Integrating Augmented Reality Into Zambia's Education System: A Case Study Of An Ar-Based Geometry App And Its Impact On Learning Outcomes

Mwangala Edward Muma,
Mbale Jameson
School of ICT,
Computer Science Department,
The Copperbelt University, Kitwe, Zambia.
mwangala139@gmail.com; jameson.mbale@gmail.com

***Abstract*—This research investigates the use of Augmented Reality (AR) to enhance the teaching and learning of geometry in Zambia's education system. Aligned with national efforts to modernize classrooms and strengthen STEM competencies, the research focuses on developing and evaluating an AR-based application that visualizes three-dimensional geometric shapes in an interactive format. The application allows students to engage with cones, pyramids, prisms, and cuboids through real-time visualization, spatial interaction, and annotated overlays anchored to image markers. Evaluation was conducted in school settings using questionnaires administered to teachers and students to identify instructional challenges, learner preferences, and pedagogical needs. Results showed that students face difficulties in visualizing 3D shapes and understanding spatial relationships, while teachers highlighted the need for interactive tools to improve engagement and conceptual understanding. Both groups expressed a strong preference for hands-on, visually rich learning methods that connect geometry to real-world contexts. The findings demonstrate that integrating AR into classrooms can revitalize traditional teaching practices, enhance comprehension of geometry, and foster deeper learner engagement. This research provides insights for policy-makers, educators, and curriculum designers seeking scalable and context-sensitive innovations for education in developing regions.**

Keywords*—*Augmented Reality (AR), Geometry Education, STEM Education, ICT Integration, 3D Visualization, Educational Technology, Zambia.

I. INTRODUCTION

Digital technologies are transforming education worldwide [1]. In Zambia, efforts to modernize classrooms and strengthen STEM literacy have opened opportunities for innovative tools, such as Augmented Reality (AR), to enhance teaching and learning. This aligns with global trends showing AR's potential to enrich STEM education through immersive, interactive experiences [2]. AR is particularly promising for geometry, where spatial reasoning is critical but often challenging for learners [3]. Students frequently struggle to visualize three-dimensional shapes and understand dimensional relationships, and traditional methods, such as chalkboard diagrams and textbook illustrations, often fail to provide sufficient interactivity.

AR applications address these challenges by overlaying interactive digital models onto the physical environment, allowing students to manipulate cones, prisms, pyramids, and other geometric figures in real time [4]. This approach fosters curiosity, improves conceptual understanding, and aligns with Zambia's Vision 2030 and ICT integration strategies, offering scalable access to high-quality STEM learning across urban and rural areas [5].

This research presents a custom-built AR geometry application for classroom use in Zambia. Using image markers and tailored visual assets, the system enables interactive exploration of geometric shapes. Data from teacher and student questionnaires provide insights into instructional challenges, learner needs, and the educational value of AR tools. By integrating technological innovation with pedagogical research, this study demonstrates the potential of AR to enhance geometry comprehension and foster deeper student engagement in Zambian classrooms.

A. Problem Statement

Despite national efforts to strengthen STEM education in Zambia [5], geometry instruction remains limited by traditional methods, low student engagement, and a lack of interactive resources. Many learners struggle to visualize 3D shapes and connect geometric concepts to real-life applications [3]. Augmented Reality (AR) presents a potential solution by allowing students to interact with geometric shapes in real time, supporting spatial reasoning and conceptual understanding [3]. This study seeks to investigate how AR can be effectively integrated into geometry instruction by examining classroom challenges, educator and learner perspectives, and strategies for scalable, context-aware implementation.

B. Research Objectives

To design and implement an Augmented Reality (AR)-based geometry application that supports interactive learning of three-dimensional shapes.

 ISBN: 978-9982-95-500-3

To examine the current challenges faced by teachers and students in geometry instruction within Zambian classrooms.
Investigate the potential of Augmented Reality (AR) as a pedagogical tool for enhancing spatial understanding and learner engagement.

To explore teacher and student perceptions of AR integration through structured questionnaires and classroom interactions.

To evaluate the effectiveness of AR-assisted geometry instruction in improving conceptual comprehension and participation among learners.

C. Research Questions

How can Augmented Reality (AR)-assisted geometry instruction enhance students' conceptual comprehension and participation compared to traditional methods, while addressing the challenges faced in Zambian classrooms, reflecting stakeholder perceptions, and informing best practices and policy recommendations for effective integration into the national education framework?
What challenges do teachers and students face in teaching and learning geometry in Zambian classrooms?
To What role can Augmented Reality (AR) play as a pedagogical tool in enhancing spatial understanding and learner engagement in geometry?
What are the perceptions of teachers and students regarding the integration of AR into geometry instruction?
What are the best practices for implementing AR technologies in Zambia's diverse educational contexts?
What recommendations can be made to curriculum designers and policy-makers for integrating AR into Zambia's national education framework?

II. LITERATURE REVIEW

Augmented Reality (AR) has gained global recognition as a transformative tool in education, offering immersive and interactive experiences that enhance student engagement, comprehension, and retention [6]. Research consistently shows that AR is particularly effective in mathematics and science, where abstract and spatially complex concepts present persistent challenges [7]. A meta-analysis by Zhang et al. [6], reviewing over a hundred AR-based studies in K–12 educations, demonstrated significant positive effects on learning outcomes. Similarly, Bacca-Acosta et al.[7] highlighted how AR supports constructivist and situated learning approaches, enabling learners to actively explore rather than passively receive information. By presenting content through multiple sensory channels—visual, auditory, and kinesthetic—AR reduces cognitive overload and caters to diverse learning needs, helping students build confidence and curiosity in problem-solving.

Zambia has made notable progress in advancing digital learning through initiatives such as the Education Sector Strategic Plan and the Smart Zambia Initiative, both of which emphasize ICT integration [10]. Some schools in urban areas have introduced computer labs and e-learning platforms, and mobile phone penetration exceeds 80 percent nationwide [11]. However, significant challenges persist. Many rural schools lack stable electricity, reliable internet connectivity, and adequate ICT infrastructure [12], [13]. Teacher training in emerging technologies remains limited, resulting in a digital skills gap that reduces the effective use of available tools [13] [14]. Despite these challenges, Zambia's youthful population, growing digital literacy, and widespread access to affordable mobile phones provide opportunities for implementing mobile-friendly, offline-capable AR applications that can reach both urban and rural learners [1]. Pilot studies with tablets in Lusaka and Copperbelt provinces have already shown that students and teachers are receptive to technology-enhanced instruction [15], suggesting readiness for more advanced tools such as AR.

Geometry presents a particularly strong case for AR adoption. Learners often struggle to visualize three-dimensional shapes and connect their properties to formulas and problem-solving tasks. Traditional methods relying on chalkboard sketches or textbook illustrations do little to support spatial reasoning [3], leading to misconceptions and disengagement. Studies conducted in contexts similar to Zambia's, such as Malaysia (Nadzeri et al. [18] and Indonesia (Ahsani et al. [3], have shown that AR-based geometry applications improve visualization skills, enhance learner engagement, and increase comprehension. Beyond cognitive gains, AR has been shown to foster collaboration, peer-to-peer learning, and inclusivity, making it especially valuable in classrooms with large student numbers and limited teaching resources. For teachers, AR serves as a supplement to existing methods, allowing them to present difficult concepts more clearly while remaining aligned with the curriculum [9].

Nevertheless, challenges remain in integrating AR into Zambia's education system. Infrastructure limitations, high implementation costs, and exam-oriented curricula present barriers to adoption [13]. Teachers also need targeted training to confidently

 ISBN: 978-9982-95-500-3

apply AR in their lessons. On the other hand, opportunities lie in Zambia's mobile-first context, the government's commitment to digital literacy, and the active involvement of NGOs and donors in ICT education. With properly designed applications, AR can be delivered on affordable smartphones and tablets, making it feasible even in resource-constrained environments [2] [16]

While many AR geometry applications have focused primarily on shape visualization, relatively few guide learners through step-by-step problem-solving, formula application, or interactive exercises. This limits their capacity to strengthen mathematical reasoning beyond visual recognition. In Zambia, very little empirical research has explored how AR might be used effectively in classrooms to address both conceptual understanding and problem-solving skills. This gap underscores the importance of the present study, which not only develops an AR geometry application tailored for Zambian classrooms but also evaluates its usability, impact, and acceptance among students and teachers, with the goal of informing scalable and context-sensitive adoption.

III. METHODOLOGY

A. Data Collection

The study employed a mixed-methods case study design, gathering data from both students and teachers. Four schools were purposively selected to capture diverse contexts, ensuring a balance between urban and rural settings. In total, 88 students and 14 teachers participated in the classroom implementation and feedback sessions. The distribution of participants is summarized in Table I

TABLE I. STUDY PARTICIPANTS BY SCHOOL

School Name	**Location Type**	**Grade Level**	**No. of Students**	**No. of Teachers**
Zambezi Primary School	Urban	Grade 9	25	4
Linda Secondary School	Urban	Grade 10	20	3
Kazungula Boarding School	Rural	Grade 10	20	4
Janda Primary School	Rural	Grade 9	23	3
Total	—	—	**88**	**14**

Students were grouped in teams of five due to limited device availability. Teachers from each school also participated by facilitating lessons and completing feedback questionnaires.

Data sources included:

Student Questionnaires – Likert-scale and open-ended items on usability, engagement, and comprehension.

Teacher Questionnaires – addressing pedagogical value, curriculum alignment, and feasibility.

Classroom Observations – documenting student collaboration, interaction with the app, and learning behaviours.

B. Data Cleaning

Survey responses were screened for completeness. Inconsistent or incomplete entries were removed. Quantitative data were coded and analyzed using Microsoft Excel, while qualitative responses were thematically categorized into domains such as usability, engagement, and conceptual understanding.

C. AR Application Design

The custom-built AR application was designed using a user-centred approach, incorporating teacher feedback during development. The app featured interactive 3D models of geometric shapes (cones, cuboids, prisms, pyramids, cylinders), activated through printed image markers.

Key features included:

Interactive Visualization: Rotation, and manipulation of 3D models.

Curriculum-Aligned Content: Labelled diagrams, formulas, and worked examples.

Offline Functionality: Optimized for low- to mid-range Android devices without internet access.

Simple User Interface: Minimalistic design for accessibility in classroom contexts.

D. Implementation Tools

To support the design, implementation, and evaluation of the AR-based geometry application, both hardware and software resources were employed. These tools facilitated classroom deployment, model development, image recognition, and data analysis. Table II presents a summary of the hardware and software used, along with their specific purposes.

 ISBN: 978-9982-95-500-3

TABLE II. HARDWARE AND SOFTWARE TOOLS USED

Category	Tools Used	Purpose
Hardware	Android smartphones/tablets (≥2GB RAM, ARCore support)	Classroom deployment
	Printed image markers (A4 format)	Triggering AR models
	Laptop with 8GB RAM + GPU	Application development and testing
Software	Unity3D	Development of 3D interactive models
	Vuforia SDK	Image recognition and AR rendering
	Android Build Tools	Packaging and deployment of APK

E. Training and Testing

Prior to deployment, students were given a short demonstration of the AR app. Lessons were then conducted in groups under teacher supervision. Classroom activities included:

Scanning AR markers to render 3D models.

Identifying shape properties such as faces, edges, and vertices.

Accessing the "Learn More" function for labelled diagrams and worked examples.

Applying acquired knowledge to workbook exercises.

Teachers observed student participation and provided assistance where necessary. After the sessions, both students and teachers completed questionnaires evaluating usability, comprehension, and satisfaction.

F. Deployment Environment

The AR geometry application was deployed in classrooms using Android smartphones that met minimum requirements (Android 8.0 or higher, 2GB RAM, ARCore support, rear-facing camera). The app was installed directly onto devices and paired with printed A4 markers that triggered interactive 3D models of cones, prisms, cuboids, pyramids, and cylinders.

Teachers introduced the app to students through short tutorials, after which learners engaged with the AR models by scanning markers, rotating, and accessing the "Learn More" function for formulas and worked examples.

Figure 1 illustrates the recognition of a 2D cylinder image marker by the camera, which triggers the rendering of its corresponding 3D model within the augmented reality environment. Figure 2 presents the learning screen for the cylinder shape, displayed after the user clicks the 'Learn More' button, and includes detailed information, formulas, and labeled diagrams.

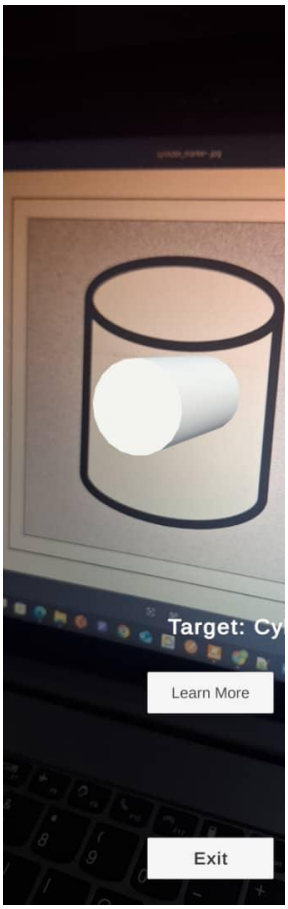

Fig. 1. A Scanned 2D Cylinder Image Triggering the Rendering of a 3D Cylinder Object

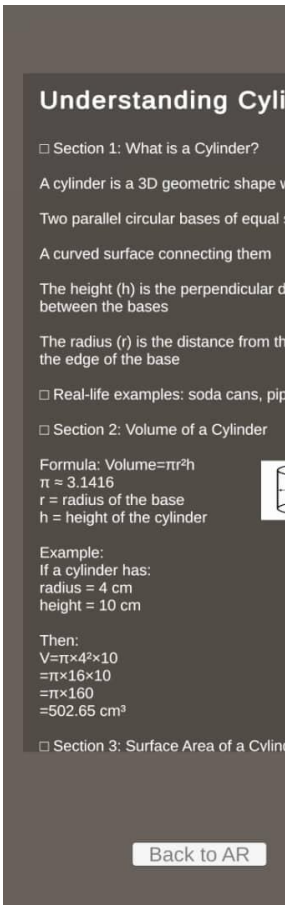

Fig. 2. Display of the Cylinder Learning Page Triggered by the "Learn More" Button

 ISBN: 978-9982-95-500-3

IV. FINDINGS AND RESULTS

A. Student Engagement

Students responded enthusiastically to the AR application. Over 75% reported that learning with the app was more enjoyable than using textbooks or chalkboard diagrams. Many described the experience as fun and easy to understand. Group activities encouraged collaboration, with learners taking turns scanning markers and explaining concepts to peers.

B. Comprehension of Geometry

The ability to rotate and zoom 3D models improved students' understanding of shape properties such as faces, edges, and vertices. The "Learn More" feature, which provided labelled diagrams and worked examples, was frequently cited as a valuable aid in applying formulas and solving geometry problems.

C. Ease of Use and Navigation

The interface was generally well received. Most students found it easy to use without assistance after a brief initial demonstration. The buttons were clearly labelled, and transitions between the AR camera and the information screen were smooth. The presence of the "Back to AR Camera" button allowed learners to return to scanning mode without restarting the app, which maintained the flow of the lesson.

However, a few students encountered difficulty positioning the marker correctly to initiate shape recognition. In some cases, poor lighting or unstable hand movements made the detection slower. Despite these challenges, students quickly adapted after observing their peers or receiving support from the teacher. This suggests that minor on boarding features, such as a short tutorial or on-screen instructions, could further enhance accessibility.

D. Comprehension of Geometric Concepts

Students demonstrated significantly improved understanding of geometric shapes and properties after using the AR application. The ability to visualize and interact with 3D models was frequently mentioned as a major aid in grasping difficult concepts. More importantly, students appreciated the "Learn More" feature, which provided concise definitions, labelled diagrams, and mathematical formulas. These were not just passively viewed, students actively referred to them while solving geometry problems in class.

Many students commented positively on the clarity of the formulas and their application. The integration of worked examples alongside the definitions helped bridge the gap between theory and practice. Several learners indicated that they used the examples as models to complete related exercises and felt more confident in their problem-solving abilities as a result.

V. DISCUSSION OF RESULTS

A. Student Feedback

Students responded enthusiastically to the incorporation of AR in their lessons, frequently expressing a desire for additional topics to be included in future versions of the app. Suggestions included algebra, angles, symmetry, and even coordinate geometry. This feedback reveals that students viewed the AR application not just as a novelty, but as a valuable learning resource they wished to use across broader areas of the mathematics curriculum.

Additionally, many learners praised the educational content presented in the app. They found the combination of 3D visualization, formula explanations, and worked examples to be especially effective. The structured learning screen, presented after clicking "Learn More" was noted as one of the most helpful aspects of the app. This screen offered a self-paced learning opportunity, allowing students to read and revisit explanations as needed, reinforcing their conceptual understanding. Figure 3 presents the results of student feedback on the AR-based geometry application. A total of 94% of students indicated that they found AR more engaging than textbooks, while 87% reported that it helped them better understand 3D shapes. In addition, 91% of learners found the "Learn More" formulas useful, and 96% expressed interest in having AR integrated into more topics.

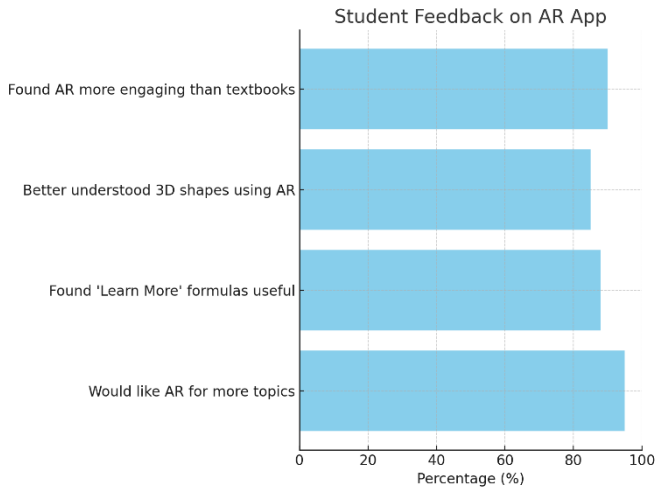

Fig. 3. Student Feedback on AR App

B. Teacher Feedback and Observations

Teacher responses to the AR-based geometry application were highly positive. Educators noted that the tool enhanced student engagement, shifting lessons

 ISBN: 978-9982-95-500-3

from passive reception to active participation, with even typically reserved learners showing greater enthusiasm. The application was particularly valued for improving visualization of three-dimensional concepts and for the "Learn More" section, which provided formulas and worked examples aligned with the Zambian curriculum. Technical usability was also highlighted, with teachers finding the interface simple, offline-compatible, and functional on commonly available Android devices. Minor challenges included initial student difficulties with marker alignment and shape detection in poor lighting, though these issues diminished with practice. A recurrent recommendation was the expansion of AR content beyond geometry to cover additional topics in mathematics and science, underscoring its perceived potential for broader curriculum integration.

Figure 4 shows teacher feedback on the AR-based geometry application. A total of 93% of teachers observed increased student engagement when using the app, while 89% found the formulas and worked examples to be helpful. In addition, 84% of teachers reported that the app was easy to integrate into lessons, and 88% suggested its expansion to cover other topics.

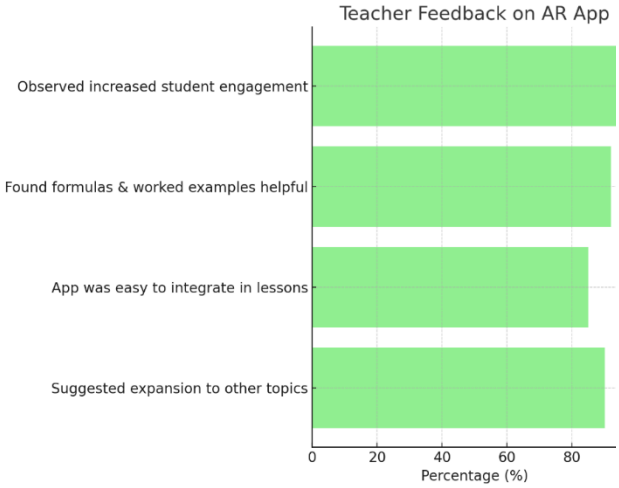

Fig. 4. Teacher Feedback on AR App

VI. RECOMMENDATIONS AND CONCLUSION

A. Recommendations

Based on the findings of this study, several recommendations are proposed to enhance the integration and effectiveness of augmented reality in Zambia's education system. First, the Ministry of Education and relevant stakeholders should consider embedding AR tools into the national curriculum, particularly within STEM subjects where visual and spatial understanding is essential. Expanding the application's content beyond geometry to include topics such as angles, algebra, measurement, and coordinate geometry would further address the expressed interest of both students and teachers. To ensure sustainable implementation, targeted teacher training workshops should be organized to equip educators with the skills necessary for effective use of AR-based learning. Additionally, device provisioning and technical support are critical, especially for rural schools, and could be facilitated through partnerships with NGOs, ICT initiatives, and the private sector. Finally, future iterations of the application should incorporate onboarding tutorials and multilingual support, thereby improving accessibility and inclusivity for learners from diverse linguistic backgrounds.

B. Conclusion

This study demonstrated that the development and classroom deployment of an Augmented Reality (AR) application can significantly enhance geometry education in Zambia. The tool improved students' ability to visualize three-dimensional concepts, increased engagement, and supported individualized learning, while teachers found it easy to integrate into lessons. Its offline functionality and compatibility with affordable devices further highlight its suitability for both urban and rural contexts. Overall, the findings affirm AR as a scalable and context-appropriate innovation capable of enriching mathematics instruction and promoting meaningful learning. With refinement and content expansion, the application presents a promising model for ICT-driven educational transformation in Zambia and similar resource-constrained settings.

REFERENCES

 ISBN: 978-9982-95-500-3

[1] UNESCO, "Digital learning in Africa: Status report and policy recommendations.," UNESCO, 2022.

[2] Z. Xuemei, L. Wenling and Z. Ruijia, "Augmented Reality and Student Motivation: A Systematic Review (2013 - 2014)," *Journal of Computers for Science and Mathematics Learning,* vol. 2, no. 1, pp. 38-52, 2025.

[3] L. A. Ahsani, N. E. Berthania, D. R. Pramana, A. P. K. Dewi and U. N. A. Syifa, "Development of Augmented Reality Based Learning Media on The Topic of Spatial Geometry for Elementary School Students," *Journal of Software Engineering, Information and Communication Technology (SEICT),* pp. 137-148, 2022.

[4] B. Galiya K, M. Akan M, S. Zoya T, Z. Larissa U and A. Botagoz N, "EVALUATING THE IMPACT OF AN AUGMENTED REALITY APP ON GEOMETRY LEARNING IN KAZAKH SECONDARY SCHOOLS," *Journal of Information Technology Education Research,* vol. 23, 2024.

[5] T. M. o. Education, "2022-2026 Strategic Plan," The Ministry of Education, 2022.

[6] M. Akcayir and G. Akcayir, "Advantages and Challenges Associated with Augmented Reality for Education: A Systematic Review of the Literature," *Educational Research Review,* vol. 20, pp. 1-11, 2017.

[7] K.-H. a. T. C.-C. Cheng, "Affordances of augmented reality in science learning: Suggestions for future research," *Journal of Science Education and Technology,* vol. 22, pp. 449-462, 2013.

[8] J. Zhang, G. Li, Q. Huang and Q. Feng, "Augmented Reality in K–12 Education: A Systematic Review and Meta-Analysis of the Literature from 2000 to 2020," *Exploring Technologies for Sustainable Learning Experience: Augmented Reality (AR) in Education Systems,* vol. 14, no. 15, 2022.

[9] J. Bacca-Acosta, S. Baldiris, R. Fabregat, S. Graf and D. Kinshuk, "Augmented Reality Trends in Education: A Systematic Review of Research and Applications," *Educational Technology & Society,* pp. 133-149, 2014.

[10] Z. N. E. C. (ZANEC), "STATUS OF EDUCATION TECHNOLOGY AND DIGITAL LITERACY AMONG TEACHERS LEARNERS AND PARENTS IN ZAMBIA".

[11] E. Mwansa, B. Sitali and M. Tembo, " ICT use and challenges in Zambian secondary schools: A case study of Lusaka District.," *Journal of Education and Information Technologies,* vol. 25, 2020.

[12] C. Mumba and M. Kalumba, "The digital divide in Zambia's basic education: A review of ICT access and usage," *Zambia Journal of Educational Research,* vol. 9, pp. 20-34, 2021.

[13] Mbale, J., Egan, J. & Frindt, T. (2013). Open Educational Resources and the Opportunities for Expanding Open and Distance Learning (OERS-ODL). International Journal of Emerging Technologies in Learning (iJET), 8(2), 57-61. Kassel, Germany: International Journal of Emerging Technology in Learning. Retrieved September 21, 2025 from https://www.learntechlib.org/p/111889/.

[14] P. Musonda, "Assessing digital literacy among teachers in Zambia: Implications for technology integration in schools," *International Journal of Education and Development Using ICT,* pp. 102 - 118.

[15] M. Mwale-Mkandawire, S. Lisulo, W. Hamweete and E. S. -. Phd, "Challenges in the Investment of ICT Infrastructure at Secondary School in Zambia, in Promoting Quality Education Delivery," *International Journal of Research and Innovation in Social Science,* 2021.

[16] J. Kalaluka and M. Zulu, "Tablet-based learning for secondary education in Zambia," *A pilot evaluation. Journal of African Education and Technology,* vol. 12, pp. 45 - 59.

[17] Mufeti, Tulimevava K.; Mbale, Jameson; and Suresh, Nalina (2011) "The Effect of Distributing Electronic Notes to Students: Ethical Considerations Raised By Computer Science Faculty at The University Of Namibia," *Journal of Information Systems Education*: Vol. 22 : Iss. 3 , 225-232. Available at: https://aisel.aisnet.org/jise/vol22/iss3/5

[18] M. B. Nadzeri, M. Musa, C. C. Meng, I. M. Ismail, M. E. Ismail, A. H. A. Hassan and M. S. I. Mustafa, "DEVELOPMENT AND EVALUATION OF AUGMENTED REALITY LEARNING APPLICATION (LearnGeoAR) ON GEOMETRY TOPIC PRIMARY SCHOOL PUPILS," *International Journal of Education, Islamic Studies and Social Sciences Research (IJEISR),* vol. 7, pp. 1-9, 2022.

 ISBN: 978-9982-95-500-3