and confidence in their ability to face the environment[26].Self-efficacy can be defined as an individual's belief in one's ability to organize and implement actions to carry out designated types of performance and tasks[63].

From self-expectation theory, argues that teachers should be accountable for their students' motivation, learning, and well-being by looking for supportive classroom environments and applying possible pedagogical approaches such as creating curiosity in learners by asking them questions that are not similar to their current knowledge, discussing learner's emotional states like anxiety and boredom, forming student's groups to facilitate them collaborate together and so on[39].These strategies can be executed successfully when teachers are internally motivated.

Teachers should set goals that determine the level of competency upon their achievement[40]. These goals not only contribute to students' abilities and achievements but also to the development of their self-efficacy[3][39].But if students cannot set clear goals to generate happy emotions and sustain motivation, they may experience negative emotions and poor motivation, which will affect teachers' motivation. Because emotions and motivation are inherently linked, this implies that teacher's motivation or demotivation can affect student motivation accordingly and vice versa [96].
However, Laura Sophie Stanszus [97]argue that promoting mindfulness is a way of fulfilling these basic psychological needs. Further research indicated that the fulfillment of these three needs not only influences daily well-being but also positively correlates with a sense of an authentic self and self-esteem.

1.4 Digital Educational Technology and Motivation in Teaching Mathematics

Children learn mathematical concepts through three stages: enactive, iconic, and symbolic. Enactive learning involves manipulating objects, iconic learning uses images, and symbolic learning uses symbols[12].In fact,learning mathematics should be active and dynamic.
Indeed,the constructivist view in teaching emphasizes that students build meaning through experiences and interactions. Elementary school children's thinking is operationally concrete, requiring concrete activities related to real objects or events. Understanding mathematical concepts requires manipulation of objects, highlighting the importance of concrete forms[12].

Acquiring all the necessary tools and materials to teach 3D geometry, enabling students to visualize the three dimensions of an object in multiple ways, poses a significant challenge in learning mathematics, particularly in geometric lessons. Traditional methods can be time-consuming, emphasizing the need for teachers to develop spatial skills and make abstract concepts applicable. Various strategies, such as AR for 3D visualization, Geometry, GeoGebra, and SimReal tools[12][36], are essential for effective teaching. The integration of experiential and active learning pedagogy with visualization tools, especially exploring teachers' intrinsic motivation to utilize digital educational technology for teaching and learning mathematical concepts, specifically in geometry, will be discussed in detail in Chapter 2.

Moreover, according to the Self-Efficacy Theory, Virtual Reality (VR) is considered an emotional amplifier. A well-designed VR, if implemented correctly, has the potential to enhance both student and teacher motivation [96]. Interestingly, Augmented Reality (AR) and Virtual Reality (VR) are often indistinguishable in the realm of immersive technology [12]. Both technologies offer unique yet compelling experiences in the digital realm. A well-designed AR also plays a significant role in enhancing the teaching of mathematics courses[12].

1.4.1 Application of Visualization Tools with Teachers

Mobile applications designed to support geometry education[81] are discussed here. This section focuses on the integration of visualization tools in teaching geometry to high school (secondary school) students. The study unveils a range of visualization tools aimed at fostering teacher autonomy in mathematics instruction, thereby enhancing their competence. Moreover, these tools not only benefit teachers but also actively engage and enhance learners' performance, through experiential and active learning pedagogy. The section introduces one specific visualization tool among others.

1. GeometriaRA (marker-based)
The GeometriaRA is an educational software utilizing augmented reality to enhance the teaching and learning of geometric solids.This app was developed by Allison Pierre,Bachelor of Computer Engineering from UNIVASF,Brazil [78].

Marker recognition involves identifying and tracking predefined markers or visual patterns in the real-world environment, a technique utilized in augmented reality (AR) applications to showcase virtual content. For instance, many AR apps utilize markers or images to trigger the display of augmented content[4].

1.4.2 Interaction with the GeometriaRA Application in Physical Surroundings

The implementation of these visualization tools in geometry lessons cultivates positive emotional interaction, diminishes fear, and fosters improved memorization, mathematical interest, creativity, and problem-solving skills. Consequently, this not only reduces anxiety but also enhances student engagement. Scientists propose the incorporation of augmented reality in mathematics education, particularly in geometry, as a potential means to enhance the overall quality of education[81].

The AR Math application provides students with the opportunity to establish connections between objects in their surroundings and geometric shapes, nurturing spatial thinking and logical connections[81]. It engages teachers and students in tasks such as representing virtual and mathematical situations, solving problems related to geometric objects, and understanding properties like base area, lateral area, surface area, and volume.
There are many applications other than the one mentioned above, such as GeoGebra AR and SimReal applications[35], which further enhance understanding and provide a platform for active and experiential learning pedagogy.
The use of mobile tools in geometry lessons or visualizing geometric figures through augmented reality applications can assist teachers in becoming proficient in teaching mathematical shapes.

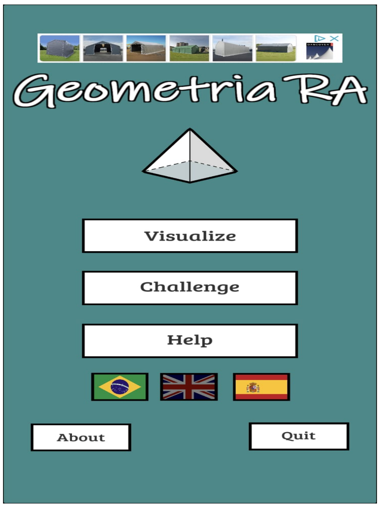


Figure 1.2: Augmented Reality Application User Interface

Features of the GeometriaRA application include visualizing geometric solids in 3D through augmented reality, animations, and challenges. The application is free with associated costs for its pro version.
The program features include the ability to visualize 3D geometric solids using augmented reality in this app. To view the geometric solid, you must point to a printed marker, one at a time. The markers are images found at the link **'bit.ly/gmark10'.** Alongside viewing these solids, the app incorporates a formation animation of the solids and a question challenge to enhance learning.
It's important to note that while the application is free, there is an associated cost for its pro version.
This application predominantly focuses on 3D shapes. Teachers using this app can effectively demonstrate various types of mathematical shapes, detailing their properties and related content, including formulas and their definitions or meanings.

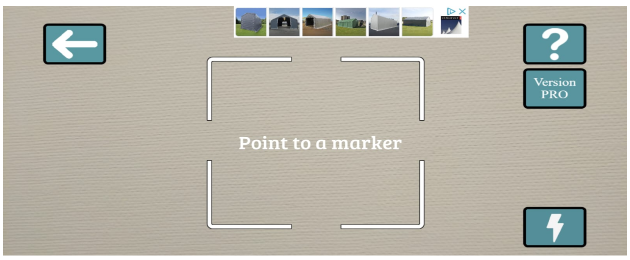


Figure 1.3: The initiation process of the Geometry AR application

The initiation process of the GeometriaRA application involves interaction in physical surroundings. It is recommended to choose a language for better understanding; the application supports

Portuguese, English, and Spanish. The application can be downloaded from Google Play store for Android. It operates independently and is available.

Presentation on 3D Geometrical Forms

The markers used are general 2D shapes[78] from cubes,cones and triangular prism as in Figure 1.4, Figure 1.5 and Figure 1.6 .

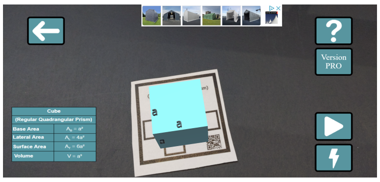


Figure 1.4: Formation of a cube using a marker.

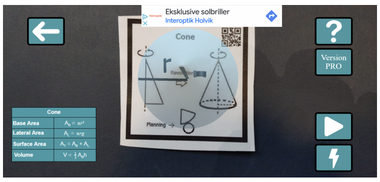


Figure 1.5: Formation of a cone using a marker.

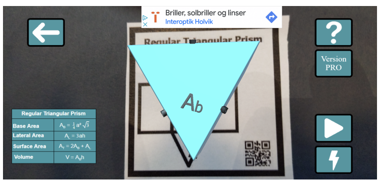


Figure 1.6: Formation of a Triangle using a marker.

The incorporation of these visualization tools, particularly Geometry Applications, will create an environment favorable for the adoption of active and experiential learning methods in exploring diverse mathematical shapes.

1.4.3 Augmented Reality Process

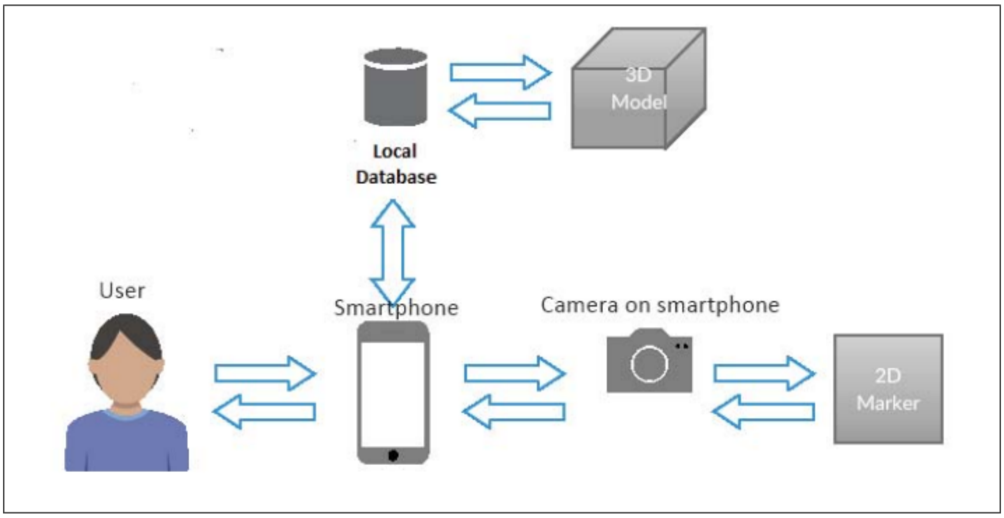


Figure 1.7: Augmented Reality Process[12]

In reference to the paper on the application of Augmented Reality in Geometry Education [12] Figure 1.7 shows that there is data exchange between the android device with the local database side after the camera scans the marker . The phone camera scans the marker and sends the data to the android device and the android device will request information to the local database in the form of a 3-dimensional model. Then the android device will display the 3 dimensional model to the user.

The components contained in Figure 1.7 include:

1) Users: Targeting math teachers in elementary schools, where geometry holds significant instructional importance, the objective is to provide digital resources that not only enhance teachers' intrinsic motivation but also foster a deeper understanding among students.

2) Android device: Mobile device that has android operating system with at least version 13.

3) Camera: The camera is on the android device itself.

4) Local Database: Local Database contained in AR application.
5) Marker: The Markers are used as shown bellow:

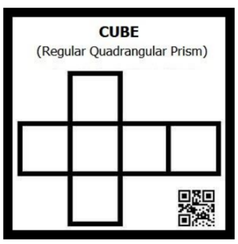


Figure 1.8: Marker 1[78].

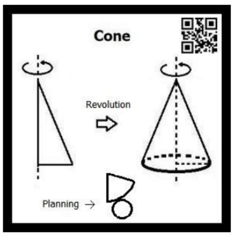


Figure 1.9: Marker 2[78].

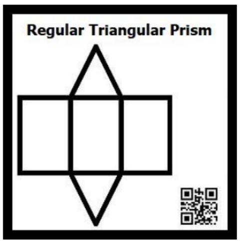


Figure 1.10: Marker 3[78].

Previous studies have highlighted an intersection between motivation and emotion in the learning process, with each influencing the other. It's conceivable that Augmented Reality, being a part of immersive technology, could contribute to the enhancement of emotional engagement[96].

The objectives of this research are to investigate factors that may demotivate teachers from delivering effective instruction and to assess teachers' intrinsic motivation to utilize digital educational technology for teaching mathematics. This has been achieved through studying motivation theory,pedagogy theory, and the application of the People Activity Context and Technology (PACT), Technology Acceptance Model (TAM), and Technology Pedagogy Content Knowledge (TPACK) frameworks. The investigation will continue through surveys and interview questionnaires. The study targets secondary school teachers in Rwanda with the aim of understanding their levels of competency, autonomy, and enjoyment in using digital educational technology to teach mathematics. The research methodology utilized the human interaction design process, incorporating survey, interview, and observation techniques for data collection. Thematic analysis techniques and NVIVO software were then applied to analyze and interpret the study results. Chapter 2 will draw on numerous citations from previous studies on motivation, educational pedagogy, research methods, and visual aid tools, providing a comprehensive exploration of the topic.

1.5 Problem Statement

Understanding teachers motivation is essential to improving the overall quality of education and the learning experiences of students[33]. One lens through which we can examine this phenomenon is the Self-Determination Theory (SDT), a widely recognized framework in psychology[24]. Richard M Ryan and Edward L Deci[85],indicate that lowered perceived performance can leave people feeling demotivated and helpless. Angel Ab os a,Leen Haerens b, Javier Sevil a, Nathalie Aelterman c, Luis García-Gonzalez a [1], have expressed the view that teachers reporting low motivation levels tend to perceive their students' motivation levels as low. Takashi Tatsuse and Michikazu Sekine[100] have shown that high levels of job dissatisfaction, stress, and fatigue can negatively influence motivation and job performance. Additionally, working environments and social factors have been found to influence teacher demotivation[71][26].
According to various researchers teachers own motivation to deliver effective teaching can be eroded by various factors, including a lack of autonomy, students' ability levels, competence, relatedness,

personal beliefs and attitudes, inadequate training, insufficient teaching facilities and lack of effective communication within evaluation process [16][106][25].

Lack of teacher motivation, leading to teacher disengagement,and dissatisfaction is a serious issue within the education sector, and specific underlying causes often varying depending on the context and circumstances. Disengaged teachers may be less effective, leading to potential negative consequences for teachers' well being,self-efficacy and students' performance.

SDT posits that individuals are driven by three basic psychological needs: autonomy, competence, and relatedness[26]. Satisfying these needs play a crucial role in shaping a teacher's motivation and job satisfaction. However,Edward L. Deci and Robert J. Vallerand and Luc G. Pelletier and Richard M. Ryan[26] proposed that promoting mindfulness is a way of fulfilling these basic psychological needs.

Further research indicated that the fulfillment of these three needs not only influences daily well-being but also positively correlates with a sense of an authentic self and self-esteem; other suggest ways to apply a pedagogical approach, such as assessing learners and providing feedback[58], which could lead to teaching effectively after contributing to teacher competency.

However, teacher competency, mindfulness, satisfaction, and other motivational variables cannot be adopted while teachers encounter various challenges in teaching. According to the study of Margarethe Synnve Moxnes Marie Risse [72] students' learning styles and interests differ, to enhance teachers' self-efficacy and cater to students' learning styles, interests, and variances, as well as ensuring universal access to information, teachers must employ a range of teaching styles. Not only that, but also visualizing the one,two or three dimensions of an object in all possible ways and with time constraints are the big issues in learning mathematics. When dealing with three-dimensional geometry, students may struggle to visualize and manipulate objects in 3D space with the traditional teaching method. In this case, teachers need to provide all the required tools and develop these spatial skills. Also, the abstract nature of geometry often deals with abstract concepts and visualizations, which can be challenging for some students to grasp without the use of technology. In other words, teachers need to find ways to make these abstract ideas more concrete and relatable. In this case, teachers will employ a variety of teaching strategies and approaches to accommodate these differences and ensure all students have access to the material.

Active learning and experiential learning, both dynamic pedagogical approaches, have gained prominence for their potential to elevate the learning experience. Active learning emphasizes student engagement and motivation through participatory methods, while experiential learning immerses students in hands-on experiences[99][27].

In light of AR,GeoGebra,SimReal and Geometry tools , visual recognition of 1D,2D and 3D objects becomes possible in an easy way. By offering teachers the opportunity to deliver courses through augmented reality technology, it can enhance existing pedagogical approaches,encourage diverse teaching styles and boost their motivational state[25][71].

Teachers who are motivated are more likely to be engaged in their work, enthusiastic about teaching, and effective in the classroom however[20], AR when is designed properly, and effectively integrated into educational settings it has the potential to increase both students and teachers' motivation by creating immersive and interactive learning practices [12][96], in addition AR can attract students' attention and make them learning more engaging. Moreover, it empowers educators to explore innovative teaching methods, enabling them to deliver content dynamically in visual attractive ways.

1.6 Research Objectives and Research Questions

1.6.1 General Objective

Exploring teachers' intrinsic motivation to utilize digital educational technology for teaching mathematics.

1.6.2 Specific Objectives

1.To examine the literature in order to gain an understanding of motivation.

2.To examine teacher's autonomy and competency in using digital educational technology to teach mathematics.

3.To determine the level of teacher's enjoyment in using digital educational technology to teach mathematics.

4. To analyze the feedback provided by teachers regarding motivation and the use of digital educational technology to teach mathematics.

1.6.3 Research Questions

1. What is a teacher's level of autonomy in using digital educational technology to teach mathematics?

2. What is a teacher's level of competency in using digital educational technology to teach mathematics?

3. What is a teacher's level of enjoyment in using digital educational technology to teach mathematics?

1.7 Hypothesis

Hypothesis: Increasing teachers' autonomy, and sense of relatedness will positively correlate with an increased utilization of digital educational technology and satisfaction in the teaching of mathematics.

1.8 Scope

This research explores teachers' intrinsic motivation to utilize digital educational technology for teaching mathematics, with a specific focus on examining teachers' autonomy, competency, and enjoyment levels in using these tools. The study is scheduled to take place in Rwanda from January 25 to April 30, 2024. According to the Rwanda Educational Curriculum Competence based curriculum(CBC)[82], an in-depth study of geometry solids is mandated in both primary and secondary education. The researcher specifically concentrates on delivering content related to geometric solids in secondary schools, targeting senior one students. This particular focus aligns with the pivotal stage at which learners begin developing a foundational understanding by engaging with diverse real-world scenarios. Since students learn mathematics through the enactive method, involving hands-on manipulation of objects, the iconic method, utilizing images, and the symbolic method, incorporating the use of symbols[12] as CBC aims is to develop in learners competences that will be enabled them to interact with the environment in more practical ways ,this rationale guides the researcher's focus on senior one mathematics teachers from Rwanda, as understanding their experience is crucial in enhancing the learning process.
Geometry augmented reality application will help teachers to teach geometric solids assigned from senior one students from points,line,angles and solids shapes with their properties such as perimeter, area ,volume and length of side. Purposive sampling, a nonrandom technique, will be employed to select participants with a minimum of three years of experience in teaching mathematics. The data collection approach combines document review, interviews, survey, and observations. In line with human-centered design principles, frameworks, and usability goals, the researcher has conducted usability testing and user feedback sessions. These sessions aim to assess educators' interest in integrating digital visualization tools into their teaching practices, along with their levels of autonomy,

competency, and enjoyment derived from using digital educational technology(Digital Visual tools). The study focuses particularly understanding the concepts of geometric shapes and their properties.

Motivation theories and factors influencing intrinsic motivation, drawn from various studies, was explored to understand their impact on individual motivation. The study also considers pedagogical theories and existing Geometry applications for teaching mathematics.

1.9 Limitations

1. Computer literacy and skills:Inadequate knowledge on technology.
2. Access to and quality of hardware, and software : Device incompatibility with available application software needed.

1.10 Ethical Considerations

In adhering to ethical considerations throughout my thesis writing, I am committed to:

• Utilizing relevant books, papers, and journals pertinent to my research topic.

• Exploring and employing appropriate theories, models, and frameworks in the study.

• Regularly updating my supervisors on the progress of my work, scheduling discussions based on their availability, such as every Friday.

• Ensuring the avoidance of plagiarism by crediting sources and citing references accurately.

• Transparently inviting study participants, providing comprehensive explanations about the research study.

• Informing research study participants about the specific techniques employed for data collection.

• Adhering to ethical principles governing research and maintaining high standards in writing skills. These key points underscore my dedication to conducting ethical research and upholding integrity in every aspect of the study.

1.10.1 Project Timeline

This is the entire list of tasks associated with writing a master's thesis.

Tasks	**Activities**	**Starting date**	Finish date	Number of days for each task
Task 1	Writing Chapter 1: Introduction	10/11/2023	31-Oct-23	20
Task 2	Writing Chapter 2: Literature Review	1-Nov-23	27-Nov-23	26
Task 3	Writing Chapter 3: Methodology,research design	28-Nov-23	29-Dec-23	31
Task 4	Building Software Prototype	22-Dec-23	2-Feb-24	41
Task 5	Test and Design Process	15-Jan-24	3-Feb-24	19
Task 6	Ongoing data collection process(writing questionaires and participants recruitment)	5-Feb-24	20-Feb-24	15
Task 7	Collecting data(serve questionaires & Observation)	27-Feb-24	10-Mar-24	12
Task 8	Start data analysis process(recoring collected data)	12-Mar-24	27-Mar-24	15
Task 9	Chapter 5. Writing Findings and discussion	28-Mar-24	24-Apr-24	27
Task 10	Chapter 6: Conclusion and recommendation	25-Apr-24	28-Apr-24	3
Task 11	Revising and correcting according to the feedback from supervisors	15-Mar-24	15-May-24	61
Task 12	Thesis Presentation (Final)	02-August-24	02-August-24	0

Table 1.1: Tasks to be done

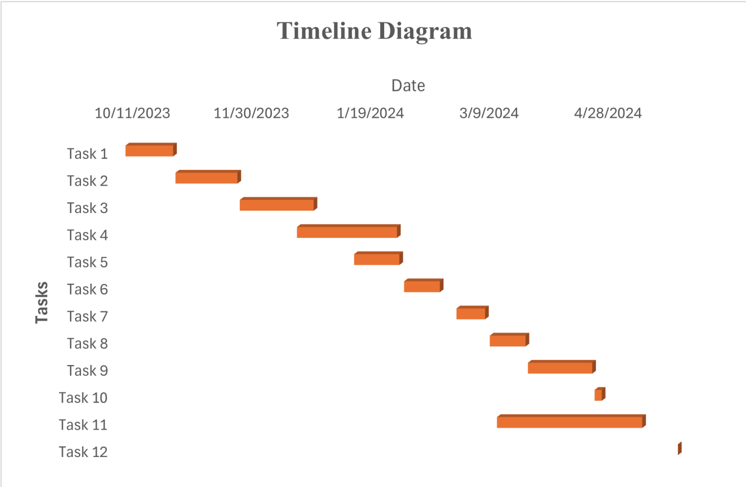


Figure 1.11: Task Gantt Chart with Time Completion Schedule

1.11 Thesis Outline

This study comprises six chapters, each contributing to a thorough exploration of intrinsic motivation among teachers and the impact of digital educational technology. The introductory Chapter 1 provides a foundation, introducing motivation, expressing the problem, and outlining study objectives, hypothesis, scope, limitations, and ethical considerations. Chapter 2 delves into a comprehensive literature review, synthesizing existing knowledge on motivation and educational technology, with a particular focus on findings from other researchers. Chapter 3 details the research methodology, clarifying the procedures and user test design employed for the investigation. Chapter 4 focuses on results analysis, offering an in-depth examination and interpretation of respondents' thoughts and experiences with digital educational technology. Chapter 5 engages in critical discussions, connecting findings to existing literature and exploring the broader implications of the study. Finally, Chapter 6 summarizes the study with conclusions drawn from key findings and formulates practical recommendations for future actions and enhancements.

Chapter 2

STATE OF THE ART

2.1 Introduction

This chapter embarks on a comprehensive examination of motivation within the context of education, with a particular focus on teachers' motivation; it elaborated relationships among the factors that impact teachers' motivation. It also delves into existing pedagogical approaches, notably the constructivist theory, and in particular, explores the promising avenue of augmented reality (AR) as a means to address teacher demotivation. By synthesizing and critically analyzing relevant scholarly works, this literature review seeks to contribute to our understanding of how motivation influences teaching practices and how innovative technological tools can potentially reintroduce educators' enthusiasm for their profession; by utilizing the framework of the Technology Acceptance Model and Technology,Pedagogy,Content and Knowledge we delved into teachers' perceptions of the ease of using AR technology, its overall usefulness, and their intentions to hold these technological tools in their teaching careers.

2.1.1 Conceptual Framework for the Study on Teacher Intrinsic Motivation to Utilize Digital Educational Technology to Teach Mathematics

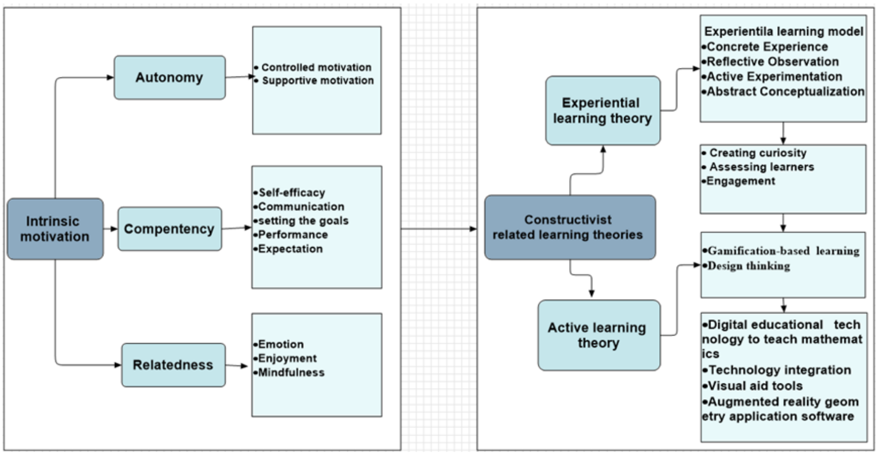


Figure 2.1: A Study Framework

All literature themes have been developed based on the conceptual framework for the study,ensuring their direct relevance to the research topic and objectives. The focus has been on selecting literature that encompasses key concepts, theories, and empirical studies pertinent to the study's conceptual framework, while also addressing research gaps.

2.2 Pedagogical Theory

The term "pedagogy" has its roots in the Greek word " paidagōgeō " where "país, genitive, paidos " means child, and " ágō " means lead. It literally translates to "to lead the child." The Latin-derived equivalent signifies "child instruction," a term now used in English to encompass the broader context of instruction, learning, and the associated processes[94]. In modern English, pedagogy refers to instructional theory, with aspiring educators (trainee teachers) learn their subject and also the pedagogy appropriate for teaching that subject. The term has ancient origins in Greece and was introduced into the Oxford English Dictionary in 1571[94].According to Murphy ideas[94] pedagogy is the term that describes the relationships and interactions between teachers, students, and the learning environment and the learning tasks.

In this section, we explore deeper into the constructivism theory[70], shedding light on how knowledge is acquired, what constitutes knowledge, and the nature of knowledge itself. In adopting the role of an artist, a teacher is encouraged to be innovative, flexible, and imaginative, avoiding confinement to a single teaching style. The prominence of active learning and experiential learning pedagogical approaches has grown, commended for their potential to enrich the learning experience. These approaches empower teachers to enhance their skills and broaden their methodological range in teaching.

2.2.1 Constructivism Theory

Constructivism has a significant impact on science and mathematics education and is increasingly influencing various educational domains. It serves as an epistemological theory that addresses human learning and the creation of meaning. Emphasizing the cultural embeddedness of learning, it employs cultural anthropology methods to explore how learning and cognition are distributed in the environment, rather than being enclosed to an individual's mind[70]. These factors play a vital role in shaping how learners acquire knowledge and how teachers facilitate its transmission. Drawing on the pedagogical benefits of social software, such as knowledge creation, engagement, and enjoyment[67],constructivism emerges as a pertinent learning theory for this study. The researcher's objective is to evaluate teachers' competency, autonomy,engagement, and enjoyment in utilizing digital educational technology for teaching mathematics.

Constructivism encompasses several learning theories, including active, situated, authentic, experiential, and anchored learning[67]. João Mattar[67]in his study took constructivism as an umbrella for the learning theories. Consequently, the following theories are discussed: activity theory, and experiential learning.

2.2.2 Experiential Learning and Active Learning

Experiential learning theory emphasizes the importance of experience in constructing knowledge[67]. Pedagogy as the art, science, or the craft of teaching capturing the diverse dimensions of the educational process[75]. Teachers are encouraged to provide opportunities for learners to interact with sensory data and construct their own understanding of the world scenarios [70].They are encouraged to develop various teaching methods to satisfy learners' interests and understandings.
Adopting Experiential learning and Active learning pedagogical strategies can aid teachers in developing various teaching styles. Because in practice, teachers learn by teaching[19]. This, in turn, enhances their level of engagement in using digital educational technology to teach mathematics.The upcoming section will delve into a discussion on how these two approaches can serve as sources of teacher engagement in utilizing digital educational technology to teach mathematics. This exploration will further contribute to understanding their levels of autonomy, competency, and enjoyment, as detailed in the subsequent section below.

2.2.3 Pedagogical Strategies for Experiential Learning

David A. Kolb's experiential learning theory indeed defines learning as the process whereby knowledge is created through the transformation of experience[99]. This succinctly captures the essence of how individuals actively engage with experiences, reflect on them, and derive new knowledge and understanding from the process.
The experiential learning theory (ELT) model by David A. Kolb identifies four interrelated modes of learning: Concrete Experience (CE), Abstract Conceptualization (AC), Reflective Observation (RO), and Active Experimentation (AE). These modes create a dynamic and iterative learning cycle where individuals engage with concrete experiences, conceptualize abstract ideas, reflect on observations, and actively experiment with new concepts, each mode responding to contextual demands. This cyclical process forms the basis of experiential learning[99].

This ELT describe the cyclical nature of the experiential learning process[27], which involves experiencing, reflecting, thinking, and acting in response to the learning situation and the subject matter. Immediate or concrete experiences form the foundation for observations and reflections. These reflections are then assimilated and distilled into abstract concepts, generating new implications for action. These implications can be actively tested, providing guidance for creating new experiences, thus continuing the iterative cycle of experiential learning.

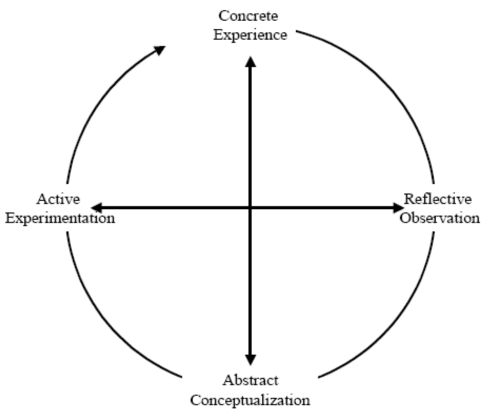


Figure 2.2: Experiential Learning Theory Model[27]

Application of the ELT Model Process

• Concrete Experience (CE):
This stage involves students actively engaging in a hands-on experience or assigned task. For instance, in learning mathematics, students might conduct a hands-on experiment by using Geometry applications to observe the construction of various math shapes and explore their properties, including length ,angles, area,volume and perimeter.

• Reflective Observation (RO):
After the concrete experience, students reflect on and carefully observe what occurred during the experience. Reflection involves thoughtful consideration of emotions, reactions, and outcomes[27]. For example, students might record their thoughts and feelings about the math science experiment, noting any unexpected results.

• Active Experimentation (AE):
In this stage, students plan and execute actions based on what they learned from the concrete experience and reflections. It emphasizes applying knowledge in new situations and experimenting with

different approaches[27]. As an example, students could design and conduct a similar experiment with variations based on their reflections from the initial experience.

• Abstract Conceptualization (AC):
After active experimentation, students draw conclusions and develop abstract concepts or theories[27]. It involves synthesizing information, forming generalizations, and creating mental models. For instance, students might formulate a hypothesis about shape construction based on patterns observed in multiple experiments.

The ELT model emphasizes the iterative and cyclical nature of learning[27], where each stage informs and influences the others. It recognizes that learning is a dynamic process involving engagement, reflection, application, and abstraction. This approach empowers learners to actively construct their understanding of various scenarios in the world, making experiential learning a powerful and comprehensive educational framework.

2.2.4 Pedagogical Strategy for Active Learning

There are diverse teaching strategies aimed at establishing an active learning environment and promoting teachers engagement in the class room[51]. The activity theory emphasizes the importance of learner engagement and action to support the learning process. Learning is considered an active construction process, inseparable from doing, and a reflection about what learners are doing, not a passive reception of knowledge[67].

Active learning involves acquiring knowledge, skills, values, and attitudes through educational strategies that involve students in activities and debates, rather than passively listening to teacher information[51]. Active learning methodologies, including flipped classroom, peer instruction, case method, problem-based learning, project-based learning, game-based learning, and design thinking[67]. Among the mentioned active learning methodologies, game-based learning, and design thinking stand out as the primary methods associated with the use of digital educational technology in this research. These are exemplified by social software applications like Geometry applications specifically designed for teaching mathematics.

Social software refers to digital tools, platforms, or applications designed to facilitate social interaction, collaboration, and communication among users over the internet.Social software, facilitates group interaction through real-time messaging, asynchronous teamwork spaces, and commenting. It fosters social feedback, digital reputation creation, and the management of personal relationships, thereby promoting communal benefits and similar attributes, particularly within educational contexts [76]. Social software plays a crucial role in implementing game-based learning, and critical thinking, constituting an active learning pedagogy. João Mattar[67]outlines several major pedagogical contributions of social software:
1. Building communities and creating knowledge: Social software provides platforms for users to connect, collaborate, and share ideas leading to the creation of communities and the generation of knowledge.
2. Engagement, motivation, and enjoyment: By incorporating interactive features, gamification elements, and multimedia content, social software engages users in learning activities, boosts their motivation, and enhances their overall learning experience by making it enjoyable and immersive.
3. Cost-Effective: Social software often eliminates the need for expensive traditional learning resources and infrastructure, making it a cost-effective solution for educational institutions and learners alike.
4. Accountable and transparent: It ensures accountability and transparency in learning processes,through features like user profiles, activity logs, and discussion threads, social software promotes accountability by tracking user participation and contributions, while also fostering transparency in learning processes by making interactions visible to all participants.
5. Bridging formal and informal learning: Social software bridges the gap between formal and in-

formal learning.
6. Addressing individual and social needs: It caters to both individual and social learning needs.
7. Ease of use: Most social software platforms are designed with user-friendly interfaces and intuitive navigation, making them accessible and easy to use for learners of all levels of technical proficiency.
8. Accessibility: Some social software is accessible because they offer options for customization, compatibility with assistive technologies, and support for multiple devices, thereby enhancing access for users with disabilities.
9. Supporting creativity: Through features such as multimedia content creation tools, collaborative brainstorming spaces, and open-ended discussion forums, social software empowers users to express their creativity, explore new ideas, and engage in innovative problem-solving activities.

2.2.5 Technology Integration

Active learning methodologies, with a specific emphasis on the utilization of digital visualization tools, are employed to stimulate dynamic participation and facilitate a profound understanding of technology integration concepts.
The question persists: to what extent do teachers integrate technology into teaching and learning activities? Previous studies contend that this is a complex process in education due to the ever-changing nature of technology[90].
To comprehend technology integration strategies, this study employs the Technology Acceptance Model (TAM) and the Technological Pedagogical Content Knowledge (TPACK) framework. TAM was utilized to explore users' acceptance of technology, while TPACK provide a comprehensive understanding of the essential knowledge domains—content, pedagogy, and technology required for effective technology integration. This dual framework approach aims to offer a comprehensive perspective on both the acceptance and pedagogical aspects of technology integration in educational settings.

2.2.6 Technology Acceptance Model (TAM)

Based on a previous studies ,TAM is defined as a theory that explains the factors influencing the intention to use information technology in order to improve performance in organizations. Perceived ease of use and perceived usefulness of technology are the most critical concepts that influence the intention to use technology; thus, external variables that affect these two concepts should be considered[46] .
Recent studies, including one by Young Ju Joo, Sunyoung Park, and Eugene Lim[49], reveal that teacher self-efficacy, perceived ease of use, and perceived usefulness positively influence their intention to use technology. Additionally, TPACK indirectly influences this intention due to increased time spent handling unexpected student behaviors[49].The study conducted by Yujung Ko and Won Sug Shin[46], highlights the significance of self-efficacy and motivational support in implementing technology-integrated lessons. Their findings confirm four influencing factors: technological pedagogical knowledge, self-efficacy, constructivist beliefs, and motivational support, which collectively influence teachers' acceptance of online and AR/VR-based instruction which are in line with the ideas of Young Ju Joo, Sunyoung Park, and Eugene Lim [49].

Not only can the intention to use technology in the classroom be influenced by perceived ease of use and perceived usefulness, as identified in the Technology Acceptance Model framework(TAM), but it can also be influenced by essential knowledge domains for teachers, as indicated in the Technology, Pedagogy, Content Knowledge framework(TPACK)[46]. (TPACK) addresses this gap by outlining essential knowledge domains for teachers—content, pedagogy, and technology TPACK underscores the significance of preparing pre-service teachers and practicing teachers to make informed choices in using technology, influencing both acceptance and integration[90]. Teachers perceiving competence in TPACK domains are more inclined to accept and integrate technology[90]. Ronny Scherer, Fazilat Siddiq, and Jo Tondeur[90] argue that, for successful technology integration, teachers must not only possess these forms of knowledge but also effectively integrate them. Additionally, teachers are more likely to embrace new technology if they perceive its relevance to their subjects, and competency in TPACK domains further enhances technology acceptance and integration in teaching.

2.2.7 Technological Pedagogical Content Knowledge

TPACK a theoretical framework that outlines the integration of technology, pedagogy, and content knowledge for successful teaching. It consists of seven domains: content knowledge (CK), pedagogy knowledge (PK), and pedagogical content knowledge (PCK), with technological knowledge added for enhanced integration[90].

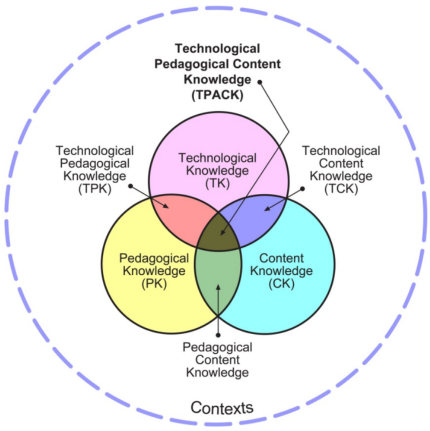


Figure 2.3: TPACK[49]

The figure above contains TPACK, which is an abbreviation of the three main knowledge categories for teachers (i.e., content, pedagogy, and technology).

Content knowledge (CK) is crucial for teachers, covering various subjects like science, art appreciation, and astrophysics. It includes understanding concepts, theories, ideas, organizational frameworks, evidence, and practices[50]. Teachers should understand the fundamental knowledge of their discipline, such as scientific facts, methods, and evidence-based reasoning, and the nature of inquiry in different fields.

Pedagogical knowledge (PK) is a teacher's comprehensive understanding of teaching methods, including educational purposes, values, and aims. It encompasses classroom management, lesson planning, and student assessment. PK also involves understanding cognitive, social, and developmental theories of learning and their application to students in the classroom[50].

PCK, emphasizes the transformation of subject matter for teaching. This involves interpreting, representing, and adapting instructional materials to students' prior knowledge and conceptions. PCK covers teaching, learning, curriculum, assessment, and reporting, emphasizing common misconceptions, connections, students' prior knowledge, alternative teaching strategies, and flexibility for effective teaching[50].

The TPACK framework's definition of TK is similar to FITness, which goes beyond traditional computer literacy. FITness requires a broad understanding of information technology for productive use, recognizing its impact on goals, and adapting to changes. Acquiring TK allows for diverse tasks and developing different methods, rather than an end state, and views it as a lifelong, generative interaction with technology.

TCK is thus an understanding of how technology and content influence and constrain each other. Teachers must master more than just the subject matter they teach; they must also have a thorough awareness of how specific technologies might alter the subject matter (or the types of representations that can be generated). Teachers must understand which technologies are best suited for addressing subject-matter learning in respective domains, as well as how the content dictates or, in some cases, alters the technology and vice versa[50].

TPK is a knowledge of how specific technologies, when applied in specific ways, can alter teaching and learning. This entails understanding the educational affordances and restrictions of a variety of technological instruments in relation to discipline- and developmentally relevant pedagogical designs and tactics. To construct TPK, a better understanding of the limits and opportunities is required[50].

TPACK is a knowledge form that transcends content, pedagogy, and technology, forming the foundation of effective teaching with technology. It involves understanding concepts using technologies, pedagogical techniques, learning difficulties, students' prior knowledge, and epistemological theories. TPACK is essential for meaningful and skilled teaching with technology[50].

Therefore TPACK, a teaching approach, emphasizes the dynamic integration of knowledge with technology, focusing on content, pedagogy, and technology. It supports specific pedagogies, uses technology as an instructional technique, and helps teachers improve student learning[46][50].

2.3 Motivation Concepts

In this section, our main focus revolves around the exploration of interpreting motivation theory, which serves as the driving strategy for our inquiry. This comprehensive examination aims to shed light on various critical aspects, including the identification of key variables that have influence over individuals' motivation levels, the judgment of motivation's inherent characteristics, and the creation of actionable insights towards fostering a positive impact on motivation within the context of teaching. Through a systematic investigation into these aspects of reading motivation theory, we aspire to gain a deeper understanding of how educators can effectively consider motivation as a catalyst for enhanced learning experiences.

2.4 Motivation Theory

Many studies identify three types of motivation: intrinsic and altruistic, extrinsic,and amotivation. In general, their meanings are common, whereby extrinsic reasons relate to aspects that are not inherent to the teaching profession; instead, they pertain to the job's working conditions (e.g., job stability, holidays, salary, and rewards). Intrinsic motivations relate directly to the teacher's professional activity, such as finding pleasure in teaching and an interest in knowledge,altruistic motivation, which is the form of intrinsic motivation pertain to an interest in contributing to the improvement of society through education and the desire to help children and adolescents develop their capacities and potentials as human beings[24],finally,amotivation refers to the lack of motivation or the absence of any desire to engage in a particular activity. When someone is amotivated, they may feel indifferent or apathetic towards a task or goal. This lack of motivation can be caused by various factors, such as a perceived lack of competence, irrelevance of the task, or a sense of hopelessness. Essentially, it's a state where individuals don't see any reason to act or make an effort.[14][86][25].
Similarly, researcher aim to foster a deep understanding of the concept of intrinsic motivation among employees, particularly teachers, by encouraging them to incorporate Augmented Reality (AR) applications into their teaching methods.This approach has been shown to induce positive emotions in teachers [96], thereby enhancing their effectiveness in the classroom. These intrinsic motivators are essential for sustaining teachers' enthusiasm and dedication to their profession, resulting in good teaching and learning performance[79].

2.4.1 Intrinsic Motivation

Self-Determination Theory (SDT) identifies intrinsic motivation as the drive to engage in an activity or behavior for its inherent joy, satisfaction, or interest, rather than external rewards or punishment. It is one of the three primary types of motivation, alongside extrinsic motivation and amotivation. Key characteristics of intrinsic motivation include autonomy, competence, relatedness, interest, and persistence. It is driven by genuine enjoyment of the task or activity, and is more likely to persist in efforts and experience a sense of flow.Fostering intrinsic motivation leads to more sustainable and meaningful behaviors and outcomes[26][86].
A study conducted in Gaza reveals a diverse array of internal motivation sources. The internal motivating factors include a passion for a career, academic honesty, psychological comfort in the school, love for children and students, religious morals, for Allah's sake, and serving the community[68].While Cognitive Evaluation Theory, a subset of SDT, highlights the significance of environmental and social factors in either sustaining or undermining self-motivation. For instance, positive performance feedback can enhance intrinsic motivation, while negative performance feedback may not have the same effect;also, SDT argues that individuals are driven by three basic psychological needs: autonomy, competence, and relatedness. Satisfying these needs plays a crucial role in shaping a teacher's motivation and job satisfaction[83].

2.4.2 Autonomy-Supportive Motivation style

In an autonomy-supportive motivation style, the emphasis is on cultivating individuals' intrinsic motivation by providing them with choices, autonomy, and opportunities to make decisions. This approach aims to satisfy the basic psychological need for autonomy,competence and relatedness[16]. According to Richard M Ryan and Edward L Deci[86] , the results of intrinsic motivation[internal motivation] resulting from satisfying all three basic psychological needs are the following: an increase in job satisfaction, less anxiety, promoting individual wellbeing, joy, and a high level of achievement.In the study of Bård Kuvaas and Anders Dysvik[57] employees with higher levels of intrinsic motivation tend to report greater job satisfaction . Richard M Ryan and Edward L Deci[86] have shown a positive relationship between intrinsic motivation and job performance and Y.-F Chang[16],shows how intrinsically motivated individuals often demonstrate higher levels of creativity, persistence, and task engagement. Further research indicated that the fulfillment of these three needs not only influences daily well-being but also positively correlates with a sense of authentic self, self-esteem, and self-efficacy[106][17].

Goal-setting approach,argues that setting goals with high commitment, in combination with self-efficacy, mediates or partially mediates the effects of several personality traits and incentives on performance[63].The logic behind this is that goals and self-efficacy are key factors in human action, reflecting an individual's appraisal of motivations and the applicability of values and good behaviors in specific situations.
This is because self-efficacy refers to an individual's belief in their ability to perform certain tasks[46],likewise teacher self-efficacy refers to a teacher's belief in their ability to plan teaching and promote student learning. Having a high level of self-efficacy can be a driving force behind a teacher's commitment to achieving their educational goals and their effective utilization of technology in the teaching process.Therefore, organizations can promote intrinsic motivation by adopting practices that support autonomy, provide opportunities for skill development, and foster positive social relationships in accordance with these scolars RD Nordgren "Pink [73]on motivation aspect. It is not appropriate to use the too much reward method because it can undermine intrinsic motivation[21].Edward L Deci, Richard Koestner, and Richard M Ryan [21] mentions organizations to be carefully balance the use of rewards to avoid diminishing intrinsic motivation. Job facilities can be considered to tap into employees' intrinsic motivation. Job enrichment, allowing employees to experience a sense of achievement, responsibility, and personal growth, can lead to increased motivation, for example, planning development training and the ability to integrate current technology in the teaching and learning process.[46] Having a high level of self-efficacy can be a driving force behind a teacher's commitment to achieving their educational goals and their effective utilization

of technology in the teaching process.

In the realm of pedagogy and the use of technology, achievement goal theory plays a crucial role in understanding the integration of technology in education.[47]It shows four types of achievement goals namely mastery, ability-approach, ability-avoidance, and work-avoidance. Mastery focuses on personal growth and academic competence; ability goals aim to demonstrate superiority or hide inferior abilities; and work avoidance aims for minimal effort.So, this mastery goal is rooted in intrinsic motivation, where teachers not only highly value their profession but also strive for competence. Nevertheless, there are internal factors that can disrupt teachers' motivation, like tiredness, psychological status, and frustration[68]. According to Agnese Karaseva, Pille Pruulmann-Vengerfeldt, and Andra Siibak[47], teachers who pursued mastery goals believed that technology led to much-needed change both in teaching and learning practices because it allowed more independent and deeper subject learning. Their findings suggest that the mastery goal demonstrates a readiness to adopt new knowledge and skills based on their interests and passion for technology[47].

2.4.3 Teaching Qualities,Attitudes and Values for Intrinsic Motivation

Engaging teachers with a pedagogy that explicitly emphasizes values leads to improved comprehension of and increased confidence in the dimensions of quality teaching[20].The following figure can offer valuable insights into the attributes of an effective teacher.

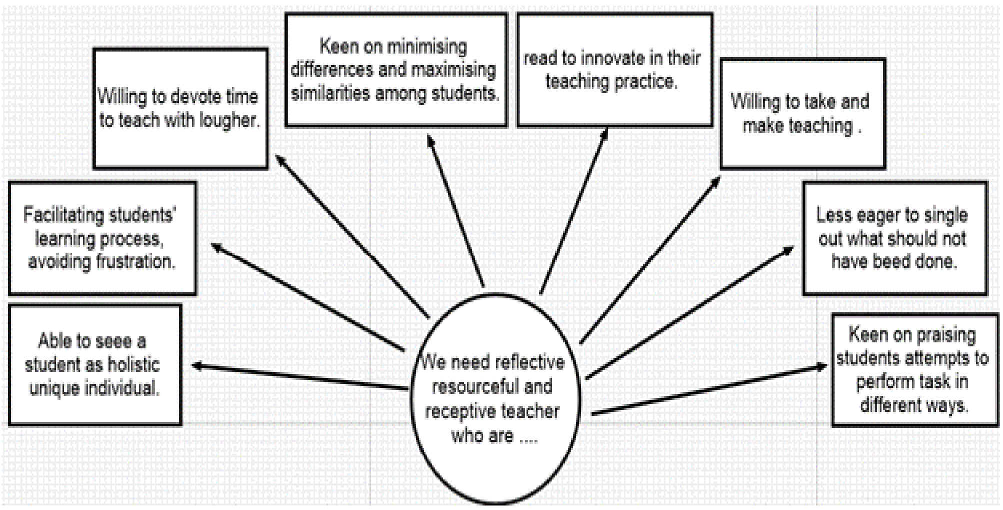


Figure 2.4: Quality of a good teacher[20]

In the provided picture, if teachers exhibit all of these eight teaching qualities, such as seeing students as holistic and unique individuals, facilitating their learning process with enthusiasm, avoiding causing frustration, dedicating time to teaching with laughter, striving to minimize differences and maximize similarities among students, being open to innovation in their teaching practices, being willing to make informed teaching decisions, refraining from singling out what should not be done, and enthusiastically acknowledging students' diverse attempts to perform tasks, it can be concluded that intrinsic motivation has developed within the teachers or is indicative that intrinsic motivation has become an integral part of their lives.

1. A teacher who is able to see students as holistic, unique individuals is one who recognizes that each student is a multifaceted person with a unique set of characteristics, strengths, weaknesses, experiences, and needs. This approach to teaching involves understanding and valuing every aspect of a student's identity and well-being, not just their academic performance.

2. The teacher who is fond of facilitating students learning processes means a teacher who enjoys and actively engages in the process of helping students learn.

3. The teacher who is avoiding their frustration refers to a teacher attempting to manage their frustrations to prevent it from affecting their teaching or student interactions. This can be due to various reasons, such as classroom challenges, administrative issues, or personal stressors.

4. The teacher who is willing to devote time to teaching with laughter signifies a teacher who values incorporating humor and lightheartedness into their teaching approach. This involves allocating time and effort for humor-based activities, jokes, or strategies. The teacher actively uses humor to engage students, make lessons memorable, and create a positive emotional connection to the subject matter. This approach can lead to increased student motivation, improved information retention, and a more enjoyable learning experience.

5. The teacher who is keen on minimizing differences and maximizing similarities among students reads to innovate in their teaching practice describes a teacher who aims to create an inclusive and equitable learning environment by minimizing differences and maximizing similarities among students. They are actively engaged in reading and staying updated on educational research and innovative teaching methods to achieve this goal. They value diversity and strive to ensure all students have an equal opportunity to learn and succeed, fostering unity and shared goals

6. The teacher who is willing to take and make teaching decisions. A teacher who is willing to take and make teaching decisions is an active, reflective, and adaptable educator who takes initiative in their teaching practices. They exercise autonomy, engage in critical thinking, adapt to the needs of their students, make informed decisions about curriculum, instructional strategies, assessment methods, and classroom management, and take responsibility for the outcomes of their teaching decisions. They are committed to continuous improvement, learning new approaches and techniques as they gain experience and knowledge. This proactive approach to teaching ensures the best possible learning experiences for their students.

For example They are willing to modify their teaching methods to incorporate AR effectively, considering factors like learning objectives, topic suitability, and student needs. They make informed pedagogical decisions, considering how AR can enhance the learning process and improve comprehension. They also take a student-centered approach, considering diverse learning styles and creating an interactive environment. They assess the effectiveness of AR technology and seek professional development opportunities to stay updated on the latest developments and best practices. This proactive, adaptable, and student-centered approach to AR integration in education is crucial for enhancing student learning.

7. The teachers who are less eager to single out what they should not have done suggests that some teachers are less enthusiastic about identifying and pointing out the mistakes or wrong actions of others, particularly their students. This can lead to teachers addressing issues differently or not at all, which can impact teaching methods, classroom management, and the overall learning environment. In other words, these teachers are hesitant or reluctant to highlight their own mistakes or errors, or perhaps they are not keen on criticizing or reprimanding others for their mistakes.

8. The teacher who is keen on praising students attempts to perform tasks in different ways efforts means teacher try to recognizing and encouraging students efforts. They use a variety of methods, including verbal praise, written feedback, constructive criticism, rewards, and personalized approaches, to cater to the unique needs and preferences of students. This approach creates a positive learning environment, enhancing engagement and performance in the classroom.

When teachers lack intrinsic motivation, the following behaviors typically manifest: Unwillingness to engage in school-related activities, inconsistent attendance, unexpected and habitual lateness, limited enthusiasm for additional training, uninspired and unengaging teaching methods, disinterest in meetings, uncooperative attitudes when assistance is sought, delays due to missed deadlines, resistance to contributing beyond minimal requirements, and the emergence of conflicts among

colleagues, ultimately undermining the overall quality of teaching and learning or the quality of education[71].
Intrinsic motivation has a key impact on shaping people's impressions of technology. Individuals who are self-motivated to complete a certain job or use a specific technology are more likely to regard it as simple and useful. In other words, in the framework of TAM, intrinsic motivation influences both perceived ease of use (PEOU) and perceived usefulness (PU)[46].

2.5 Teaching Aid Tools

Teaching resources in education are a variety of materials, tools, and aids used to enhance the teaching and learning process[92]. They support educational goals, engage students, and convey information effectively. Common types include textbooks, audiovisual aids, digital resources, teaching aids, manipulative, online learning management systems, library resources, teacher-made materials, educational games and simulations, peer-reviewed articles and research papers, and guest speakers and field trips [74][88]. The choice of teaching resources depends on the educational context, student age and needs, and the subject matter being taught. Renée Schulz, Ghislain Maurice Norbert Isabwe, and Andreas Prinz[92],conducted a study in response to Task-driven Mobile Teaching Tools for Enhancing teachers' motivation, hence exploring the potential use of gamification. They highlight the use of smart tools (smart phones) in learning activities, highlighting their potential to refine strategies, monitor progress, set goals, and support everyday thinking processes [92]. Effective educators often employ a combination of these resources to create engaging and effective learning experiences.Thus, Task-driven Mobile Teaching Tools aid in interaction between learning and teaching participants, enabling the collection of valuable feedback from tasks done by students and optimizing the management of their learning experience[92]. Dale H Schunk[93], believes that knowing what to do to perform a task raises self-efficacy.This has the potential to result in a beneficial boost to an individual's self-efficacy, which is the primary factor in induced intrinsic motivation at work. Because Self-efficacy is a crucial factor in the teaching profession, as it influences teacher performance, student outcomes, and overall education quality. Previous studies argue that teachers with high self-efficacy are more confident in their ability to plan effective lessons, manage classrooms, adapt to challenges, try new teaching strategies and technologies, and be willing to experiment and adapt their methods to meet the diverse needs of their students[93]. As a result, this adaptability can lead to more engaging and effective teaching practices, leading to positive student outcomes.

2.5.1 Visualization Tools and Geometric Concepts

Visualization tools and augmented reality (AR) apps are two methods for teaching 1D, 2D, 3D, or any other mathematical Geometry shapes[35].

2.5.2 Visualization Tools

Visualization tools, software applications displaying geometric shapes on flat screens, open up new possibilities for mathematical learning. Through dynamic animations, interactive simulations, and live streaming of lessons, these tools foster visual, dynamic, distributed, and embodied approaches to mathematics, moving away from individual achievements and static representations[36].
Hadjerrouit[35] explores the SimReal visualization tool in teacher education, focusing on its technological, pedagogical, and socio-cultural benefits for students' mathematical abilities. SimReal, a versatile tool used for teaching various mathematical topics at both university and school levels, offers features such as a graphic calculator, video lessons, live streaming, video simulations, and interactive features[35]. It boasts over 5000 applications across diverse mathematical areas, including Sim2Bil[35].
Technological affordances address usability issues and describe the tool's functionality. Educational affordances, including pedagogical aspects, outline student-teacher interactions. Subject-area teaching facilitates the learning process, and social affordances promote interactions within the learning environment[35].

From a functional standpoint, SimReal aids in calculations, drawing graphs and functions, solving equations, constructing diagrams, and measuring figures and shapes. At the student level, the tool provides pedagogical affordances, such as building mathematical expressions, manipulating parameters, simulating concepts, and exploring regularity[35].

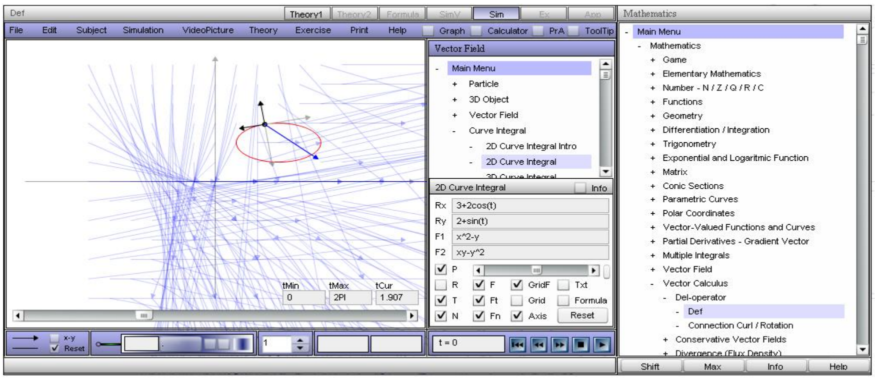


Figure 2.5: SimReal Application[36]

The study suggests that, aligning with Constructivist theory, Active Learning, Experimental Learning pedagogy, as well as TPACT and PACT frameworks, SimReal enriches the comprehension of mathematics through dynamic visualization examples. However, an even more effective approach may involve a combination of traditional methods, digital visualizations, and chalkboard usage,all while acknowledging and respecting teachers' autonomy in employing digital educational technology for teaching mathematics.

2.5.3 Teacher Competence in Using Digital Educational Technology to Teach Mathematics

Digital competence, within the realm of teacher education, encompasses an individual teacher educator's proficiency in using ICT[54]. This proficiency is intertwined with sound pedagogical judgment and an understanding of its implications for learning strategies. It involves a combination of knowledge, skills, attitudes, and awareness when using ICT and digital media. These competences empower individuals to perform tasks, solve problems, communicate, manage information, collaborate, create and share content, and build knowledge effectively, ethically, and reflectively. In accordance with TAM (Technology Acceptance Model) and TPACK (Technological Pedagogical Content Knowledge), teachers are more likely to embrace new technology when they perceive its relevance to their subjects. Proficiency in TPACK domains not only strengthens competence but also fosters the acceptance and seamless integration of technology in teaching[46][90].
From the study of Rune Johan Krumsvik[54] it was identified that teachers were inadequately competent in using digital technology effectively . Addressing this gap, there is a pressing need to enhance the digital competence of teacher educators (TEs) through continuous training[54].Such proficiency is crucial for various purposes, including work, leisure, participation, learning, socializing, consuming, and empowerment.

2.5.4 Enhancing Teaching and Learning Mathematics Competences Through Augmented Reality Software

AR application use augmented reality technology to overlay digital content on the real-world environment through the camera of a mobile device or AR headset. This allows learners to interact with geometric shapes as if they were present in the physical space. AR apps provide a more immersive and spatial understanding of 3D shapes (geometric concepts) by placing them in the learner's physical environment, allowing learners to physically move, rotate, and resize virtual shapes. They also offer interactivity, allowing learners to draw or manipulate shapes on the screen, observe them from different angles, and develop a better sense of their properties in a real-world context, but this is limited to the digital environment.

2.5.5 Augmented Reality Technology

Immersive technologies, such as augmented reality, offer a hands-on learning experience, allowing students to explore subjects through artificial replication and providing new revelations[7].Also AR is a real-time combination of digital and physical information using various technological devices, adding virtual information to physical ones, thereby adding a synthetic part to reality[11].
Historically, Augmented Reality (AR) has its roots in the early days of VR, with the introduction of the "Sensorama" machine in 1968. In the 1970s, the first HMD prototype, "The Sword of Damocles," introduced new elements to physical reality. AR has since been available on various devices and mobile phones. In 1974, a dedicated AR Lab was opened to create interaction patterns between users and digital overlays. AR gained its own term in 1990, with stakeholders including the air force and spacecraft[61].It has been explored in research labs, the military, and other industries since the 1990s as mentioned earlier.Software toolkits for desktop PCs have been available as both open source and proprietary platforms since the late 1990s. The proliferation of smart phones and tablets has accelerated industrial and consumer interest in AR. Much of today's interest and excitement for AR is moving toward wearable eye-wear AR with optical see-through tracking. Devices such as Microsoft HoloLens, Metavision's Meata headsets, and others use depth sensors to scan and model your environment and then register computer graphics to the real-world space[60].Currently, AR technology is associated with a number of common characteristics, namely immersion, navigation, and interaction.

2.5.6 Different Types of Technologies to Produce AR Environments

Creating augmented reality (AR) environments requires a diverse array of technologies[60]. These technologies play pivotal roles in crafting immersive and interactive AR experiences that blend the digital and physical worlds seamlessly. From sophisticated computer vision algorithms for object recognition to advanced hardware components like sensors,display(HMD) and cameras, each facet contributes to the richness and functionality of AR environments.Sensors provide tracking information through optical cameras, GPS, accelerometers, and gyroscopes. Optical tracking can be marker-based or marker-less, and other forms include acoustic, electromagnetic, or mechanic. Displays are the most impactful part of AR hardware, typically visual, and less common are tactile, audio, and olfactory. Input devices range from keyboards to voice inputs[88][11].
Furthermore, powerful software development tools, augmented reality SDKs (Software Development Kits), and immersive design techniques are vital for constructing AR applications that engage users and provide meaningful interactions[11][60].

2.5.7 Programming Languages and Frameworks Development Tools

Developers use specialized AR development kits (SDKs) and frameworks to create AR experiences efficiently. Choosing appropriate programming languages (e.g., Unity Script C# and frameworks (e.g., A-Frame, Vuforia) for developing AR features[4].

AR software

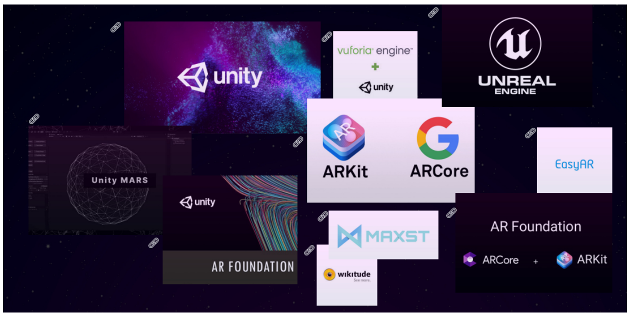


Figure 2.6: Software tools[91]

Unity Script : Unity is one of the most popular game development engines, supporting AR development. Unity uses C# as its primary scripting language for AR application development and is widely employed for both mobile AR and AR experiences on other platforms[60].

Frameworks and SDKs: The SDK also supports text target recognition.
ARCore (Android): ARCore is Google's AR platform for Android devices. It enables developers to build AR applications that leverage motion tracking, environmental understanding, and light estimation on a wide range of Android smartphones.

Vuforia: Vuforia is a popular AR development platform that supports multiple platforms, including iOS, Android, and Unity. It offers features like image recognition, 3D object recognition, and extended tracking.

The Vuforia SDK-based AR application consists of a camera, image converter, tracker, video background renderer, application code, device database, and cloud database. It supports various types of targets, including 2D and 3D, and supports localized occlusion detections. It offers faster local detection, efficient tracking in low light conditions, and extended tracking capabilities. It supports multiple target configurations, including cylinder targets, marker-less image targets, frame markers, and cloud recognition targets[4].

Unity 3D: Unity, a powerful game development engine, extensively supports AR development. It is compatible with both ARKit and ARCore, allowing developers to create cross-platform AR experiences.

AR applications have been implemented in various curricular areas, such as engineering, architecture, town planning, mathematics-geometry, art and history, language learning, technology, design, chemistry, and geography. The aim is to promote students' positive attitudes towards science, develop healthy habits, and develop games for school coexistence[11].

AR Challeges

1.Weak detection of markers or GPS position.
2.Teachers' resistance to adopting the AR technology,due to the substantial investment of time and effort required to create educational content that meets their standards of quality[88].

2.5.8 Impact of Digital Educational Technology on Teacher Satisfaction and Motivation in Mathematics Instruction

Researchers have found that augmented reality (AR) enhances learning by providing a hands-on experience and improving student interaction, self-control, and self-confidence[8].AR improves individual attention, satisfaction, motivation, critical thinking, confidence, learning interest, creativity, and overall performance. It also encourages collaboration, group learning, memory retention, and engagement, even in the absence of an instructor[11].AR enhances learning content understanding, aids long-term memory retention, improves physical task performance, and boosts student motivation through satisfaction and fun activities[88].

Digital educational technology enhances teacher enjoyment by increasing engagement, enhancing creativity, streamlining administrative tasks, providing access to educational resources, and promoting professional growth. Interactive and multimedia elements make teaching more enjoyable, while digital tools offer a variety of options for creating dynamic learning experiences. Teachers can also benefit from ongoing learning and staying current with educational trends, enhancing their overall teaching experience. For example, Virtual Reality (VR) and Augmented Reality (AR) technologies enable teachers to create immersive learning experiences that bring abstract concepts to life. Science teachers may use VR simulations to allow students to explore outer space or AR apps to overlay

3D models of anatomical structures onto real-world objects, thereby enhancing understanding and engagement.

2.5.9 Teacher Autonomy in Using Digital Educational Technology to Teach Mathematics

According to Self-Determination Theory, respect for autonomy involves acknowledging individuals' preferences, values, and goals, allowing them to make decisions aligned with their interests and values[16].
In the context of using digital educational technology, teacher autonomy refers to the degree of independence and control that teachers have over decisions related to integrating and implementing technology in their teaching practices. It involves the freedom for educators to make choices about what,how, when, and why they use digital tools and resources to enhance the learning experiences of their students in the subject of mathematics. This is crucial because Educational Technology is the field concerned with the design, development, utilization, management, and evaluation of processes and resources for learning[64].This ensures that teachers can take control of automatic functions of the system as needed[59], enabling them to adjust the system functionality in accordance with the content provided in the educational curriculum of mathematics.

Digital educational technology empowers teachers to personalize and innovate their mathematics instruction methods, fostering active and experiential learning. Examples include the Flipped Classroom Model, adaptive learning platforms, interactive whiteboards, online problem-solving platforms, and virtual manipulative. These tools enable teachers to tailor learning experiences for students, facilitating more interactive activities and personalized support during class time. By implementing these innovative teaching methods, educators create a more engaging and effective learning environment. For instance, through Problem-Based Learning, teachers utilize platforms like Desmos or GeoGebra to immerse students in solving real-world problems or exploring mathematical concepts via interactive simulations. Similarly, the integration of Virtual Manipulatives enhances students' understanding of geometric shapes and concepts. For example, when studying three-dimensional shapes like cubes, students may struggle to visualize how different views of the cube relate to each other. By using virtual cubes, students can rotate and manipulate the shape to see it from various angles, aiding in understanding faces, edges, and vertices more intuitively. Likewise, when studying polygons, students may have difficulty understanding properties like interior angles or the relationship between different types of polygons. With virtual manipulatives for polygons, students can interactively explore various shapes, manipulate their sides and angles, and observe how changes affect properties like perimeter or area, fostering deeper understanding of geometric principles. Additionally, active learning strategies like peer instruction or collaborative problem-solving activities further enhance student engagement and comprehension in mathematics. Experiential learning approaches, such as virtual field trips or simulations, provide students with hands-on experiences that deepen their understanding of mathematical concepts and foster a lifelong love for learning.
However, it is important to consider behavior surrounding the use of technology and the factors associated with its acceptance, as mentioned in the previous section using PACT, TAM, and TPACK frameworks[89][2][49].

2.5.10 Teacher Relatedness in Using Digital Educational Technology to Teach Mathematics

The need for relatedness entails the desire to establish and maintain strong interpersonal connections, fostering a sense of acceptance and belonging[41]. Teacher involvement, characterized by positive regard, empathy, and commitment to learning, enhances students' satisfaction and fosters psychological well-being[48].
Numerous studies affirm that satisfying the psychological needs for competence, autonomy, and relatedness predicts overall psychological well-being and self-motivation across cultures, contributing to mental health[24][23]. While rewards can initially provide enjoyment, they can undermine intrinsic motivation, especially when individuals confuse extrinsic rewards with inherent enjoyment

derived from their work [21]. Previous studies underscore the importance of relatedness in the workplace, emphasizing the positive outcomes of autonomy and supportive leadership styles. Leaders who support employees' psychological needs through individualized consideration and refraining from pressuring behaviors are more successful in fostering motivation[22]. The concept of teacher relatedness encompasses the quality of interpersonal relationships among teachers, students, and educational communities. It emphasizes the importance of positive interactions and collaboration to create a supportive learning environment. When teachers feel connected and valued within their professional community, they experience greater job satisfaction and motivation, leading to improved teaching practices and student outcomes. As students' sense of relatedness serves as a catalyst for engagement and achievement, fostering positive teacher-student relationships is crucial for promoting academic success[48].

While the majority of today's graduating teachers are expected to be digital natives i.e the individuals who have grown up in the digital age, typically those born after the widespread adoption of digital technology such as computers, smartphones, and the internet and are familiar with a variety of technological tools, in-service teachers are or have been expected to develop these abilities through alternative means, such as supplementary courses, workshops, and peer collaborations[28]. However, merely knowing how to use technological tools, such as a digital camera or scientific software , is insufficient for teachers to effectively employ technology in the classroom. In reality, if this were true, there would be little, if any, difference between teachers' personal and instructional usage of technology. Understanding how to teach using technology requires instructors to broaden their knowledge of teaching techniques across multiple disciplines, encompassing aspects of the planning, implementation, and assessment processes[28]. For example, when employing technology as an instructional tool, teachers must be able to create strategies for teaching software to students, select appropriate software, and manage computer gear and software to fulfill curriculum and learning needs.

For this reason, teachers must be prepared to use technology to enhance effective student learning, requiring extra understanding of the subject matter they are expected to teach, the pedagogical strategies that assist student learning, and the unique ways in which these methods can be supported by technology. As teachers engage their students in more interdisciplinary work, their content knowledge requirements increase.

2.6 Gaps and Proposed Solutions

S/N	Gaps	Solutions
1	Human motivation theory has been applied across various groups of people, a notable research gap exists in its specific application to certain specific populations, notably teachers, and within distinct subjects like Geometry[25][16].	To fill this gap, the master's thesis research focused on investigating the intrinsic motivation of teachers in utilizing digital educational technology in teaching geometry concepts because understanding teacher motivation to use digital educational technology can improve teaching practices, enhance technology integration, and enhance student learning.
2	While motivation theory documents clearly identify factors (Autonomy, Competence, Relatedness) contributing to individual intrinsic motivation, there is a gap in addressing individual satisfaction levels derived from these factors [48] [25]	To address this gap, the researcher used a human-centered design approach, which has helped to recognize individual emotions and reactions and the engagement and satisfaction levels of teachers in the educational environment.This approach is beneficial as it places teachers and their experiences at the forefront, allowing for a deeper understanding of their intrinsic motivations and preferences regarding the use of digital educational technology in teaching geometry concepts.
3	While satisfying Autonomy, Competence, and Relatedness are recognized as induced factors contributing to individual self-efficacy and intrinsic motivation, there is a gap in considering other factors, such as adapting digital education technology[7].	To address this gap, the integration of visualization tools (Geometry applications) is proposed as an amplifier for individual self-efficacy, emotions, high satisfaction levels, and intrinsic motivation.By incorporating these tools into the educational environment, teachers can maximize their potential to boost confidence, evoke positive emotions, heighten satisfaction, and stimulate intrinsic motivation among both educators and students
4	The GeometriaRA is an educational software utilizing augmented reality to enhance the teaching and learning of geometric solids. However, its current limitations lie in interactivity and customization[78].	To bridge this gap, the researcher aims to enhance the application by incorporating the following features: Interactivity: Enable users to interact with 3D geometric shapes by allowing manipulation, rotation, and resizing. This enhancement aims to facilitate a better understanding of the properties of these shapes.

Table 2.1: Gaps and Solutions

Examining the various factors influencing teachers' motivation and the intention to use technology, this research within the PACT, TAM, and TPACK frameworks seeks to deepen our understanding of teachers' intrinsic motivation and digital educational technology for teaching mathematics. By implementing strategies that foster autonomy, competence, and relatedness, the study aims to enhance technology integration among teachers' autonomy, competence, and relatedness in using digital educational technology in teaching mathematics. Furthermore, the investigation has considered both the opportunities and limitations of geometry application tools, providing recommendations for effective and usable artifacts and experiences.

Chapter 3

RESEARCH METHODOLOGY

In this chapter, we opt to use a systematic design science research process. We outline the analysis methods to be employed, the criteria for evaluating usability, and a diverse set of tools and methodologies essential for collecting high-quality qualitative research data. These encompass a range of techniques, including a human-centered approach for usability testing, the utilization of thematic analysis and NVIVO software for data analysis, and the incorporation of survey questionnaire, observational, and interview strategies. All of these techniques are pivotal in obtaining data for this study, contributing to addressing the research question.
In this Design Science Research Methodology ,a designer can answer the questions relevant to human problems via the creation of innovative artifacts, thereby contributing new knowledge to the body of scientific evidence[38][38]. Therefore, it aids in generating innovations that define ideas, practices, technical capabilities, and products essential for the effective and efficient analysis, design, implementation, and use of information systems. The design science research methodology assists researchers in conducting effective studies, contributing to effective problem-solving.

3.1 Design Research Process

The Design Science Research Methodology (DSRM) involves six steps: problem identification and motivation, solution objectives, design and development, demonstration, evaluation, and communication[38].
The first and second steps involves defining the research problem and justifying the value of a solution. This helps and motivate the researcher and audience to pursue the solution and understand the reasoning behind it,researchers in design science often incorporate efforts to transform problems into system objectives, also known as meta-requirements or requirements. This process is part of data collection, or the search for relevant problems. Identified problems do not necessarily translate directly into performance objectives for a solution, as design is a partial and incremental process. After identifying the problem, researchers define the objectives for a solution, which can be quantitative or qualitative. The third step is design and development. The core of design science across disciplines is design and development, which involves creating an artifact with a research contribution embedded in it. The fourth step is demonstration, in which the solutions can range from a single act of demonstration to a more formal evaluation of the developed artifact. The artifact is then demonstrated to solve the problem, and the evaluation is conducted to compare the objectives of a solution to actual observed results, which encompasses the fifth step of evaluation. Finally, communication is crucial, as it involves presenting the problem, its importance, the artifact, its utility, novelty, rigor, and effectiveness to researchers and relevant audiences, requiring knowledge of the disciplinary culture[38].

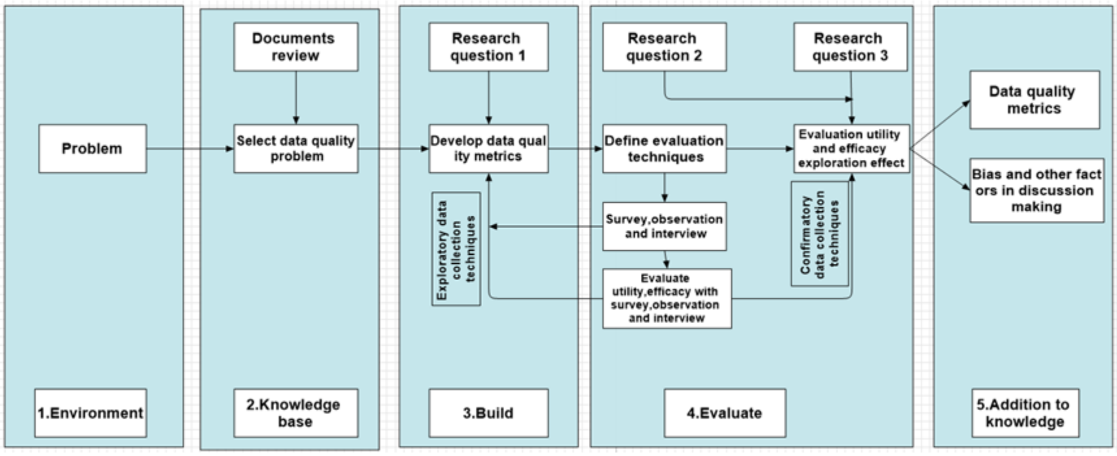


Figure 3.1: Design Research Process Adapted from Design Research in Information Systems Theory and Practice[38]

The above Design Research Process figure comprises five stages:

• Environment: At the outset, researcher visualizes, study, and identify community problems and opportunities. They respond to these issues by creating artifacts that offer tangible solutions.

• Knowledge Base: Researcher delves into existing literature and solutions to understand past efforts and pinpoint gaps for improvement. Data quality problems, like completeness and appropriate sample size, are addressed to ensure accurate analysis.

• Build: This stage focuses on identifying system and user requirements, designing interactive systems, and developing application prototypes. For instance, in this research, an augmented reality application prototype was developed for teachers.

• Evaluate: Various data quality metrics, including unallocated data and sample size indicators, are employed to assess both the collected data and the produced solution. The unallocated data metric helps monitor and control missing data, ensuring analyses are based on complete datasets. The sample size indicator aids in evaluating the adequacy of the sample size for drawing reliable conclusions and generalizing findings[38].
The data quality problems addressed are completeness and the appropriate amount of data. Completeness ensures all respondents answer all required questions in a survey dataset, while the appropriate amount of data ensures there's enough data volume to support the research objectives[38].

• Addition to Knowledge: The final stage demonstrates new insights gained through the research process. Once evaluation confirms the solution's effectiveness, it contributes to the body of knowledge in the field. Researcher bears the responsibility of collecting, manipulating, and integrating data to provide precise solutions to research questions.

3.2 Study Setup, Data Collection Techniques, and Sample Size

3.2.1 Study Setup / Study Participants

The study setup for this research project is detailed in Chapter One, encompassing objectives, research questions,hypothesis, and a timeline. Chapter Three discusses the study design, focusing on human-computer interaction, data collection procedures, and the data analysis plan. It outlines the goals, methods, variables, and procedures for data collection and analysis, ensuring a systematic and intensive approach to research that produces reliable and valid results.
In this study, teachers in Rwanda serve as the designated participants. The emphasis on Rwanda

arises from its educational curriculum, which adopts a competencies-based approach. This curriculum seamlessly incorporates the utilization and learning of digital educational technology. The overarching goal is to cultivate competencies in educators and learners, enabling them to engage with their environment more practically. The desired outcome is to equip learners with the necessary knowledge and skills applicable across various learning domains[102].The researcher intends to assess the teachers' intrinsic motivation to utilize digital educational technology for teaching mathematics, specifically examining the autonomy,competences and their level of enjoyment among secondary school teachers regarding the potential use of visual tools for teaching mathematics.

3.2.2 Sampling Technique

Purposive sampling, also known as judgment sampling, was employed in this research to select participants based on their expertise in mathematics education or experience teaching mathematics. Because it is a nonrandom method that aims to identify information-rich cases for optimal resource utilization, the technique involves selecting individuals or groups knowledgeable about the phenomenon of interest, as well as their availability and willingness to participate. The ability to communicate experiences and opinions effectively is also crucial[29].
The researcher used purposive sampling. The idea behind purposive sampling is to concentrate on people with particular characteristics who will better be able to assist with the relevant research [29]. Incorporating Technology, Pedagogy, and Content Knowledge (TPACK), it's crucial to have educators with practical experience in augmented reality (AR) technology. This hands-on experience enabled us to evaluate their readiness to integrate AR into teaching practices and measure its overall effectiveness.

3.2.3 Sample Size

The determination of the sample size was based on the Yamane formula, taking into account both the unknown population size and unknown population proportion[18],since in certain scenarios, accurately determining the population size becomes challenging due to logistical feasibility issues. Factors such as limited resources and inaccessible populations' data make it difficult to obtain accurate information about population size.

$$n = \frac{z^2}{4e^2} \tag{3.1}$$

whereby:
n stand for sample size.
z stand for z score value form Normal distribution table[13].
e stand for marginal error.

The table below illustrates the calculation

Variable	Value
z	1.65
z^2	2.7225
e	0.1
e^2	0.01
n	68

Table 3.1: Sample size determination

The initial sample size of 68 was adjusted due to cost, time constraints, and participant availability. Additionally, consistent responses were anticipated from the majority of participants. Therefore, only approximately 40% of respondents 68*0.4=27.2), equivalent to 28 teachers, were selected for guided interviews and one-on-one surveys, considered representative of the population. Large sample sizes entail significant costs, time, and resource allocation for data collection and analysis.

Researchers chose to reduce the sample size to 40% to accelerate the research process, conserve resources (including participant incentives), and address cost and time constraints.
The study focuses on secondary school teachers in Kamonyi District, Rwanda, utilizing a purposive sampling method. Twenty eight schools coresponding to the twenty eight teachers were selected from each of the five targeted sectors: Gacurabwenge, Rukoma,Rugalika, Musambira,and Ngamba sector. The specific schools chosen are detailed in the figure 3.2 below:

<table>
<tr><th colspan="5">Kamonyi District</th></tr>
<tr><th colspan="5">Sector/Schools</th></tr>
<tr><th>Gacurabwenge Sector</th><th>Rukoma Sector</th><th>Rugalika Sector</th><th>Musambira Sector</th><th>Ngamba Sector</th></tr>
<tr><td>GS Sancta Maria</td><td>Gs Remera Rukoma</td><td>GS Sheli</td><td>GS Bitsibo</td><td>GS Ngamba</td></tr>
<tr><td>GS St Jean Bosco kamonyi</td><td>GS Bugoba</td><td>GS Gihara</td><td>Gs Wimana</td><td>GS Masogwe</td></tr>
<tr><td>Rosa Mystica secondary school</td><td>GS Kabuga Icyerekezo</td><td>GS Kiboga</td><td>ES Musambira</td><td rowspan="5">GS Kabasare</td></tr>
<tr><td>GS Gacurabwenge</td><td>GS Muhehe Icyerekezo</td><td>GS Masaka</td><td>GS Gihembe</td></tr>
<tr><td>GS Gatizo</td><td>GS Muhondo</td><td>GS Rugalika</td><td rowspan="3">GS Mpushi</td></tr>
<tr><td>GS Kagarama</td><td>GS Nyarubuye</td><td rowspan="2">ES Karama</td></tr>
<tr><td>GS Kigembe</td><td>GS Murehe Protestant</td></tr>
</table>

Figure 3.2: Sectors and Schools.

3.2.4 Data Collection Techniques

In this research study, the primary techniques employed for data collection included documents review, observation, interviews, and survey. Each objective was achieved by utilizing the human centered design approach and designated data collection techniques as outlined in the table 3.2 below.

Number	**Objective**	**Technique to be used for each objective**
1	To examine the literature review in order to gain understanding of motivational concepts to enhance teacher's intrinsic motivation.	Documents review was employed to gain insight into motivation.
2	To examine teacher's autonomy and competence in using digital educational technology to teach mathematics.	Survey,Interview and Observation .These techniques were employed to test an Augmented Reality (AR) system prototype, with researcher focusing on key aspects such as user interaction, ease of use, skill acquisition, effectiveness, user satisfaction, errors, task performance, system adaptability, engagement,and user preference. Researcher also observed user gestures, movements, difficulties encountered, learning process, and the system's effectiveness in fulfilling its intended purpose.
3	To determine the level of teacher's enjoyment in using digital educational technology to teach mathematics.	Human centered Design approach,Interviews and Observation. By employing Human-Centered Design (HCD) principles ,observation and interview techniques, researchers can delve into teachers' experiences, perceptions, and attitudes regarding the use of digital educational technology in mathematics teaching. This approach yields valuable insights into their level of enjoyment with these tools.
4	To analyze the feedback provided by teachers regarding motivation and the use of digital educational technology to teach mathematics.	Thematic analysis and NVIVO software .Thematic analysis, supported by NVivo software, facilitated the identification, analysis, and interpretation of patterns within qualitative data. This approach aided in understanding the meanings and experiences of participants' thoughts. NVivo served as a valuable tool for researcher by assisting in the organization, coding, and analysis of qualitative data. It enabled efficient management, assessment, and interpretation of data, enhancing the precision and richness of the research process.

Table 3.2: Methods Utilized for each Objective

3.2.5 Document Review

Document review involves the systematic examination and analysis of existing documents or materials related to the research topic. These materials encompass academic papers, reports, articles, books, government publications, and any other written or recorded information relevant to the study[77].This technique has facilitated a deeper understanding of motivational styles and factors, contributing to the understanding and enhancement of teacher motivation.

Search Strategy for Obtaining Documents for Review

The search strategy and inclusion criteria for this study follow the approaches outlined by Webster, Jane and Watson, Richard T[105] for screening and categorizing documents .
Utilizing resources such as the Google Scholar database, Semantic Scholar database, IEEE Explore database, UiA library, Artificial Intelligence tools, and online platforms, researcher employed the following predefined keywords:

- Motivation,
- Research methods,
- Pedagogy approaches,
- Augmented Reality,
- Digital Educational Software,
- Visualization Tools,
- Mathematics Education .

These keywords were used to search for relevant documents. The search encompassed papers, online resources, books, and electronic journals in English as clearly shown in the table below.

Predefined keyword	**Publication**	**Initially documents found**	**Selected document**	**duplication**	**Selection criteria**	**Selection strategy**	**Exclusion/ Inclusion criteria**
Motivation Theory ,Pedagogy Theory,Math education	Journal of Bulletin of Educational Psychology; Sciencedirect.com;Kluwer Academic Publishers;Sage Publications Sage CA: Thousand Oaks, CA;Routledge;cita konsultindo;University of Nairobi;International Journal of Educational Qualitative Quantitative Research;Wiley Online Library;Journal of Research in Innovative Teaching;American Psychological Association;Springe;Taylor & Francis;IEEE;Universitetet i Agder ; Google scholar,Semantic sholar	67	45	22	The range of years(1999-2023) ,English	Predefined keywords were used, and research questions were carefully considered	Unrelated documents to Motivation and pedagogy were removed, while related documents were taken into consideration
Augmented reality,Digital Educational software	Springer;Sciencedirect;IST-Africa Institute,Sematic scolar,Universidad de Alicante;Springer Singapore Pte. Limited;Routledge;Wiley Online Library;University of Agder;Academia.edu;Packt Publishing Ltd;American Psychological Association;Cogent OA;Association;Springe;Educational Publishing Foundation;Academy and Industry Research Collaboration Center (AIRCC)	78	59	19	The range of years(2000-2023) ,English	Predefined keywords were used, and research questions were carefully considered	Unrelated documents to AR and technology integration were removed, while related documents were taken into consideration
Total		145	106	41			

Table 3.3: Documents for review

3.2.6 Survey

Surveys are a widely used method for data collection, involving a standardized questionnaire with closed-ended questions that has been sent to a chosen sample of respondent[44].Creating effective survey questions is essential for obtaining reliable data, as the quality of questions directly influences the quality of responses. Questions in a survey can broadly be categorized as open or closed. Closed questions offer a fixed set of response options, such as yes/no, multiple choice, checkboxes, or Likert scale questions. In contrast, open questions allow respondents to answer freely, often with essays or short responses[31].

This technique have facilitated the examination of a teacher's autonomy, competency, and enjoyment level in using digital educational technology to teach mathematics. It was conducted through online questionnaires through Nettskjema, an online form for data collection.They helped to gain insights into individuals' opinions and attitudes about digital visualization tools.

3.2.7 Interview

An interview is a qualitative research method that relies on asking questions in order to collect data. It involves two or more people, one of whom is the interviewer, asking the questions, and the other is the interviewee, giving the responses. An interviews were conducted between a researcher and a respondent from Kamonyi District at the secondary school laboratory where the respondent works. A prepared questionnaire was answered during the interview.

User interviews are a valuable method for understanding the users' identities, experiences, needs, values, and desires. In these interviews, the interviewer poses questions, listens to responses, and generates diverse ideas. When conducted effectively, user interviews offer profound insights into users' lives, experiences, and challenges, aiding a researcher in identifying solutions to enhance user experiences[42].

Forms of Interview

Interviews come in various types, each tailored to specific characteristics and purposes[42].
Structured Interviews: Utilizing a predetermined set of questions in a standardized order, these interviews aim to systematically gather specific information.

Semi-Structured Interviews: Combining open-ended and closed-ended questions, these interviews offer flexibility for exploring participants' experiences, perceptions, and perspectives in depth.

Unstructured Interviews: With no predefined questions, these interviews resemble open-ended discussions, allowing participants to share experiences and perspectives in their own words.

The data were collected using the interview forms mentioned above to minimize interviewer bias, ensure consistency in data collection across participants, and provide flexibility in questioning. The information gathered was utilized to construct various artifacts, enhancing the understanding of user experiences and needs. This interview technique have facilitated the examination of a teacher's autonomy, competency, and enjoyment level in using digital educational technology to teach mathematics.

3.2.8 Observation

Observation offers vast data for analysis, with digital recording aiding[6].Observation refers to the systematic and purposeful examination of a phenomenon or system to gather relevant information for the design and evaluation of a solution. It plays a crucial role in understanding the current state of a system, identifying challenges, and informing the design process[103][42].This technique had facilitated the examination of a teacher's competency and their enjoyment in using digital educational technology to teach mathematics. Additionally, it had provided insight into perceived ease of use, usefulness, attitude toward usage, and behavioral intention to use the system. In our case, we are focusing on visualization tools (Geometry Applications), which have contributed to the actual system use. The researcher can observe and analyze user behavior, interactions, and trends through physical interview.

3.3 Analysis Methods

3.3.1 Thematic Analysis Technique

In analyzing data, researcher has used thematic analysis techniques. Thematic Content Analysis (TCA) is a method used to analyze qualitative data, such as interview transcripts or other texts, by identifying common themes [5]. According to Anderson and Rosemarie[62], thematic analysis is a qualitative method that consists of three components: individual codes, categories, and researcher-produced themes. This technique had facilitated to analyze the feedback provided by teachers regarding motivation and the use of digital educational technology to teach mathematics.

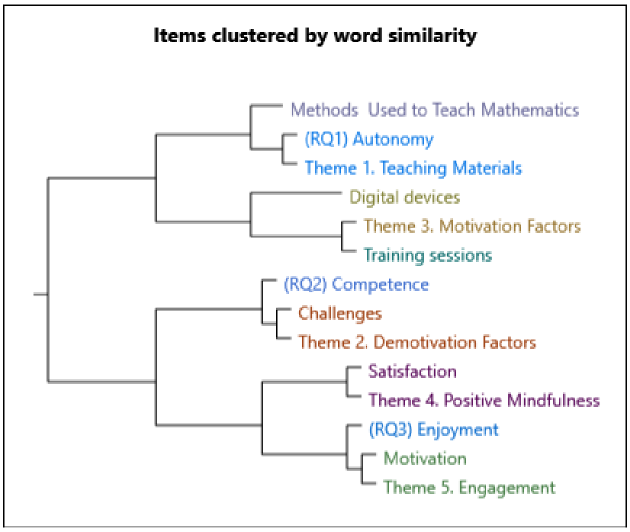


Figure 3.3: Developed Codes,Categories and Themes.

Codes are words or phrases that assign a summative, salient, essence-capturing, and evocative attribute to a portion of qualitative data[87]. They connect the researcher's analysis with the collected data, and codes play a powerful role in identifying patterns and assigning value to different perspectives or experiences. In research, codes are often used to capture the essence of the participant's experience[62]. Data for this study include interview transcripts, observations, journals, documents, survey responses, images,websites and published academic literature.
Categories are the first step in identifying patterns in codes, defining unrelated and dissimilar patterns. Patterns explain interrelationships and serve as the basis for themes, which are operationalized within data analysis as categories.Themes thus serve as an invitation to explore more deeply a particular aspect of the dataset[62]. This Figure 3.3, presented above, has been thoroughly examined and discussed in Chapter 4 and 5.

3.3.2 Analytical Approaches Employed to Gathered Data

The researcher had employed the following steps in utilizing the thematic analysis technique:

After distributing the survey questionnaire to respondents via email,whats-app platforms and collecting the responses, the researcher conducted interviews. Transcribing the interviews, survey responses, and relevant observational text provided a comprehensive dataset for analysis, facilitating a more efficient and thorough examination of the data. The researcher used a highlighting technique to mark key descriptions, then compiled all collected data into a single file, labeling them as initial codes, categories, and themes using key words or phrases from the highlighted texts. Subsequently, the researcher systematically reviewed the transcript, grouping and regrouping similar and dissimilar codes, and re-labeling them as appropriate. Following this, the researcher thoroughly reviewed all meaning codes and themes within each category, adjusting and reordering codes or themes as necessary. This iterative process was repeated multiple times to ensure a robust interpretation of the data. Utilizing NVivo software, the developed themes were recorded within the software to facilitate a more comprehensive analysis and interpretation of the results,ultimately contributing to the investigation of teacher motivation in utilizing digital educational software for mathematics instruction.

3.3.3 Analytical Approaches Employed in Literature Review

In the examination of literature reviews, researchers employ a variety of analytical techniques[32] to unravel the complexities of existing knowledge.This study highlights three key methodologies utilized in literature review analysis:
1. Synthesis: This involves the amalgamation and combination of information from diverse sources to construct a coherent overview, emphasizing the relationships and connections within the literature with the utilization of Microsoft word and excel.
2. Conceptual Framework Development: Researcher often constructed conceptual frameworks to systematically organize essential concepts and theories, furnishing a structured understanding of the literature.
3. Identification of Research Gaps: A critical aspect of literature review analysis is pinpointing areas necessitating further research or recognizing gaps in the existing literature. This identification serves as a compass for guiding future studies in meaningful directions.

3.4 Human-Centered Design

The human-centered design (HCD) method was utilized to understand the context of use, assess and establish user requirements, and conduct usability test. Human-centered design (HCD) is a group of methods and principles aimed at supporting the design of useful, usable, pleasurable, and meaningful products or services for people[30].

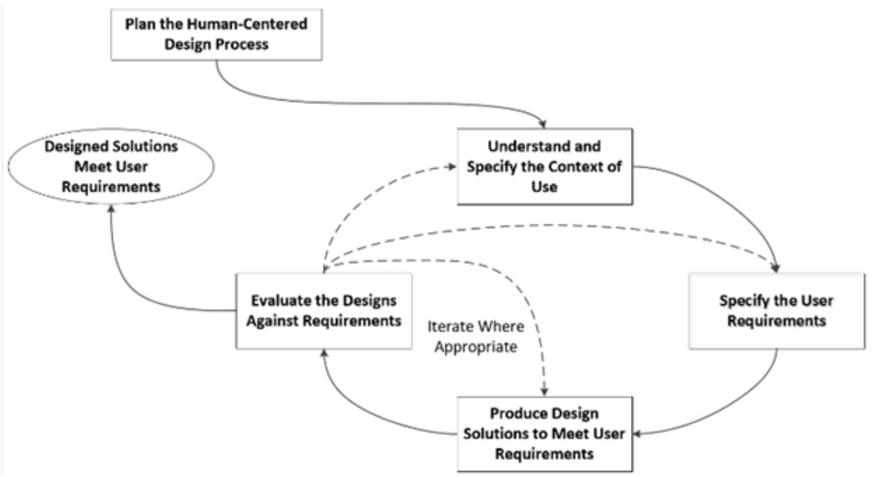


Figure 3.4: Human centered design phases[37]

The HCD process starts with the planning phase, during which a designer establishes what is necessary to carry out the HCD activities for a given design project. During planning, the designer defines how all the HCD activities was integrated in an iterative manner with consideration to the required resources, responsibilities, time schedules and milestones, communication plan, activities, and outputs expected at each phase of the process[37].

3.4.1 Understanding and Specifying the Context of Use

To gain a thorough understanding and precisely define the context of use, it is crucial to collect data from users through various research methods in human-computer interaction. These methods include document review, surveys, interviews, and observation. In this research study, the primary tools for data collection comprised document review, observation, interviews, and survey. The analysis of the context of use aids in systematically specifying user characteristics, tasks, and usage circumstances[37][65]. This was accomplished through the development of personas, user scenarios, user stories, and use cases, employing document review, interviews, and survey methods as seen in Figure 3.5 below.

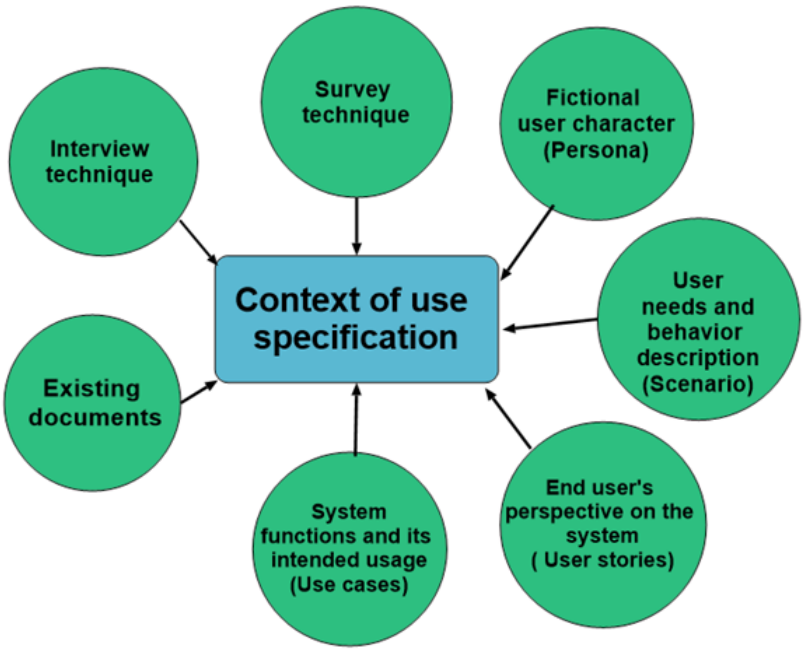


Figure 3.5: Context of use from human centered design phases[37]

The context of use is comprised of the characteristics of user and user tasks.
User: Designers should consider their target users, encompassing not only those who directly use the system but also those who request the system, those who commission it, and any other individuals impacted by its use. This collective group is commonly referred to as "stakeholders." In the context of this research, the users for the digital visualization tools system are teachers and students.
Another context of use characteristics is user tasks: In this study, where the system is represented by digital visualization tools, the tasks involve constructing mathematical shapes and comprehending their associated properties.

Developing Personas

Personas: are fictional characters, which you create based upon your research to represent the different user types that might use your service, product, site, or brand in an equivalent way [34]. Bellow are the personas created in order to understand the context of use for visualization tools.

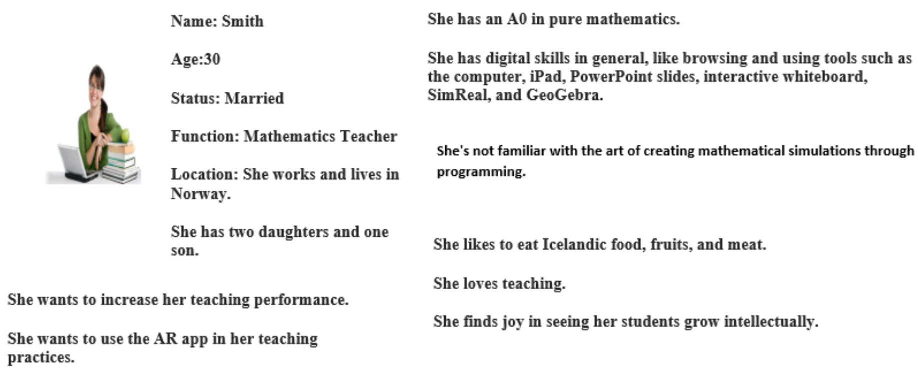


Figure 3.6: Persona 1

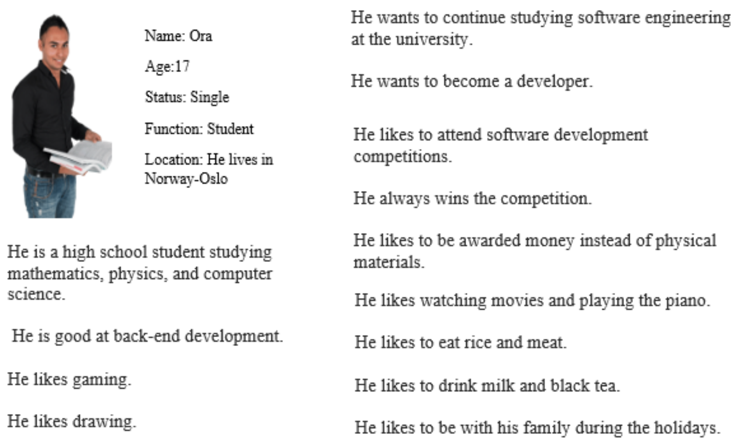


Figure 3.7: Persona 2

Development of the User Scenario

User scenarios are detailed descriptions of a user typically a persona that describe realistic situations relevant to the design of a solution. By painting a "rich picture" of a set of events, teams can appreciate user interactions in context, helping them to understand the practical needs and behaviors of users[34]. Below is an example of the development of a user scenario.

Ms. Smith, a high school mathematics teacher, has always been passionate about math courses. She genuinely loves teaching her students and helping them develop a deep appreciation for course content. While teaching mathematics in the classroom, she combined a blend of technology, utilizing tools such as the iPad, PowerPoint slides, interactive whiteboard, AR apps,SimReal, and GeoGebra to enhance the learning experience. She finds joy in seeing her students grow intellectually and emotionally through the study of content or handling challenging math questions.

User Stories

A user story is an informal, general explanation of a software feature written from the perspective of the end user. Its purpose is to articulate how a software feature will provide value to the customer

[101].Below is an example of the development of a user story.

As a mathematics teacher, I want to incorporate an AR app into my teaching methods to enhance the teaching and learning experience for both myself and my students so that I can be able to raise my competence in teaching geometric concepts, foster increased motivation among students, and ultimately deepen their understanding of mathematical principles.

Use Cases

Gaining an understanding of the context of use through use cases entails identifying and describing how a system, specifically the visualization tools specified as Geometry augmented reality applications in this case, facilitates comprehension for those who can share their opinions on how the system functions and its intended usage[37]. Bellow, the use cases provide detailed descriptions of requirements between users and the Geometry augmented reality application, outlining specific actions, expected outcomes, and the overall flow of events.

1. User Activation: The user lifts the smartphone.
2. Application Launch: The user opens and initiates the application.
3. User Interface Display: The app displays the user interface home elements.
4. Navigation: The user navigates through the application.
5. Marker Recognition: The user scans markers in front of the camera view.
6. Marker Tracking: The app recognizes and tracks the markers.
7. Shape Formation: The app forms a shape with a default color.
8. Shape Examination: Users place a virtual shape on a phone and rotate it to examine its different faces, edges, and vertices.
9. Shape Identification: The app provides the appropriate shape type.
10. Side Measurement: The app provides the length size of the sides.
11. Angle and Distance Measurement: Users measure angles and distances between points in a real-world setting.
12. Area Calculation: The app displays the area of the drawn shape.
13. Perimeter Calculation: The app displays the perimeter of the drawn shape.
14. Volume Computation: The app provides the volume of the shape.
15. Angle Measurement: Users measure the angles formed by the corners of the shapes or the length of a side of a triangle.
16. Geometric Object Manipulation: Users can manipulate virtual geometric objects, such as scaling, rotating, or translating them, to observe how these transformations affect the shape and properties of the object.
17. Users conceptualize and visualize geometric concepts more concretely, leading to a deeper understanding of mathematical principles.

3.4.2 Analyse and Specify the User Requirements

3.4.3 What are Requirements ?

The IEEE defines requirements as necessary conditions or capabilities for a system to solve problems or achieve goals, and fulfill contracts, standards, specifications, or other formal documents[98]. requirements define the needs of organizations, groups or people along with their surroundings and describe what a solution must offer in order to satisfy those needs[98][84].

System Requirements

System Requirements are crucial for system verification post-development and can be categorized into functional and non-functional requirements[98].

Functional requirements

Functional requirements describe the functionalities expected from a solution, including necessary tasks, actions, and responses. They describe inputs, outputs, and behavioral relationships between them. A functional specification is used to communicate these requirements to customers, system, and software engineers[98].

Non-Functional Requirements

Non-functional requirements, also known as quality attributes, are essential aspects of a system's performance, describing its characteristics independently of its functional goals. They include aspects like usability, likability, performance, reliability, or safety[98].
In the upcoming section, we will provide a concise yet comprehensive overview of the user and system requirements for this geometry application software. This was facilitated by the utilization of the Volere template, a powerful tool designed to streamline and articulate requirement specifications effectively.[84].

3.4.4 Usability and User Experience Goals

Usability is thinking about how and why people use a product or system. The word "usability" also refers to methods for improving ease-of-use during the design process[80].

Usability Goals

In the pursuit of creating an effective and user-friendly system, it is imperative for the researcher or system designer to assess the system requirements. This evaluation, conducted through rigorous usability testing, serves as a critical checkpoint to ensure that the specified requirements align seamlessly with the overarching usability goals outlined bellow in accordance with ISO 9241[80]. By subjecting the system to real-world user interactions and feedback, this methodical approach not only validates the usability objectives but also provides valuable insights for refining and enhancing the overall user experience goals.In addition, the system is designed to be helpful, incredibly motivating, and have a delightful sense of humor to keep users engaged. Its interactive nature makes the experience enjoyable, ensuring that user satisfaction is justly met and maximized, aligning with the diverse range of user needs.The following are the usability goals:

1.Learnability: An System interface which is easy to learn allows users to build on their knowledge without deliberate effort. This goes beyond a general helpfulness to include built-in instruction for difficult or advanced tasks, access to just-in-time training elements, connections to domain knowledge bases which are critical to effective use.
2.Efficiency: can be described as the speed (with accuracy) in which users can complete the tasks for which they use the product. ISO 9241 defines efficiency as the total resources expended in a task.
3.Memorability: The system should be ease to remember up on return from use.
4.Errors:An error tolerant program is designed to prevent errors caused by the user's interaction, and to help the user in recovering from any errors that do occur.
5.Satisfaction: How pleasant is it to use the design? This goal is associated with user satisfaction from using the system.
Effectiveness :is the completeness and accuracy with which users achieve specified goals? It is determined by looking at whether the user's goals were met successfully and whether all work is correct.

3.4.5 Task Analysis

During the task analysis process, the researcher learns about the tasks necessary to achieve the goals. Users observe the Geometry augmented reality application prototype in user action to understand in detail how they perform tasks and achieve their intended goals.Task analysis helps identify the tasks that applications must support and can also assist designers in refining or redefining navigation by determining the appropriate content scope. Cognitive task analysis is applied in this research because it focuses on understanding tasks that involve decision-making, problem-solving, memory, attention, and judgment[69].

3.4.6 Requirements Specification Using the Volere Template

The Volere Requirements Specification Template is intended for use as a basis for requirements specifications[84]. The requirements shell, also known as a "snow card," serves as a guide for writing each atomic requirement as it appears in the figures below.

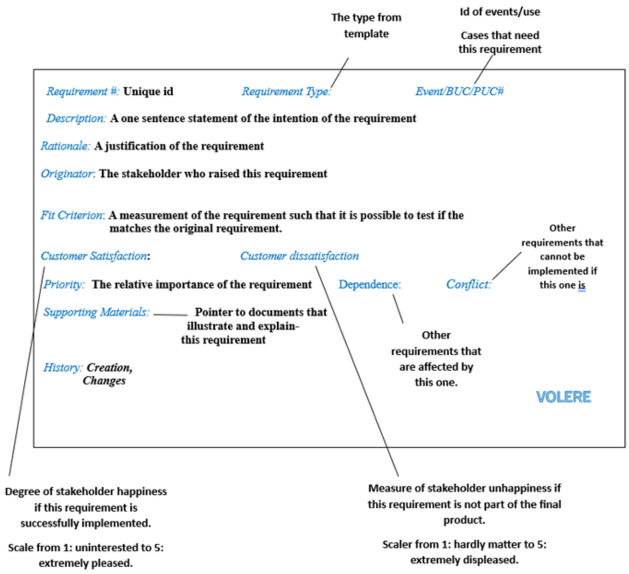
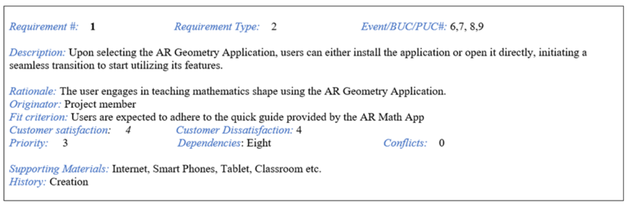


Figure 3.8: Requirement template adopted from [84]

For our AR Geometry Applications prototype, we require a comprehensive requirements specification outlining the system functionality, relevant facts,assumptions, and performance benchmarks.This is essential to ensure a seamless and effective educational experience.



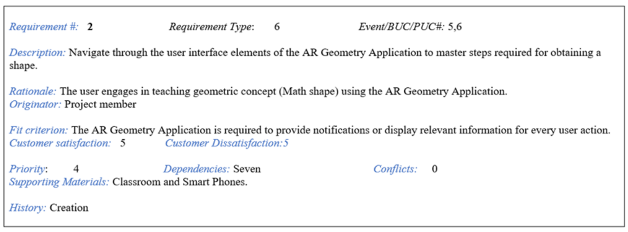
Requirement #: **1** *Requirement Type:* 2 *Event/BUC/PUC#:* 6,7, 8,9

Description: Upon selecting the AR Geometry Application, users can either install the application or open it directly, initiating a seamless transition to start utilizing its features.

Rationale: The user engages in teaching mathematics shape using the AR Geometry Application.
Originator: Project member
Fit criterion: Users are expected to adhere to the quick guide provided by the AR Math App
Customer satisfaction: 4 *Customer Dissatisfaction:* 4
Priority: 3 *Dependencies*: Eight *Conflicts:* 0

Supporting Materials: Internet, Smart Phones, Tablet, Classroom etc.
History: Creation

Figure 3.9: Requirement number 1



Requirement #: **2** *Requirement Type*: 6 *Event/BUC/PUC#:* 5,6

Description: Navigate through the user interface elements of the AR Geometry Application to master steps required for obtaining a shape.

Rationale: The user engages in teaching geometric concept (Math shape) using the AR Geometry Application.
Originator: Project member

Fit criterion: The AR Geometry Application is required to provide notifications or display relevant information for every user action.
Customer satisfaction: 5 *Customer Dissatisfaction:5*

Priority: 4 *Dependencies:* Seven *Conflicts:* 0
Supporting Materials: Classroom and Smart Phones.

History: Creation

Figure 3.10: Requirement number 2

Requirement #: 3 Requirement Type: 2 Event/BUC/PUC#: 10,11

Description: User should select the markers commanded for obtaining a triangle and bring them in the front of camera view.

Rationale: The user can verify and identify Triangle properties on the display panel.

Originator: Project member
Fit criterion: The AR Geometry Application is required to display relevant information for every user action.

Customer satisfaction: 4 Customer Dissatisfaction: 4
Priority: 5 Dependencies: One Conflicts: 0

Supporting Materials: Internet, Smart Phones, Tablet, Classroom etc.
History: Creation

Figure 3.11: Requirement number 3

Requirement #: 4 Requirement Type: 9 Event/BUC/PUC#: 10,11,12

Description: The app forms a Triangle shape with a default color.
Rationale: The AR Geometry Application enable the user to verify and identify Triangle properties on the display panel.

Originator: Project member
Fit criterion: The AR Geometry Application is required to display relevant information for every user action.

Customer satisfaction: 5 Customer Dissatisfaction: 5
Priority: 5 Dependencies: One Conflicts: 0

Supporting Materials: Internet, Smart Phones, Laptops, Tablet, Classroom etc.
History: Creation

Figure 3.12: Requirement number 4

Requirement #: 5 Requirement Type: 9 Event/BUC/PUC#: 11,12,13,14

Description: The AR Geometry Application forms a Quadrilateral shape with a default color.

Rationale: The App enable the user to verify and identify Quadrilateral properties on the display panel.

Originator: Project member

Fit criterion: The AR Geometry Application is required to display relevant information for every user action.

Customer satisfaction: 5 Customer Dissatisfaction:4

Priority: 5 Dependencies: One Conflicts: 0
Supporting Materials: Classroom and Smart Phones.

History: Creation

Figure 3.13: Requirement number 5

Requirement #: 6 Requirement Type: 6 Event/BUC/PUC#: 1,3,4

Description: Users measure the angles formed by the corners of the shapes or the length of a side of a triangle.
Rationale: Users develop proficiency in measuring and understanding spatial dimensions, enhancing their mathematical skills.
Originator: Project member
Fit criterion: The smartphone must be in good working condition, and there should be a reliable internet infrastructure.
Customer satisfaction: 5 Customer Dissatisfaction: 5
Priority: 1 Dependencies: Five Conflicts: 0

Supporting Materials: Internet, Smart Phones, Tablet.
History: Creation

Figure 3.14: Requirement number 6

3.5 Producing Design Solutions ,Testing and Evaluating the Design

The design solutions evolved through a thorough examination of user scenarios, user stories, task analysis,and requirement specifications. The initial stages of product development in Unity commenced before the formalization of requirements. Following the establishment of requirements, the ongoing development of the product could proceed.

3.5.1 Concrete Design of Geometry Application

Concrete design refers to the tangible and detailed aspects of an application's appearance, feel, and function. The prototype mentioned below helped us envision how our application will look after final development.

3.5.2 Prototype

A prototype is a working model built to develop and test design ideas[104]. The prototype stage is where the design of the appearance of AR Geometry App is carried out and implements the idea to produce a visual display prototype in the form of low and high-fidelity wireframes[55]. Prototyping is a crucial phase in the design process, prompting designers to reflect on the created product. Testing the product early in the design process helps identify potential usability problems and ensures it aligns with user requirements. Given that low-fidelity prototypes may not resemble the final product, the preference in this research was to develop a high-fidelity prototype.

Wireframe Low-fidelity

A low-fidelity wireframe is a basic, simplified representation of the layout and structure of a digital interface.This paper prototype was created by drawing on white paper using a pencil.Given that low-fidelity prototypes may not resemble the final product, the preference in this research was to develop a high-fidelity prototype.The low-fidelity prototype for the AR geometry app was crafted using paper symbols, words, and pictures.

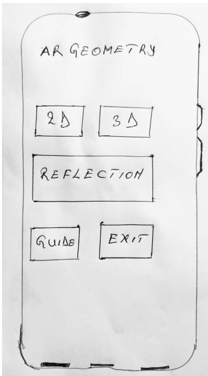


Figure 3.15: Paper prototype

Wireframe

A high-fidelity wireframe is a more detailed and polished form of the design that includes specific visual elements, layout, and sometimes even interactive features and is closer to the final look and feel of the product.

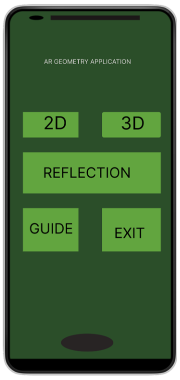


Figure 3.16: prototype

A high-fidelity prototype closely resembles the final product and can be constructed using production or digital tools to advance the high-fidelity prototype, Unity 3D and Vuforia were chosen as the development tools, employing the C# programming language.

3.5.3 Conceptual Model

A conceptual model describing how a system is organized and operate, therefore provides the designer outlining what the interface must deliver to the user,defining the appearance and functionality of objects and actions, as well as preserving the relationships inherent in the design[45].

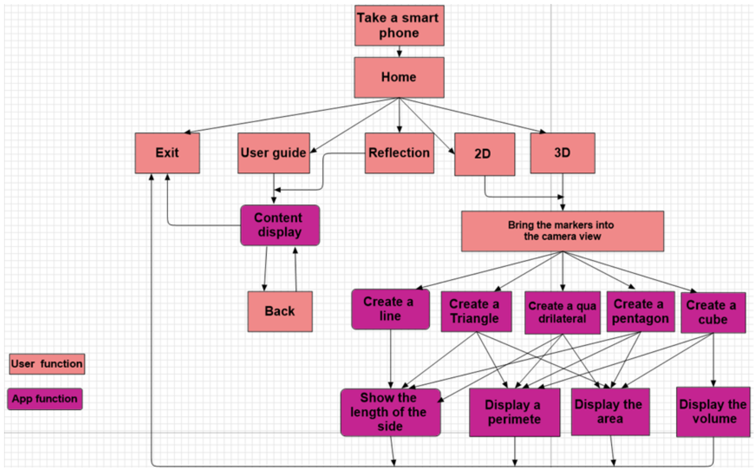


Figure 3.17: Conceptual model

This conceptual model plays a crucial role in shaping the user interface of an application by defining not only user functions but also the broader spectrum of application functions. It serves as a guiding framework that influences the design decisions, ensuring a cohesive and intuitive experience for users as they interact with both the application's features and their own specific functionalities.

3.5.4 Design and Development

To develop user-friendly and effective Augmented Reality (AR) application prototype, we diligently apply design principles and adhere to human interface design guidelines. As advocated by Steve Krug in his book 'Don't Make Me Think'[53], users generally tolerate a series of clicks if each interaction is smooth, and they maintain confidence in their navigation. This underscores the importance of placing the user at the center of the design process, understanding their needs, preferences, and behaviors. In our design approach, we have implemented these principles to create an intuitive and satisfying user experience.

- **Naturalness**

User interfaces that you interact with using modalities such as touch, gestures, or voice are often referred to as natural user interfaces (NUI). In our AR Geometry applications, this principle manifests through the inclusion of several touch-responsive buttons, providing users with intuitive controls for navigation and interaction.

For example, this AR Geometry app prototype , contains five control buttons, which are the following:

• 2D button • 3D button • Reflection button • Guide button • Exit button.

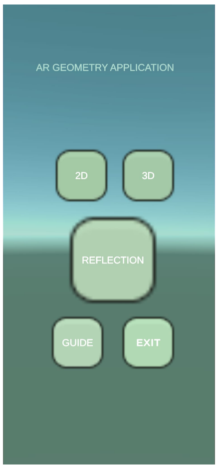


Figure 3.18: User Interface elements

- **Strong Visual Hierarchy**

The article by Oleksandr Koza[52] explains what a strong visual hierarchy is and how it helps the user understand the order in which the visual elements on the screen should be viewed. It allows setting the sequence and smoothly directing the user's view from one interface element to another. With a weak visual hierarchy, the interface looks overloaded and confused.
The application of this principle in our AR Geometry app is defined through careful consideration on creating a clear layout that guides users' attention to the most important elements and actions. This can be achieved by prioritizing important elements, using size and scale to emphasize them, using contrast to create visual distinction, incorporating abundant white-space to give them room to breathe, choosing colors and typography styles strategically to reinforce the hierarchy, maintaining consistency throughout the app, and progressively revealing information and features as users interact.

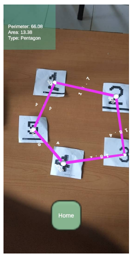


Figure 3.19: Marker Recognition with strong visual hierarchy

To advance the high-fidelity prototype, Unity 3D and Vuforia were chosen as the development tools, employing the C# programming language. This prototype is designed to operate seamlessly on Android smartphones.

- **Consistency**

Consistent UI allows users to transfer existing knowledge to new tasks, master new aspects faster, and focus on solving the problem, rather than waste time understanding the differences in the use of certain controls, commands, etc. By ensuring the continuity of previously acquired knowledge and skills, consistency makes the interface design recognizable and predictable.
The application of this principle in our AR app maintains a consistent approach for selecting markers. This continuity extends to dragging and dropping these markers in front of camera view in the real environment. The use of exit , next or back buttons remains uniform across all windows or scenes, ensuring simplicity and memorability in the steps required to fulfill actions. The user experience is designed to be both straightforward and consistent throughout the app.

- **Friendliness and Forgiveness**

An effective interface should support any error that can be made by the user, either by mistake or accidentally. It is better if the user has the opportunity to cancel or correct the actions performed. A friendly interface should prevent situations that are likely to result in errors. The UI design should also be able to adapt to potential user errors and facilitate the process of eliminating the consequences of such errors. In this AR Geometry app prototype, there are no negative consequences associated with incorrect drawings or the misuse of predefined buttons. Users can explore and experiment without fear of adverse outcomes, fostering a user-friendly and forgiving environment.

- **Step-by-step Information Flow**

The screen has to show only the necessary information. If a person has to make a choice, it has to provide enough information to make a decision and proceed with details on the following screens. There is no need for unnecessary details all at once. In this AR Geometry app prototype, the interface displays the essential elements required to accomplish a task.

- **Interaction**

Interaction in human-computer interaction (HCI) design involves the interaction between users and digital systems[55]. Key aspects include the user interface (UI), user experience (UX), interaction, feedback, usability, navigation, accessibility, and gestures. UI is the point of contact, UX is the overall experience, interactivity is the degree of user control, feedback is clear and timely, usability ensures intuitive, efficient, and error-resistant interactions, navigation is the structure and flow, accessibility is inclusive, and gestures and touch interaction are essential for touchscreens.
In this AR Geometry app prototype, users can interact with the real world and virtual objects, aligning the system seamlessly. The interfaces are designed to execute specific tasks, from constructing shapes to getting calculations, and their effectiveness is computable.

Teachers' tasks or activities include planning a comprehensive lesson on 1D,2D and 3D shapes using visualization tools like the AR geometry application. This lesson should incorporate engaging activities that encourage students to identify, manipulate, and calculate properties of virtual geometric shapes. Additionally, teachers should prepare a model of a geometric shape before the lesson to facilitate hands-on learning. This model will aid in side measurement, angle measurement, area calculation, perimeter calculation, volume computation, and geometric object manipulation. By providing these resources, teachers enable learners to distinguish between surface area and volume of shapes, fostering skills applicable to careers in design and packaging. Moreover, teachers should engage learners in various activities to spark interest and encourage innovation. These activities allow learners to visualize different types of shapes(solids), design common shapes, and calculate the materials required. It's essential to focus on active learning strategies, ensuring that learners actively participate in tasks to enhance their understanding and retention of concepts. Our commitment to user-centric design is evident in the reduction of clicks required to reach the target. Each user interface (UI) element is thoughtfully defined, enhancing attractiveness and functionality. Significantly, there is no risk of negative consequences arising from the misuse of UI elements, contributing to a smoother and more enjoyable user interaction.

Enhancements in the AR Geometry Application for Teaching and Learning Geometric Concepts in Mathematics

Building upon the existing application GeometriaRA, as detailed in Chapter 1, we have developed a prototype known as the AR Geometry Application. This application is specifically designed to assist in teaching and learning geometric shapes, with the primary objective of increasing teacher engagement, self-efficacy, and satisfaction, ultimately contributing to heightened intrinsic motivation, as outlined in the main goal of this study.

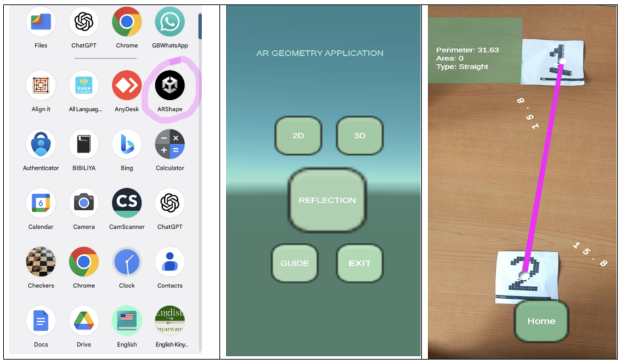


Figure 3.20: All Scenes from Final Prototype

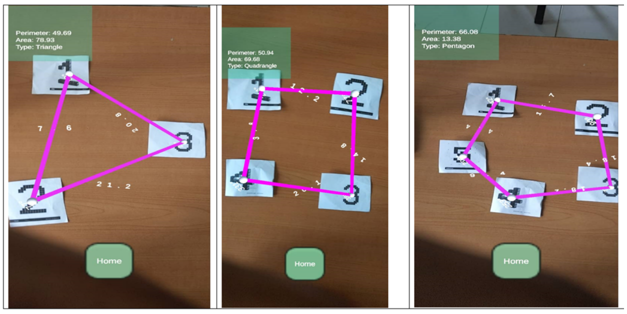


Figure 3.21: Polygone Screen Shoot from Final Prototype

Cube shapes are widely utilized across various fields like furniture design, packaging, and gaming, where they maximize storage space and feature prominently in games and puzzles. In mathematics education, cubes serve as vital tools for teaching geometry principles such as volume and symmetry, facilitating hands-on exploration and problem-solving. Points, angles, and polygon shapes serve as foundational elements across disciplines, informing structural calculations in architecture and spatial relationships in design. Beyond mathematics, they find practical applications in fields such as computer graphics and engineering, underpinning advancements in computer-aided design and geographic information systems.

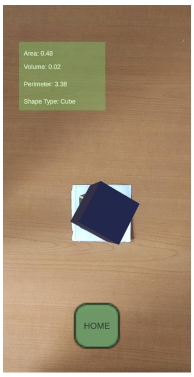


Figure 3.22: Cube Screen Shoot from Final Prototype

As depicted in the screenshot above, our focus is on enhancing the application by introducing the following features:
Interactivity: Enabling users to engage with 1D,2D and 3D geometric shapes (Lines, triangles, quadrilaterals, pentagons, and cubes) through manipulation, rotation, and resizing. This improvement aims to facilitate a deeper understanding of the properties, such as length, side, perimeter,

area, and volume, associated with these shapes.
Shape Creation: Achieved through marker scanning, enhancing the process of creating geometric shapes within the application.

Performing computed calculations on shape properties such as perimeter, area, side length, and volume offers multifaceted benefits to students. It fosters conceptual understanding, problem-solving skills, mathematical proficiency, real-world application, preparation for advanced topics(such as estimation), and career readiness. Through these calculations, students grasp geometric concepts more deeply and apply mathematical operations in practical contexts, strengthening their ability to solve real-world problems. Moreover, computed calculations provide opportunities for learners to verify their manual calculations, enhancing accuracy and understanding. Mastery of shape properties serves as a solid foundation for mastering shape properties serves as a solid foundation for addressing more complex geometric concepts and is essential for careers in architecture, engineering, design, manufacturing, and construction. Ultimately, computing shape properties empowers students to develop a comprehensive understanding of geometry, sharpen problem-solving abilities, and prepare for future academic and professional opportunities.

Figure 3.23: Marker one

Figure 3.24: Marker two

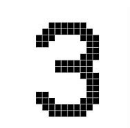


Figure 3.25: Marker three

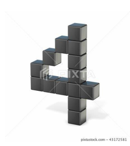


Figure 3.26: Marker four

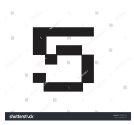


Figure 3.27: Marker five

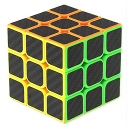


Figure 3.28: Marker six

These markers were chosen for their distinct patterns or shapes, which facilitate accurate detection and tracking by the phone camera.

3.5.5 Test and Evaluate the Design

Design solutions need to be evaluated to check if they meet the requirements. In a human-centered design (HCD) process, the design solutions have to be evaluated to check if they meet the user requirements. Since HCD is iterative in principle, user testing is expected to take place at different steps of the process, including user testing of the design idea itself but also towards the final stages of design.

Referring to the DECIDE framework, a valuable checklist for planning an evaluation study, it involves determining goals, exploring questions, choosing evaluation methods, identifying practical issues, deciding on ethical considerations, and evaluating, analyzing, interpreting, and presenting data[56]. Many factors need consideration during the conduct of an evaluation of the current study design , including:

- The goals of the study;
- Involvement or not of users;
- The methods to use;
- Practical & ethical issues;
- How data will be collected, analyzed & presented.

3.5.6 Involvement of Users:

Users should actively participate in the evaluation process in a usability study and in the whole application design process for this AR mobile app, involving users and they have to perform specific tasks then after provide real-time feedback.
To involve users in testing, researcher use purposive sampling techniques to determine the participants for the testing process, as well as user observation,survey and interview techniques for data collection[42].

3.5.7 Evaluation Approach and Method

Considering the goals and nature of the project, methods such as survey, interview, observation, and usability testing have been utilized in the evaluation process.

Interviews, as a qualitative research method, rely on asking questions to collect data involving two or more people one being the interviewer and the other being the interviewee[77]. These user interviews offer valuable insights into users' identities, experiences, needs, values, and desires. Observation was used to provide vast data for analysis, with digital recording aiding in playing a crucial role in understanding the current state of a system[6], identifying challenges, and informing the design process.Surveys method involves questionnaire with close-ended questions which have been sent to a chosen sample of respondents[44];this helped us understand participants' opinions, attitudes, and perceptions regarding the use of AR application software.
Five mathematics teachers were recruited as participants for the user test. The recruitment took place via e-mails and Whats-App platforms.Specific times, days, and locations were mutually agreed upon for each participant to conduct the test, ensuring a structured and organized approach to the evaluation process.

For the usability testing method, the evaluation adhered to user-based testing utilizing well-established tools like the Usability Test Plan Dashboard. Assessing the effectiveness (PEU and PU) of the AR Geometry Application, usability testing may include observing how the user navigates the interface and comprehends the content or context of its use. Additionally, usability testing encompassed conducting interviews to gather feedback on the user experience with the AR application software.

Usability Test for Geometry App Prototype

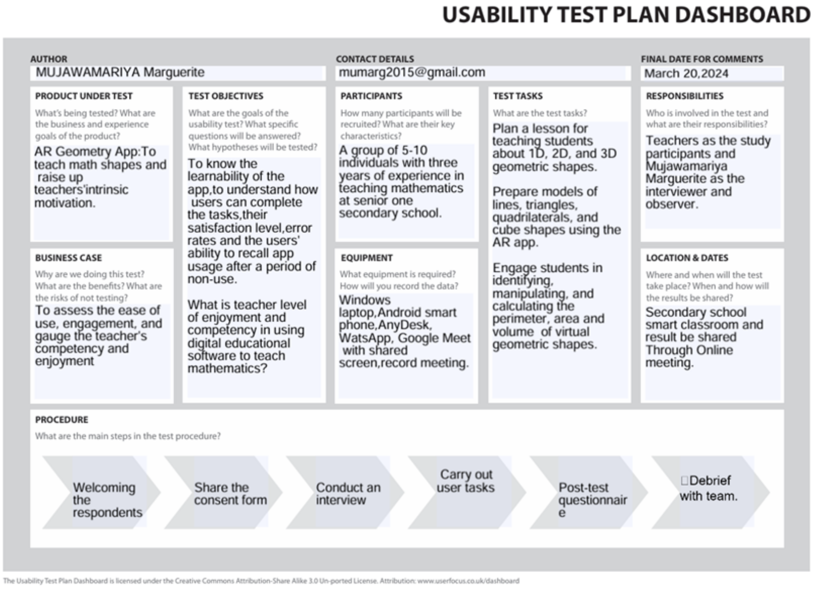


Figure 3.29: Usability test plan dashboard

3.5.8 How Data was Collected, Analyzed & Presented

In this research study, the main tools utilized for data collection included document review, observation, interviews, and surveys, as discussed in more detail in the previous section.
Thematic analysis techniques for analyzing qualitative data entail identifying and analyzing recurring patterns within the data. These techniques aid researchers in comprehending complex phenomena and deriving insights from contextually embedded data, facilitating a deeper understanding of participants' experiences[9]. The data was presented and manipulated using application software such as MS Word, MS Excel,and NVivo.

3.5.9 Practical & Ethical Issues

Various constraints, such as time limitations and respondent availability, have been taken into account. Ethical considerations, including user privacy and obtaining informed consent, have also been addressed.

To address the mentioned issues, the researcher has implemented the following strategies:
Time Constraints:
The prepared questionnaire has been designed to be answered within 10 minutes to mitigate time limitations.

Survey Implementation:
Conducting the survey with teachers is done online to overcome practical constraints and reach a diverse sample.

Interviews :
Interviews with teachers have been conducted on the school laboratory, minimizing practical constraints and ensuring a more diverse participant pool.

Ethical Considerations:
Ethical considerations involve anonymizing and protecting user data to safeguard privacy and ensure informed consent.

3.5.10 User Tests

The researcher conducted a usability test to evaluate the user experience and identify system usability issues of our AR Geometry App across three distinct iterations. The primary objectives were to pinpoint potential usability problems, align the system with user requirements in both low and high-fidelity prototypes, gather user feedback, and assess the overall system usability. This assessment aimed to gauge system performance, user satisfaction, and system learnability in achieving user goals across Iteration 1 ,Iteration 2 and Iteration 3.

3.5.11 Procedure

For iteration 1 of the low-fidelity prototype, five participants were recruited. Subsequent iterations involved a new group of 10 participants, divided into two groups of five for iterations 2 and 3, which tested the high-fidelity prototype. Participants performed specific tasks, and their interactions were observed. Interviews were conducted in all iterations, and the System Usability Scale (SUS) questionnaire was administered in Iteration 3.

In a series of iterative user testing sessions, fifteen participants were engaged. Iteration 1, focused on the low-fidelity prototype, involved five participants. Iteration 2, also with five participants, continued testing with the high-fidelity prototype. Finally, Iteration 3, with five participants, further explored the high-fidelity prototypes. Recruitment was conducted through social media platforms like WhatsApp and email, ensuring diverse representation across various age groups.

The high-fidelity prototype user testing sessions comprised ten participants, divided into two phases. Initially, five individuals participated in the initial user test. Subsequent modifications were made for the following prototype iteration, and an additional five participants tested the refined version. Recruitment was facilitated through social media channels(WhatsApp and email).

Participants were instructed to independently access the high-fidelity prototype, following provided instructions on application installation and specific areas to focus on during testing. After the testing phase, participants completed a questionnaire utilizing a Likert scale with five levels (ranging from "Strongly Disagree" to "Strongly Agree") to evaluate application usability. The questionnaire covered standard usability statements addressing factors such as application complexity and the need for technical assistance. Participants were encouraged to provide detailed comments in a text field, addressing research questions, motivational aspects, and suggestions for improvements. Additionally, participants were prompted to report any encountered bugs. Subsequent to the initial testing round, iterative adjustments were implemented based on feedback received through the questionnaire.

3.5.12 Tasks:

Tasks include planning a lesson to teach students about 1D, 2D, and 3D geometric shapes, creating models of lines, triangles, quadrilaterals, and cubes using the AR app, engaging students in identifying ,measuring and manipulating virtual geometric shapes, and constructing shapes by placing markers in front of the phone camera. These tasks are designed to evaluate both low and high-fidelity prototypes for user interface and functionality. As a result, users can explore the various properties and characteristics of the shapes. They can rotate the shape to examine it from different angles, measure its dimensions such as length, width, and height, calculate its area, perimeter, and volume, and even manipulate it further to understand how changes affect its properties. Additionally, users can compare the created shape with other geometric shapes or real-world objects to deepen their understanding and enhance their learning experience.

3.5.13 Evaluation from the Low-Fidelity Usability Test

Iteration 1: Low-Fidelity Prototype User Tests

In Iteration 1 of the low-fidelity prototype user tests, users encountered difficulties with system interaction, resulting in confusion. These issues included unresponsive navigation paths, making it challenging for users to perform actions or navigate between screens. In addition, the prototype lacked interactivity, limiting dynamic engagement and exploration. This static nature hindered users from fully experiencing the app's features. Enhancing interactivity by incorporating dynamic elements and addressing navigation inconsistencies is crucial for improving usability and user experience.These issues significantly diminish the user experience, negatively impacting it by 67% however,positive feedback included appreciation for the project.

Figure 3.30: Low fidelity user test

Iteration 2: High -Fidelity Prototype User Tests

Improved navigation observed, with users finding features more intuitively. However, some users reported issues with font size, background colors in certain scenes, and difficulties in accurately placing markers within the AR environment. Common themes included a desire for clearer icons, and concerns about font size.High-fidelity users expressed greater satisfaction with the overall layout and navigation.

Iteration 3: High-Fidelity Prototype User Tests

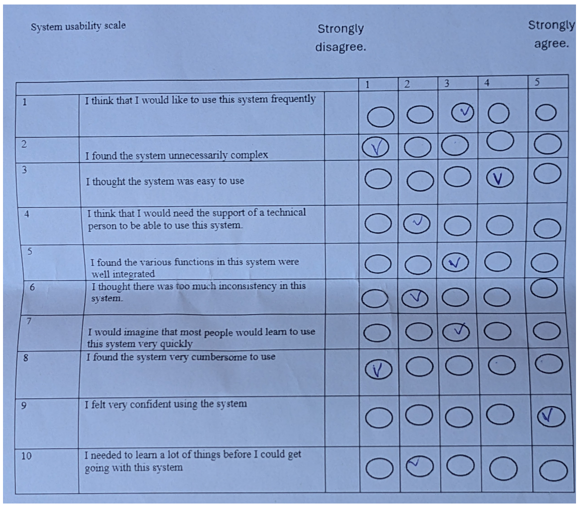
Streamlined on boarding reduced user confusion significantly. In Iteration 2, users expressed satisfaction but emphasized the importance of feature accessibility.
SUS Questionnaire: High Fidelity SUS Score: 80, showing a significant improvement in perceived usability.

Figure 3.31: High fidelity user test

Teachers can enhance their teaching by utilizing the AR app to plan engaging lessons that incorporate 1D, 2D, and 3D geometric shapes. They can prepare models of various shapes using the app and guide students in identifying, manipulating, and calculating the properties of these virtual shapes. Additionally, teachers can encourage students to construct geometric shapes by placing markers in front of the phone camera and checking the properties of overlaid shapes. These activities promote active learning and a deeper understanding of geometry concepts. By integrating AR technology into their teaching practices, teachers can create interactive and visually stimulating lessons, increasing student interest and retention of geometric concepts while also fostering their own professional growth and staying updated with educational trends.

Pre-test Interview: A brief pre-test interview was conducted to determine participants' familiarity with immersive technology and favored methods of instruction. Three questions addressed participants' digital device use, teaching methods for mathematical concepts, and frequency of using digital methods in teaching.

Post-test Interview: A thorough semi-structured interview was conducted to gain a deeper understanding of participants' experiences, provide clarifications, and inquire about reasons for specific behaviors. This interview supplemented survey responses and assessed user experience using the SUS questionnaire[10] as illustrated by the feedback from a participant in the figure below.



System usability scale

		Strongly disagree. 1	2	3	4	Strongly agree. 5
1	I think that I would like to use this system frequently			✓		
2	I found the system unnecessarily complex	✓				
3	I thought the system was easy to use				✓	
4	I think that I would need the support of a technical person to be able to use this system.		✓			
5	I found the various functions in this system were well integrated			✓		
6	I thought there was too much inconsistency in this system.		✓			
7	I would imagine that most people would learn to use this system very quickly			✓		
8	I found the system very cumbersome to use	✓				
9	I felt very confident using the system					✓
10	I needed to learn a lot of things before I could get going with this system		✓			

Figure 3.32: System usability scale

3.5.14 Results from Usability Test:

Various bugs were identified during user tests, such as compatibility issues with certain Android versions and marker size challenges. Bugs were documented and addressed promptly, showcasing a commitment to enhancing overall user experience. The test lasted for 30 minutes, during which participants constructed various shapes.

The transition from low to high fidelity led to notable improvements, particularly in navigation and overall user satisfaction. Feedback from interviews aligned with quantitative data, emphasizing the importance of visual elements like font size and scene colors.

The iterative design process from low to high fidelity prototypes effectively addressed early usability issues. User preferences for clearer icons, background colors for each scene, and font size considerations are crucial for future refinements.

In conclusion, the comparative usability tests across three iterations underscore the project's iterative design approach, illustrating tangible improvements in user experience. The iterative approach from low to high fidelity prototypes demonstrated significant enhancements in overall usability and user satisfaction. Ongoing attention to user feedback guided future refinements, ensuring the continuous improvement of the AR Geometry app.

3.5.15 Analysis of Data from Observation

Participants were provided with smartphones containing the installed prototype of the application and were directed to execute user tasks while under observation. Observations played a crucial role in evaluating whether the prototype met its objectives. Often complementing interviews during user testing, observations involved recording participant statements, actions, and assisting them in overcoming any encountered obstacles.

The researcher(observer) noted participants' actions and verbal expressions, providing assistance whenever necessary or in instances where participants faced challenges in proceeding. Observing 10 users testing a prototype for an AR Geometry application, designed to enhance the teaching of mathematics and improve the context of use to boost teachers' engagement and satisfaction in teaching the subject. All users successfully completed the assigned tasks, including shape formation and navigating application elements, within the allocated 30 minutes. Navigation ease, rated on a scale from 1 to 4, varied among users, with four participants giving a score of 4, another four providing a rating of 3, and two users assigning a score of 1.

Notably, four users reported similar positive experiences, encountering no issues during the testing process. However, the remaining six users, while finding the application generally easy to navigate, raised a common concern regarding the cube construction shape process, indicating a need for further clarification in that specific aspect of the application. This observation suggests an overall positive response to the prototype, with a focused area for improvement identified to enhance the user experience, particularly in cube construction.

Chapter 4

RESULT ANALYSIS

4.1 Introduction

This chapter includes study findings about the exploring teachers' intrinsic motivation to utilize digital educational technology for teaching mathematics in Rwanda in the context of secondary education institutions. Due to constraints in time and budget, coupled with the need for in-depth insights from mathematics teachers with a minimum of three years of experience, we opted for a purposive sampling approach. This method allowed us to efficiently select participants who met specific criteria relevant to the study's objectives.This method facilitated the creation of a targeted and representative sample consisting of 28 secondary school teachers. The focus was specifically on those teaching mathematics at the senior one level in the Gacurabwenge, Rugalika, Musambira,Ngamba and Rukoma sectors of Kamonyi District, Rwanda, as indicated in figure 4.1.

Kamonyi District				
Sector/Schools				
Gacurabwenge Sector	Rukoma Sector	Rugalika Sector	Musambira Sector	Ngamba Sector
GS Sancta Maria	Gs Remera Rukoma	GS Sheli	GS Bitsibo	GS Ngamba
GS St Jean Bosco kamonyi	GS Bugoba	GS Gihara	Gs Wimana	GS Masogwe
Rosa Mystica secondary school	GS Kabuga Icyerekezo	GS Kiboga	ES Musambira	GS Kabasare
GS Gacurabwenge	GS Muhehe Icyerekezo	GS Masaka	GS Gihembe	
GS Gatizo	GS Muhondo	GS Rugalika	GS Mpushi	
GS Kagarama	GS Nyarubuye	ES Karama		
GS Kigembe	GS Murehe Protestant			

Figure 4.1: Sectors/Schools.

The purposive sampling aligns with the research objectives while mitigating potential delays and expenses associated with broader or more extensive sampling methods was used. This strategic approach ensures that the study remains viable within the specified resource constraints, optimizing the utilization of time and financial resources without compromising the research's validity and relevance.

The study involved 28 secondary school teachers from 28 schools, each with three years of experience in teaching mathematics at the senior one level, as indicated in Figure 4.1. Among them, 15 teachers participated in interviews and tests, while 15 provided survey responses. Reading material was also utilized to gather necessary data for this study. The primary objective of this research is to delve into teachers' intrinsic motivation in utilizing digital educational technology for teaching mathematics. Augmented reality geometry applications were selected as the preferred technology, enabling the researcher to address pertinent questions related to human problems by creating innovative artifacts, such as the AR geometry app. This approach contributes to the generation of new knowledge within the scientific evidence framework.

4.2 Comprehensive Analysis of Teachers' Motivation Across Educational Software Utilization in Teaching Mathematics

From the respondent's perspective, common themes, such as teaching materials,demotivating factors, motivation factors, positive mindfulness , and engagement, have been identified and developed. These thematic categories have proven instrumental in organizing the codes frequently employed to encapsulate the essence of the participant's experiences.

4.2.1 Identification of Motivational Factors

These motivation factors are highlighted from existing studies:Passion for the teaching profession commitment to academic integrity, psychological comfort within the school environment, affection for children and students engagement, adherence to religious principles, sense of duty towards serving the community, recognition of the significance of environmental and social factors, and positive impact of performance feedback[68][83].
As indicated in the figure below, 60% of respondents derive motivation from a passion for teaching, fostering a positive influence, and enhancing student engagement and performance. Meanwhile, 13% cite motivation linked to improved compensation, recognition, appreciation, and the avoidance of punitive measures. Additionally, 34% express motivation through innovation, creativity, professional growth, and personal satisfaction. Another 13% of respondents find motivation in all the aforementioned motivation factors, with an added emphasis on control, supervision, and the avoidance of punishment.

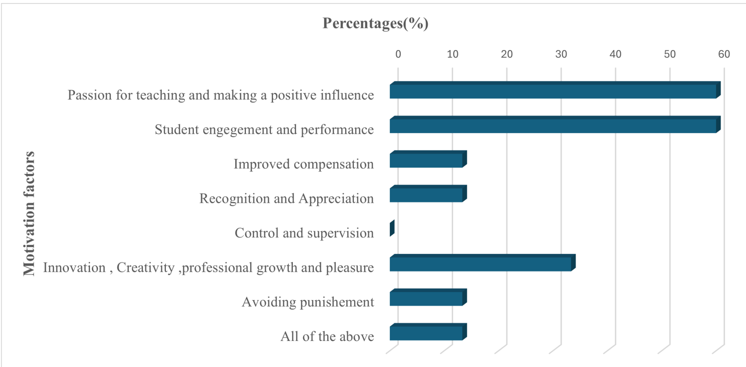


Figure 4.2: Motivation factors

Motivation factors can be categorized into internal and external factors, which influence either intrinsic or extrinsic motivation. Internal factors include passion for teaching, desire to make a positive impact, innovation, adherence to religious principles, creativity, professional growth, and personal satisfaction. External factors encompass avoidance of punishment, control and supervision, student engagement and performance, improved compensation, recognition, and appreciation. According to the respondents, all of these factors except for control and supervision can influence their motivation.

4.2.2 Digital Educational Devices for Enhanced Learning

The common reason behind respondents' responses during interviews, when asked about the digital devices they use in their daily activities, stems from their shared objective of enhancing their technology skills to improve their effectiveness in teaching mathematics. Additionally, survey responses indicate that each participant has utilized various technological tools or devices in their educational practices. This consensus stems from their acknowledgment of the prevalent role of technology in today's world, as reflected in the diagram 4.3 below, where everyone demonstrates proficiency in using technology devices. The analysis of participant data revealed a predominant preference for utilizing laptop or desktop computers, with a notable 87% of respondents indicating such usage. The prevalence of this choice suggests a familiarity and comfort level with traditional computing devices among the participants. Notably, it was surprising to identify an individual who exhibited familiarity with interactive whiteboard technology and its applications. This finding underscores the diverse technological backgrounds and experiences within the participant group, offering valuable insights into their technological preferences and competencies.

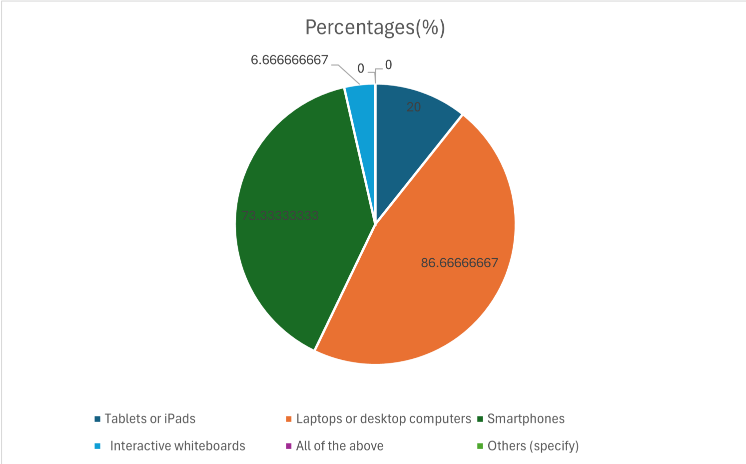


Figure 4.3: Digital devices

4.2.3 Methods and Materials for Visualizing Geometric Concepts in Teaching

As depicted in the figure 4.4 below, 87% of respondents utilize visual aids and charts. Additionally, 47% incorporate educational videos and animations, while 13% employ geometry software and simulations. Another 7% of participants utilize interactive software applications and interactive whiteboard applications in their teaching practices.These teaching methods prove effective in translating abstract mathematical concepts into tangible forms, fostering a more profound understanding of geometric principles.

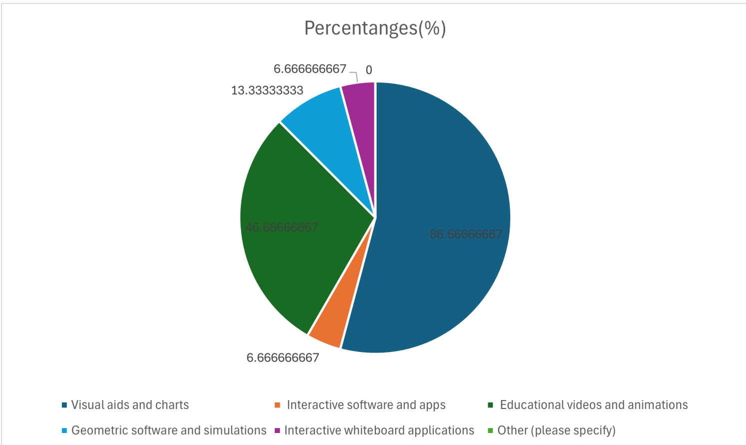


Figure 4.4: Methods do you use to teach mathematical concepts

This result indicates that a small percentage of respondents use educational interactive software to teach geometric concepts in mathematics courses. Specifically, 7% of respondents, represented by 1 out of 15 respondents, utilize interactive software and applications, while 13%, represented by 2 out of 15 respondents, employ geometric software and simulations.

4.2.4 Frequent Use of Digital Visual Methods in Teaching Mathematical Concepts

While all respondents demonstrated the capability to utilize visual aids, charts, interactive software applications, educational videos, animations, geometric software, simulations, and interactive whiteboard applications as potential methods for teaching mathematical concepts, the figure 4.5 below illustrates variations in frequency. Specifically, 73% (11 out of 15) of teachers reported employing these methods most days, 13% (2 out of 15) used them once per month, 7% (1 out of 15) utilized them every day, and another 7% (1 out of 15) incorporated them once per week.

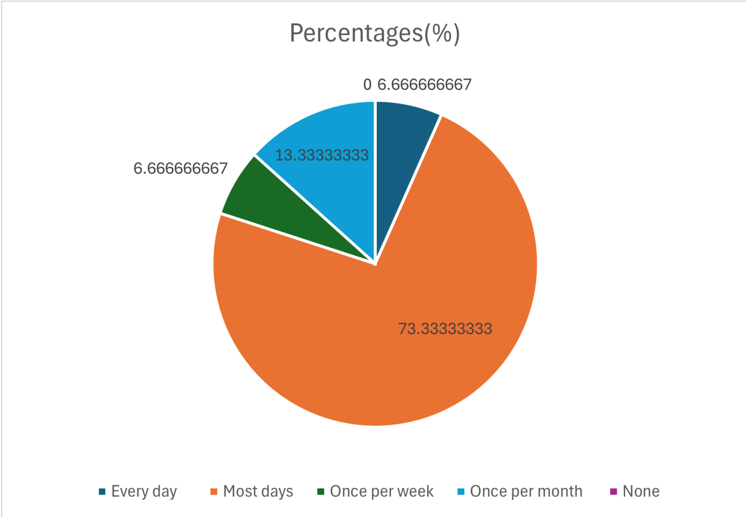


Figure 4.5: Frequency of Digital Visualization methods Utilization

This underscores visual aids, charts, educational videos, and animations as the predominant methods utilized in teaching mathematics, with the majority of educators incorporating these tools into their teaching practices. This trend is evident from the findings presented in figure 4.4 and 4.5.

4.2.5 Satisfaction with Digital Teaching Methods in Mathematics

On a scale from 1 (not satisfied) to 6 (very satisfied), respondents were asked about their satisfaction with the digital teaching methods mentioned for teaching mathematics and the figure below indicates their responses.

The diagram 4.6 in the research reveals that, following the utilization of visual aids, charts, interactive software applications, educational videos, animations, geometric software, simulations, and interactive whiteboard applications as potential methods for teaching mathematical concepts, 60% of teachers express very satisfaction at a value of 5 on the scale ranging from 1 (not satisfied) to 6 (very satisfied). Additionally, 13% report being extremely satisfied with a value of 6, 7% are neutral at a value of 3, and another 7% express satisfaction at a value of 4 on the same scale.

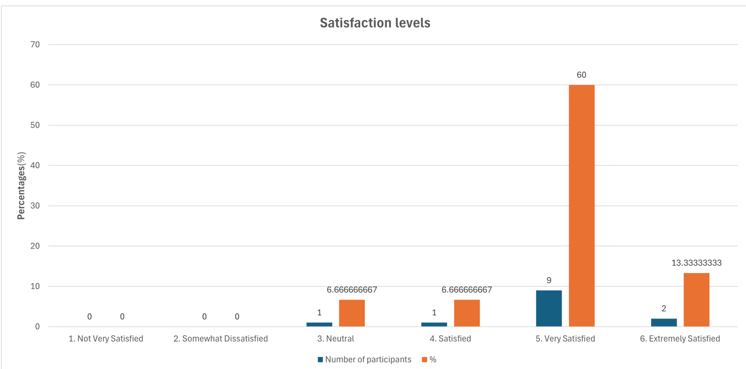


Figure 4.6: Assessment of satisfaction

4.2.6 Teacher's Enjoyment with Digital Educational Technology in Math Teaching

In NVIVO analysis, percentages represented the occurrence of specific themes within the data, participant responses across different categories or themes, or the level of agreement or disagreement on specific issues. For instance, Figure 3.3 illustrated categories such as enjoyment, satisfaction, dissatisfaction, competence, and autonomy among teachers in using digital educational technology to teach mathematics. While figures 4.3, 4.4, 4.5, and 4.6 illustrated categories such as autonomy, competence, frequency of digital device utilization, and satisfaction derived from digital teaching methods in mathematics instruction, respectively. The measurement of enjoyment typically relied on Likert scales, where participants rated their enjoyment level from "Strongly Disagree" to "Strongly Agree," or through qualitative descriptions during interviews and observations. NVIVO calculated percentages based on the frequency of codes or themes related to enjoyment. For instance, if "enjoyment" was coded in segments of text, NVIVO computed the proportion of segments coded as "enjoyment" relative to the total number of segments analyzed. These percentages offered insights into the significance of enjoyment as a theme within the data.
User testing and interviews detail high ease of use and satisfaction with the AR Geometry App Prototype as outlined in Chapter 3. However, Fig 4.7 illustrates that the enjoyment level of using digital educational technology for teaching mathematics remains low for each participant.
Figure 4.7 illustrates the varying levels of enjoyment among the respondents throughout the sample.

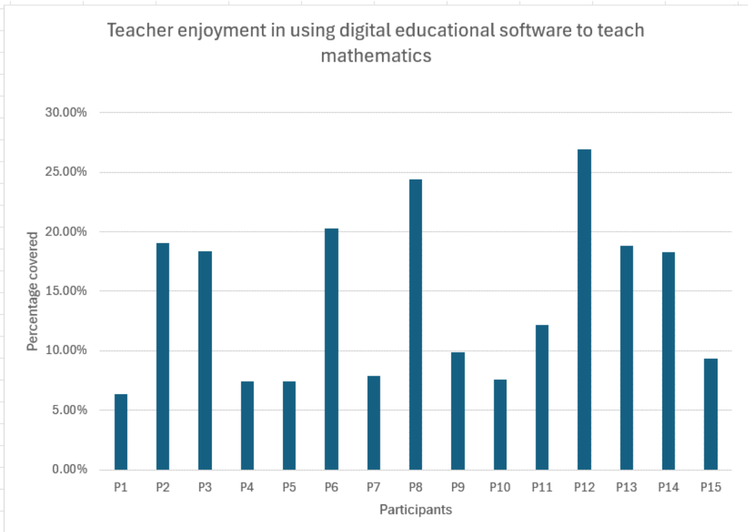


Figure 4.7: Teacher's levels of enjoyment.

The results from the user test suggest that while respondents (teachers) derive enjoyment from using the developed AR Geometry application prototype, their satisfaction with the existing digital teaching methods for mathematics instruction is lacking. Hence, there is a pressing need to adopt AR Geometry application software, given its efficacy in visualizing geometric concepts. Additionally, there is a call to evaluate the current technology utilized by teachers in teaching mathematics and to make decisions accordingly, such as enhancing technology training practices. According to the above figure, almost all respondents have a low level of enjoyment from their use of software designed for teaching mathematics. From the first respondent to the last one, none has at least 50% satisfaction or enjoyment from these mathematics software.

4.2.7 Teacher's Competence with Digital Educational Technology in Math Teaching

The percentages of competency levels calculated by NVIVO represented the proportion of coded segments related to competency within each respondent's data. These percentages provided insights into competency distribution and helped identify trends. However, to understand competency fully, specific criteria such as subject matter knowledge, teaching techniques, and technological proficiency were considered. The calculation was based on the frequency of codes or themes associated with competency, helping quantify the prevalence of competency-related themes within the dataset. Tasks were assigned for teachers to test the prototype aligned with specific competencies being measured, such as technology integration in mathematics instruction. Tasks included planning lessons, creating virtual models, and facilitating interactive activities. Each task assessed different aspects of competency, such as technological proficiency and adaptability in teaching strategies. By aligning tasks with desired competencies, researchers could effectively evaluate the prototype's impact on teacher performance and identify areas for improvement.The competency levels varied among the respondents, as depicted in the figure below.

In line with prior research, the fulfillment of fundamental psychological needs specifically, the need for competence, relatedness, and autonomy proves to be pivotal in providing satisfaction, enjoyment, and capability for educators in their teaching practices. However the majority of participants articulate their levels of competence as low. A notable correlation observed an increase in competence corresponds to an increase in enjoyment and autonomy.

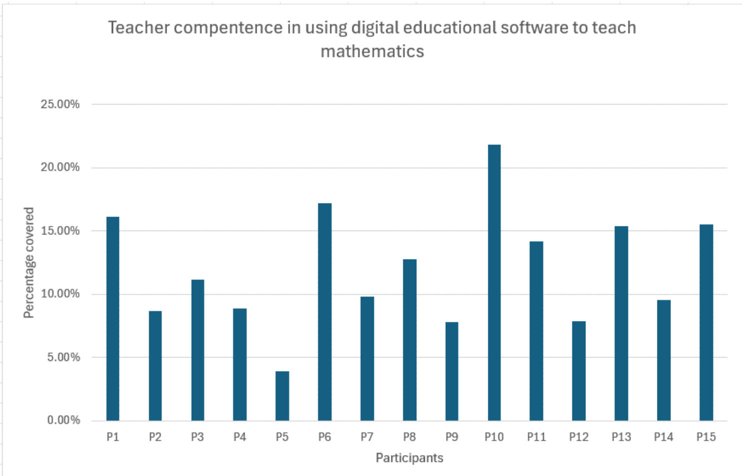


Figure 4.8: Teacher's level of competence.

4.2.8 Teacher's Autonomy with Digital Educational Technology in Math Teaching

To determine the autonomy level, NVIVO software was utilized to code teaching materials and methods used in mathematics instruction. These codes and themes categorized information related to teachers' freedom to choose specific technological tools and pedagogical methods for enhancing learning and teaching performance. NVIVO was employed to analyze qualitative data and calculate percentages for each participant's autonomy level. The percentages represent the proportion of coded segments related to autonomy within each participant's data. Autonomy was measured based on the frequency of codes or themes associated with teachers' freedom to choose teaching tools and methods. The calculation basis involved determining the total number of segments coded for autonomy relative to the total number of segments analyzed, providing insights into the prevalence of autonomy-related themes within the dataset. The autonomy levels of the respondents varied across the sample, as illustrated in the figure below.

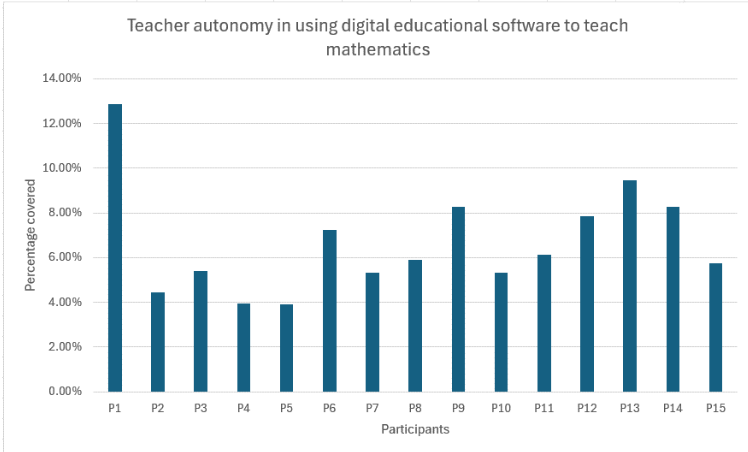


Figure 4.9: Teacher's level of autonomy.

The findings indicate that respondents are familiar with certain technological devices and educational interactive software, yet their frequency of use remains low. While they utilize visual aids tools in teaching mathematics, the adoption of technology software for the same purpose is still limited. Moreover, their level of selecting which software to adopt for teaching is minimal, suggesting that awareness of developed software and its context of use is limited to a few individuals. Consequently, there is a pressing need for updates on newly developed technological software, tools, devices, and their contexts of use.

4.2.9 Digital Teaching Methods' Contribution on Mathematics Learning

This diagram 4.10 demonstrates that 47% of teachers strongly agree that the utilization of visual aids, charts, interactive software applications, educational videos, animations, geometric software, simulations, and interactive whiteboard applications as potential methods for teaching mathematical concepts contributes to students' learning in their classrooms. Another 47% agree with this statement, while 7% of teachers remain neutral on the impact of utilizing these methods on students' learning in their classrooms. This indicates that respondents recognize the role and contribution of digital technological tools, which can positively impact teachers' performance and competency.

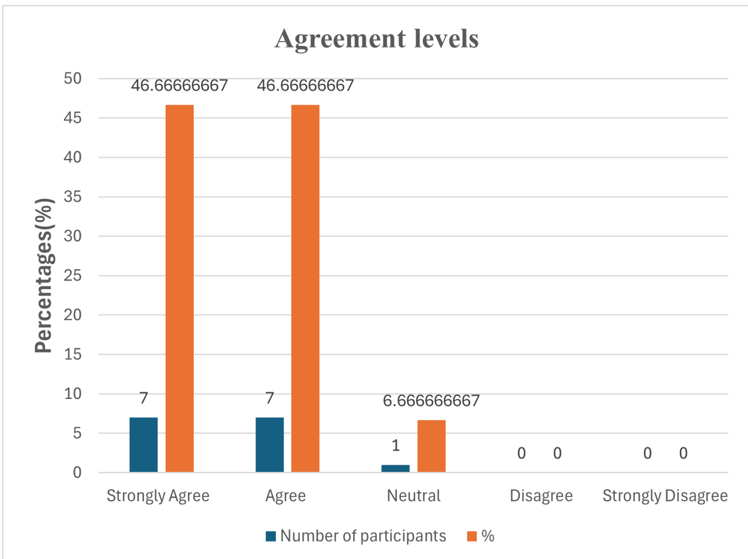


Figure 4.10: Contribution of digital teaching methods

Moreover, an overwhelming 93% of participants express agreement that digital teaching methods significantly contribute to students' learning of mathematics in their classrooms, as highlighted in the figure 4.10.

4.2.10 Interest in Technology Skills Workshops

The findings highlight a shared aspiration among participants to improve their technological skills. The table bellow demonstrates agreement among respondents to attend workshops or training sessions focused on technology aspects, thereby reinforcing their commitment to enhancing competence in this area.This could increase teachers' competence and sense of relatedness.

Interest in Technology Skills Workshops	**Number of Respondents**	**Percentage(%)**
Yes	15 out of 15	100
No	0 out of 15	0

Table 4.1: Interest in Technology Skills Workshops

4.2.11 Factors Contributing to Teacher Satisfaction in Mathematics Teaching

Table 4.2 reveals that respondents find motivation and satisfaction in various factors, including a high level of student engagement and performance, establishing strong connections with the community, learning new teaching methods and strategies, reflecting on their achievements, and the freedom to select and implement digital teaching methods in their classrooms. Responses indicate that 67% of respondents derive satisfaction from high levels of student engagement and performance, 40% from reflecting on their achievements, another 40% from the freedom to choose and implement digital teaching methods, and 27% from establishing strong connections with the community (parents, students, and colleagues).

Satisfying Math Teaching Practices	**Number of Respondents**	**Percentage(%)**
High level of students engegement and Performance	10 out of 15	67
Establishing strong connections with community(parents,students,fellow teachers and collegues)	4 out of 15	27
Learning new teaching methods and strategies	6 out of 15	40
Reflecting on my achievements	6 out of 15	40
Freedom to select and implement digital teaching methods for my classroom	6 out of 15	40

Table 4.2: Satisfying Math Teaching Practices

4.2.12 Challenges in Integrating Digital Educational Tools into Mathematics Teaching

The diagram 4.11 below, reveals numerous challenges faced by teachers in integrating digital educational tools into mathematics instruction. Specifically, 47 % of teachers encounter issues related to lack of familiarity, 40 % express a preference for traditional methods, 60 % grapple with technical difficulties, and 73% face challenges stemming from inadequate access to digital devices or reliable internet connections. Additionally, 47% of teachers contend with limited time within the curriculum, potentially restricting the seamless incorporation of digital tools.

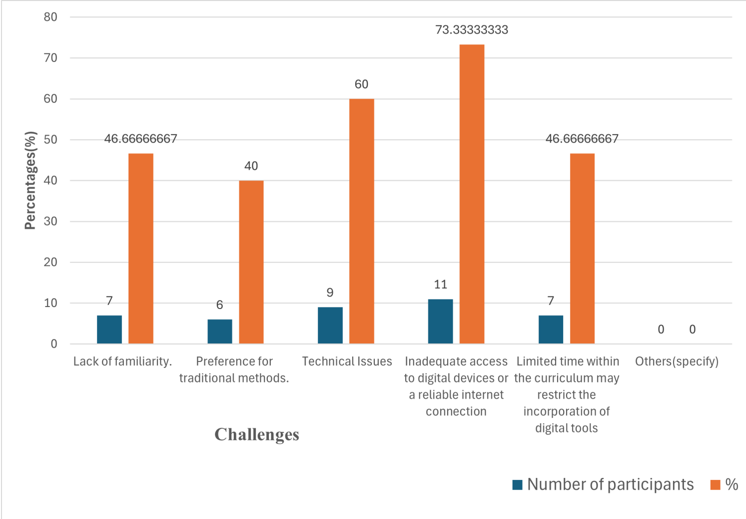


Figure 4.11: Challenges in integrating digital tools for mathematics teaching

Consistently emerging themes, encompassing teaching materials, demotivating factors, motivation factors, positive mindfulness and engagement, have been identified and developed. These themes signify that multiple factors as appeared in figure 3.3 play a role in influencing teachers' autonomy, competence, and enjoyment levels when utilizing digital educational technology for mathematics instruction. Importantly, factors such as teaching methodology, motivation, digital resources, training opportunities, social factors(social support,peer influence) and satisfaction hold the power to enhance positive mindfulness, satisfaction, enjoyment, engagement, self-efficacy, teacher commitment, and intrinsic motivation. Conversely, challenges like insufficient familiarity with technological tools, technical issues, limited access to digital devices or stable internet, time constraints, resistance to change, anxiety, frustration, social factors(group dynamic,cultural norms) and inadequate training can undermine teachers' intrinsic motivation.

4.2.13 Usability Test Results of an Augmented Reality Geometry Prototype

Iterations	Tasks conducted	Outcomes
1	Understanding Key Functionalities of the Application	During the testing of application functionalities, users encountered difficulties with interaction, such as unresponsive navigation paths. However, positive feedback included user appreciation for the overall application and its potential benefits
2	Teachers could plan lessons on 1D, 2D, and 3D concepts by creating models of lines (1D), triangles and quadrilaterals (2D), and cubes (3D). These hands-on models would help students better understand the properties and differences between dimensional spaces	Construction of virtual geometric shapes. Users can measure and explore the dimensions and properties of shapes, such as length, width, height, area, perimeter, and volume. Users are able to rotate the shapes for a comprehensive understanding of their structure. This interactive approach allows for deeper engagement with geometric concepts in both 2D and 3D spaces.
3	Addressing the reported issues includes: Adjusting the font size for the application menu to improve readability. Modifying background colors in specific scenes to enhance visual clarity. Conducting user interviews to gather feedback on usability and aesthetic preferences.	The improvements and steps taken include: Rearranging the application layout for better usability. Setting a medium font size for the menu and markers to improve readability. Creating models of lines, triangles, quadrilaterals, and cubes for interactive learning. Conducting interviews to gather user feedback. These changes collectively contribute to users demonstrating increased autonomy, competence, and enjoyment while utilizing augmented reality geometry applications

Table 4.3: Usability Test Results

Chapter 5

DISCUSSION

The findings from previous studies suggest a strong correlation between intrinsic motivation and enhanced individual performance [86][85]. The achievement of higher performance levels is often attributed to factors such as setting SMART goals, individual commitment to goal attainment, access to professional development opportunities, effective communication, and the fulfillment of basic psychological needs[63][3].

In alignment with the objectives of exploring teachers' intrinsic motivation to utilize digital educational technology for teaching mathematics and students engage with mathematics learning through an approach this encompasses the active method for hands-on manipulation, the iconic method incorporating images, and the symbolic method involving the use of symbols[12]. As stipulated by the Rwanda Educational Curriculum's Competence-Based Curriculum, a comprehensive study of geometric shapes is integral in both primary and secondary education[82]. The researcher focuses on delivering geometry-related content to secondary school students, particularly targeting senior one students. The key contents aim to develop students' skills in calculating the surface area and perimeter of polygons, as well as the volume of cubes. Students should also understand the significance of faces, edges, and angles in geometric shapes and be able to identify them. Exploring real-life examples of shapes like lines, triangles, quadrilaterals, rectangles, and cubes is crucial to demonstrate the practical relevance of geometry in everyday situations. Moreover, students should grasp fundamental mathematical arguments, including comparisons of areas and perimeters, volume and surface area calculations using formulas, and the impact of symmetrical properties on transformations. Discussions on the practical applications of geometric concepts in architecture, engineering, art, and design can further enhance students' understanding of how geometry solves real-world problems.This particular focus aligns with the pivotal stage at which learners begin developing a foundational understanding by engaging with diverse real-world scenarios. The emphasis is on cultivating learners' competences, enabling them to practically engage with their environment.

Furthermore, the integration of an augmented reality (AR) geometry application aligns with TPACK educational framework, offers a visually engaging and accessible means for teachers to manipulate, visualize, and interact with geometry concepts[7]. This technological tool facilitates a transition from conceptual understanding to concrete application, fostering a meaningful comprehension of geometry concepts. Through augmented reality (AR),teachers and students can explore and manipulate geometric shapes in their physical environment. For instance, students could use an AR app to overlay virtual cubes onto objects in their classroom . They could then interact with these shapes, measure their dimensions, calculate their surface areas and volumes, and observe how they interact with other objects in the environment. This hands-on experience allows students to directly apply geometric principles in a practical context, enhancing their understanding of geometry concepts.

The application of the PACT framework in understanding the context of use for this AR geometry application underscores its user-centric design[89]. By prioritizing user needs and enhancing overall enjoyment, the framework ensures that the interactive system aligns with the requirements of its users, particularly educators. Additionally, the Technological Pedagogical Content Knowledge

(TPACK) framework is instrumental in guiding the integration of technology, pedagogy, and content knowledge for effective teaching. Through the incorporation of AR technology in mathematics education, the TPACK framework underscores the importance of a harmonious blend of these three domains, ensuring successful and impact teaching practices. This integrated approach contributes to a holistic exploration of teachers' intrinsic motivation, shedding light on the intricate interplay between pedagogical methods, technological tools, and educators' motivational factors in the context of mathematics education.

Additionally, the availability of facilities such as well-equipped classrooms with modern teaching aids, communication platforms, evaluation feedback mechanisms, and laboratories with a wide range of resources and study materials contributes to individual self-efficacy, satisfaction, positive emotions, well-being, happiness, and increased engagement in task completion. These facilities provide learners and educators with the necessary tools, resources, and support to enhance their learning and teaching experiences. Drawing upon insights derived from survey, interviews, observations, and documentation, the research questions can now be addressed with greater clarity and depth.

5.1 What is Teacher's Level of Competency in Using Digital Educational Technology to Teach Mathematics?

In exploring other researchers' findings, it becomes evident that competency is one of the key factors that contribute to the enhancement of individual self-efficacy and vice-versa [25]. Geometry applications not only engage teachers but also enhances their competence, transforming abstract geometric concepts into concrete forms. Game-based learning, and design thinking the active learning methodologies, stand out as the primary methods associated with the use of digital educational technology [67]because they contained game elements that facilitate the users (teachers and students) to be interactive, engaged, and enjoy doing their tasks.

Figure 3.3 from chapter 3 illustrates the identification of categories, themes, and codes in the qualitative data collected through survey.
In response to Research Questions (RQ1), (RQ2), and (RQ3), the following categories:
Autonomy, Competency, and Enjoyment have been developed to discern related or unrelated patterns. The themes of teaching materials,demotivating factors,motivation factors,positive mindfulness and engagement serve as the foundation for exploring the study aspects deeply through the collected data. Codes such as methods used to teach mathematics,digital devices,training sessions,challenges, satisfaction,and motivation, are crucial for identifying patterns and capturing participants' experiences.These patterns or codes within the thematic focus were grouped based on word similarity across all study participants.

For instance, satisfaction and motivation reflect positive mindfulness and engagement, leading to heightened levels of enjoyment and competence among teachers. Conversely, various challenges arise from demotivating factors such as the lack of appreciation for efforts, unclear goals, inadequate resources and support, negative feedback, boredom, stress, high workload, limited growth opportunities, poor work-life balance, unfair treatment, and lack of autonomy over tasks. These factors hinder teachers' competence and overall effectiveness.
The coded elements, such as digital devices, methods used to teach mathematics, and training sessions, are closely aligned with autonomy in selecting teaching materials. These aspects not only serve as motivational factors but also act as sources of intrinsic motivation for teachers when utilizing digital educational technology in teaching mathematics.
The depicted figure 4.3 illustrates the proficiency levels of each participant in effectively utilizing digital educational tools while teaching mathematics. The accompanying graphic indicates that teachers' competences in utilizing digital teaching resources for mathematics instruction remains significantly low(Figure 4.8). None of the surveyed teachers reported possessing even half a percent proficiency, indicating a competence level were below the 50%.

Digital devices and motivational factors play crucial roles in shaping individuals' competencies and their utilization of digital learning tools and software, provided that they possess the requisite skills but need to be improved. However, several challenges impede this process. Accessibility issues, such as lack of compatibility and poor interface design for students with disabilities,limited skills, along with inadequate internet connectivity and technical problems like compatibility issues with various operating systems and devices, as well as slow loading times, hinder both individual competencies and enjoyment. These obstacles not only impact competencies but also diminish enjoyment, ultimately stifling intrinsic motivation. This phenomenon aligns with the self-determination theory, wherein the failure to fulfill basic psychological needs for autonomy, competency, and relatedness reduces individual intrinsic motivation, consequently decreasing satisfaction, enjoyment, performance, self-efficacy, and positive mindfulness.

5.2 What is Teacher's Level of Autonomy in Using Digital Educational Technology to Teach Mathematics?

Providing teachers with the autonomy to choose from a diverse range of teaching methods and digital learning tools, encompassing visual aids tools and digital devices, fosters a sense of commitment and self-driven engagement. This commitment encourages educators to proactively explore and acquire knowledge about their selected technologies, fostering a deeper understanding and heightened proficiency. Essential to complement this autonomy is the facilitation of professional training, offering crucial support for their self-directed learning journey. Additionally, the establishment of effective communication channels to address challenges contributes significantly to the overall capacity-building process, facilitating continuous improvement and fostering ongoing professional growth.

Similarly, aligning with the goal-setting theory [63], allowing individuals to set their own goals proves more effective than assigning goals to them. Supporting individuals in achieving their goals involves providing training and autonomy supportive, an effective strategy for goal attainment. This highlights the role of goals in fostering commitment, enabling individuals to recognize and realize their competence. The achievement of goals enhances self-efficacy, further motivating individuals in their endeavors. Self-efficacy, characterized by a strong belief in one's ability to perform tasks or to use digital devices successfully, fosters his or her confidence , competence and autonomy.

Allowing teachers to choose from interactive whiteboards, digital educational apps, or traditional teaching methods provides them with the autonomy to tailor their approach based on students' needs and subject matter. As indicated in diagram 4.9 above, which illustrates that teachers' autonomy levels in utilizing digital educational tools in teaching mathematics remain notably low. None of the respondents (teachers) reported having even half a percent, indicating a level considered below average. The lack of creativity, innovation, or skills on developed software for teaching mathematics can pose significant challenges. Satisfaction contributes to increased individual enjoyment and intrinsic motivation, whereas dissatisfaction serves as a discouragement factor and hinders individual intrinsic motivation. Materials used to teach mathematics (Visual aid tools) determine individual autonomy, and the use of digital learning tools is based on personal desire and choice during individual activities. However, it would be beneficial to conduct workshops for both new and existing digital tools to familiarize users with their application within their work and individual activities. Thereby, enhancing their intrinsic motivation, engagement, and satisfaction levels.

5.3 What is Teacher's Level of Enjoyment in Using Digital Educational Technology to Teach Mathematics?

In the analysis, I have identified factors such as student engagement and performance, passion for teaching, and making a positive influence as key contributors to increasing teachers' intrinsic motivation. This is evident in above figure 4.4 and 4.6 , where these factors represent 60% of respondents' preferences and satisfaction. According to Bandura's self-efficacy theory[63][3], high self-efficacy not only enhances competence but also fuels motivation and fosters positive mindfulness. Positive mindfulness, in turn, contributes positively to individual satisfaction,well being and enjoyment.

Aligning with previous studies, Augmented Reality has been shown to improve individual attention, satisfaction, motivation, critical thinking, confidence, learning interest,engagement, creativity,enjoyment and overall performance as elucidated in the research findings from Chapter 2 and 3 [7], the discussion centers prominently on the system usability test evaluation. Similarly, in this study, participants from prototype testing and interviews unanimously expressed feeling confident and enjoyment using the Augmented Reality Geometry application. That is why all participants also agreed that they can use this system frequently in response from system usability scale questionnaire as indicated in figure 3.32 in chapter three.

When individuals are intrinsically motivated, they take accountability for their daily activities and assigned tasks, leading to improved performance and overall well-being, both economically and psychologically [95]. This intrinsic motivation significantly contributes to individual satisfaction, enjoyment, and happiness. However, in the figure 4.11 shows the challenges arise for teachers when integrating digital educational tools into mathematics, with 70% facing inadequate access to digital devices or a reliable internet connection, 60% encountering technical issues, 47% grappling with a lack of familiarity, and 40% expressing a preference for traditional methods. These challenges, rooted in limited skills and information due to poor communication can diminish individual enjoyment demand proactive initiatives from leaders to help teachers overcome obstacles hindering goal achievement. Government intervention is crucial, addressing financial resource constraints through effective communication, training programs, and diversifying sources of income for teachers and their partners.
Collaboration among leaders, teachers, and the community is pivotal to enhance the sense of relatedness. Table 4.2 highlights that establishing strong connections with the community, including parents, students, fellow teachers, and colleagues, can be a practice contributing to teachers' overall satisfaction in teaching mathematics resulting from happiness.

Qualitative responses highlighted that teachers who have the autonomy to choose digital learning tools and teaching methods, as presented in the diagram 4.3 and 4.4 from Chapter 4, express a higher level of satisfaction in their teaching practices, as clearly demonstrated in the figure 4.6, where 60 percent of the respondents confirm their satisfaction. Educators who feel empowered to select digital tools tailored to their teaching style demonstrate a higher level of enthusiasm and commitment during lessons. Despite the overall positive trend, some teachers express challenges related to limited access to certain technologies, as indicated in the figure 4.11 from Chapter 4. It's noted that addressing these challenges and providing adequate support can further enhance the positive impact of autonomy on commitment, satisfaction and engagement.
Findings suggest that all teachers who are willing to attend professional training on utilizing digital tools reported a more significant positive impact on increasing skills, satisfaction, engagement, and familiarity in teaching practices. Therefore training not only increased their technical proficiency but also boosted confidence and competences in incorporating digital methods. The Detailed insights from system usability test ,observation,interviews and the survey provide depth to the understanding of these relationships and emphasize the importance of effective communication, addressing challenges, and providing training for optimal engagement and happiness in doing teaching practice.

The tests conducted with the AR Geometry application prototype among study participants have significantly enriched our understanding of educational technology software's contextual use. These evaluations have been pivotal in enhancing participants' proficiency in utilizing the geometry application, fostering a sense of enjoyment and satisfaction from its usage. The insights garnered from this testing phase offer invaluable information on user experience, laying the groundwork for potential refinements and enhancements. Overall, this study illuminates the multifaceted impact of AR technology in education, emphasizing its educational effectiveness and capacity to engage and satisfy teachers and learners. Moving forward, the integration of innovative tools such as AR technology holds tremendous potential to reshape and elevate the educational landscape.

However, Figure 4.7 from Chapter 4 illustrates the reported enjoyment levels of the teachers who participated in the data collection process. It is evident that the enjoyment level remains consistently low for all teachers. This could be attributed to various challenges, including limited skills and familiarity with new technologies such as virtual and augmented reality. Additionally, resistance to change may hinder the adoption of new teaching methods or mathematics software, impacting teachers' competence, creativity, and innovation. These factors likely contribute to the low levels of satisfaction in using digital software for teaching mathematics.

Therefore, addressing all discussed factors is crucial, such as providing training sessions, teaching materials, facilities, evaluating performance through effective communication, discussing and eliminating teachers' challenges, setting SMART goals, establishing appropriate policies, rules, and regulations. Additionally, factors like recognizing and rewarding teachers' efforts, promoting a collaborative and supportive environment, and fostering continuous professional development should be considered to enhance teachers' enjoyment,engagement and intrinsic motivation and satisfying basic psychological needs.

5.4 Autonomy and Relatedness Impact on Digital Technology Use in Math Teaching

Strong interpersonal connection and a sense of belonging are fundamental human needs that are addressed by the need for relatedness[41]. By involving traits like empathy, curiosity, and dedication to learning, teachers can significantly increase student satisfaction. According to the study of Deci, Edward L and Ryan, Richard M [24], meeting the psychological requirements for relatedness, competence, and autonomy predicts self-motivation and general psychological well-being across cultural boundaries, which supports mental health and well-being. While rewards can be enjoyable at first, they may unintentionally weaken intrinsic drive, particularly when people mistake intrinsic rewards for the pleasure that comes from their job[21]. Leaders that provide their staff members personalized attention and autonomy to meet their psychological requirements are more successful[22].

In the analysis of the hypothesized relationship, the study findings support the idea that increasing teachers' autonomy and fostering a sense of relatedness positively correlates with increased utilization of digital educational technology and satisfaction in the teaching of mathematics. This is evidenced in Table 4.2, where 27% of respondents indicated that establishing strong connections with the community (parents, students, fellow teachers, and colleagues) can provide and foster their motivation and satisfaction. Figures 4.3 and 4.4 in which approximately 87% of respondents further illustrate the preferences of teachers in choosing technology devices and educational tools for their mathematics teaching practices. Additionally, these factors are associated with certain satisfaction and enjoyment in mathematics teaching. Notably, 60% of respondents from Figure 4.6 and all of the respondents from Figure 4.7 affirm this correlation. Many teachers freely incorporate various digital devices into their teaching practices, underlining a prevalent trend and some argue strong community connections enhance math teaching satisfaction. Furthermore, all participants express a keen interest in participating in technology training sessions, demonstrating a collective aspiration to enhance their proficiency in utilizing digital devices for teaching mathematics, as indicated in Table 4.1 and survey results from the study by Peggy A. Ertmer and Anne T. Ottenbreit-Leftwich[28] confirm that peer collaborations can enhance individual competences, with competence being one of the factors contributing to a high level of satisfaction. Previous studies emphasize the value of relatedness in the workplace by emphasizing how workers' awareness of their influence on others promotes successful outcomes[24][22].

Augmented reality (AR) technology represents a transformative tool that enhances existing pedagogical approaches by encouraging diverse teaching styles through gamification and critical thinking hence fostering an enriched motivational state among both teachers and students. Through the integration of AR technology, teachers can effectively address various challenges encountered in teaching, thereby enhancing their competency, mindfulness,enjoyment, satisfaction, and overall motivational variables. This innovative approach not only enriches the learning experience but also equips educators with the means to overcome obstacles and optimize instructional delivery.

Chapter 6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

In conclusion, this study successfully achieved its primary objective of exploring teachers' intrinsic motivation to utilize digital educational technology for teaching mathematics.The investigation addressed four key objectives and corresponding research questions.
The initial objective delved into an examination of motivational styles, revealing that an autonomy-supportive style is associated with intrinsic motivation, which affirms satisfying three basic psychological needs autonomy, competence, and relatedness significantly increases individual motivation levels, leading to satisfaction and engagement in tasks. Additional factors such as effective communication, performance evaluation of teachers and students, setting SMART goals, favorable work environments, access to facilities, community acceptance, professional training, and diverse teaching methodologies were identified as crucial contributors to a positive mindset and heightened individual motivation. Also Bandura's self-efficacy theory underscores that high self-efficacy not only enhances competence but also acts as a catalyst for motivation, and fostering positive mindfulness as has been investigated in the literature review.

The second objective focused on evaluating teachers' autonomy and competency in using digital educational technology in teaching mathematics .The study recommends ongoing training initiatives to familiarize a larger number of teachers with educational technology software and to address challenges that impede teachers' performance and competence in fulfilling their roles. Moreover, the importance of maintaining an autonomy supportive style, allowing teachers to make choices in implementing methodologies and using software, was emphasized.

The third objective aimed to assess teachers' enjoyment when using digital educational technology in teaching mathematics, revealing that their levels of enjoyment, competence, and autonomy were notably low.To enhance these aspects,it is crucial to address the identified factors at a higher level. Strategies should focus on enhancing intrinsic motivation, providing state-of-the-art facilities, offering comprehensive professional development to enhance competencies, fostering student engagement and performance, nurturing passion for teaching, creating a positive influence, setting and achieving goals, and gaining community acceptance. Elevating these factors to a higher level will contribute to a more satisfying and motivating experience for teachers in utilizing digital tools for teaching mathematics.

Finally, the fourth objective involved analyzing feedback provided by teachers regarding motivation and the use of digital educational technology. Thematic analysis,NVIVO,MS Excel and human-centered design, including testing the developed Augmented Reality (AR) Geometry application prototype for teaching geometric concepts, were instrumental in gaining valuable insights. Empowering individuals to set their own goals emerged as a significant measure of competency, aligning with the principles of self-determination theory and goal-setting theory. These approaches were identified as critical solutions to the research problems and instrumental in achieving the research objectives.

The study also conducted a comprehensive analysis of diverse digital visualization tools and developed a prototype for an Augmented Reality (AR) Geometry application. This effort aimed to deepen the understanding of the tools' contextual use, facilitating teachers in seamlessly incorporating the application into their mathematics teaching practices. The overarching goal is to significantly enhance the overall happiness, engagement, and satisfaction of teachers in their esteemed profession. Recognizing the pivotal role of government intervention, particularly in addressing financial constraints, emerges as a critical aspect. Strategic measures, such as effective communication, robust training programs, and diversification of income sources for teachers and their partners, are essential steps. These initiatives are pivotal in creating a supportive environment that empowers educators and ensures the successful integration of innovative educational tools into the teaching landscape.

6.2 Recommendation

Some suggestions have been developed and are directed to the government,schools ,teachers and developers . These recommendations are based on findings and are consistent with the study's objectives.

Teachers:
Adopt diverse teaching methods tailored to goals to enhance engagement, satisfaction, and overall performance. Actively participate in professional training opportunities to continuously enhance competencies and stay updated on effective teaching practices. Conduct regular self-evaluations of teaching performance, assessing progress towards set goals, and openly communicate challenges.
Educational Institution:
Provide ongoing training for both new and existing educational technology methods and software to ensure teachers are well-equipped.
Developers:
Design and create educational technology systems in alignment with the educational curriculum to ensure they align with desired learning outcomes and institutional goals.

6.3 Future Work

For future research endeavors: Conduct additional user tests with students to assess their satisfaction, engagement, and critical thinking skills while using the system. Explore further opportunities to enhance the system based on user feedback and evolving educational technology trends. These recommendations and future works are aligned with the study's objectives and findings, aiming to contribute positively to the field of educational technology and teacher satisfaction.

Appendix A

LETTER TO RESPONDENTS

Dear Respondent,
I trust this message finds you well. I am currently pursuing a Master's degree at the University of Rwanda, College of Science and Technology, and I am conducting research on "Exploring Teachers' Motivation to Use Digital Technology in Math Education" This research is being undertaken as part of the requirements for the Master of Science in Information Systems.Enclosed is a form designed to gather valuable data for my research, which will contribute to the completion of my master's thesis. Your participation and cooperation in providing accurate information are crucial to the success of this study.

I sincerely appreciate your time and effort in contributing to this research endeavor. If you have any questions or concerns, please feel free to contact me via mumarg2015@gmail.com.

Thank you for your cooperation.

Best regards,

MUJAWAMARIYA Marguerite

A.1 Survey Questionnaire

The survey questionnaire was created using the online form called Nettskjema, as provided in the following link: https://nettskjema.no/user/form/364639.

A.2 Interview Questions and System Usability Scale Survey

1. Which digital devices have you utilized, or do you intend to use in your teaching practice?

2. What digital methods do you use to teach mathematical concepts in your classroom?

3. How frequently did you utilize the digital methods mentioned in question 2 while teaching mathematical concepts in your classroom?

System usability scale

Strongly disagree. Strongly agree.

			1	2	3	4	5
1	I think that I would like to use this system frequently						
2	I found the system unnecessarily complex						
3	I thought the system was easy to use						
4	I think that I would need the support of a technical person to be able to use this system.						
5	I found the various functions in this system were well integrated						
6	I thought there was too much inconsistency in this system.						
7	I would imagine that most people would learn to use this system very quickly						
8	I found the system very cumbersome to use						
9	I felt very confident using the system						
10	I needed to learn a lot of things before I could get going with this system						

Figure A.1: System usability scale figure

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