



ARUNG: A Cultural Heritage-Based Application for Android Augmented Reality in Learning Geometry

Nilam Permatasari Munir^{1*}, Aswar Anas², Lisa Aditya Dwiwansyah Musa³, Zakaria Ndemo⁴

^{1,3}Mathematics Education, Institut Agama Islam Negeri Palopo, Indonesia

²Mathematics Education, Universitas Cokroaminoto Palopo, Indonesia

⁴Department of Science and Mathematics Education, Bindura University of Science Education, Zimbabwe

*Correspondence to: nilam_permatasari@iainpalopo.ac.id

Abstract: Although Augmented Reality (AR) has been extensively discussed and reported in mathematics education, there is limited research on its integration with local culture. This study introduces ARUNG, an Android-based application that integrates cultural heritage into geometry education. The innovation focuses on three main aspects: the integration of local cultural heritage into ARUNG, the design of the ARUNG system for geometry learning, and the analysis of the effectiveness on geometry concept comprehension. A research and development (R&D) study was conducted, involving three stages: input, output, and feedback. ARUNG was applied to 25 junior high schools in the eighth grade. Data on the conceptual understanding test results were analyzed to test the research hypothesis using a paired t-test. Cultural heritage markers integrated into ARUNG included Walasuji (cube), the walls of the Jami Tua Mosque in Palopo (rectangular prism), the Soko Guru pole (twelve-sided prism), the royal tomb of Lokko'e (square prism), and the PNIEL church (octagonal pyramid). The findings revealed that students' average comprehension of geometry concepts improved after using ARUNG compared to before. This research contributes to the field by introducing an innovative AR learning medium that incorporates cultural heritage, thereby promoting cultural awareness.

Keywords: android application; augmented reality; culture heritage; geometry; learning media

Recommended citation: Munir, N. P., Anas, A., Musa, L. A. D., & Ndemo, Z. (2026). ARUNG: A Cultural Heritage-Based Application for Android Augmented Reality in Learning Geometry. *Journal of Innovation in Educational and Cultural Research*, 7(2), 322-331.

INTRODUCTION

Mathematics plays a fundamental role in developing students' logical thinking, problem-solving abilities, and quantitative reasoning skills, which are essential for success in education and everyday life (Munir et al., 2021). As a core subject in the school curriculum, mathematics not only supports academic achievement across disciplines but also equips learners with the tools to navigate and make informed decisions in a data-driven world. PISA 2022 results show that in Indonesia, only 18% of students reach at least proficiency level 2 in mathematics, a figure that is significantly lower than the OECD average of 69% (OECD, 2023). Moreover, virtually no Indonesian students attain the highest levels of proficiency (Level 5 or 6) in the PISA mathematics assessment, compared to 9% on average across OECD countries. One example of high-level mathematical problems comparable to PISA is found in the "space and shape" content domain, which assesses students' understanding of spatial and geometric relationships. This includes the ability to interpret the dimensions of three-dimensional objects, calculate volume, and apply geometric reasoning to real-life contexts involving spatial structures. Hence, enhancing geometry learning through innovative approaches or innovative technology.

The revolution in the teaching of geometry has shifted away from the traditional reliance on chalkboards, textbooks, and printed images. Nowadays, learning media has become increasingly sophisticated with the advent of digital technologies such as Augmented Reality (AR). Augmented Reality is defined as an enhanced reality or technology that combines two- or three-dimensional virtual objects with the real world and projects them in real time (Kerr, 2020; Moreno-Guerrero, 2020; Tzima, 2019). It assists in visualizing an object in a combined two- and three-dimensional representation (Richardo et al., 2023). This technology can elevate an object from a flat, two-dimensional image, making it appear real and seamlessly integrated with the surrounding environment (Tresnawati & Albani, 2021). It is designed to provide learners with a new experience in studying subjects that require visualization, making the learning process more interactive (Firmansyahputra & Cherid, 2020). Furthermore, it brings innovation to education by expanding the boundaries of traditional learning beyond letters, numbers, and images. Its immersive capabilities allow for a more comprehensive integration with the real world (Bower et al., 2014). Augmented Reality serves to bridge the virtual world with real objects, where this connection is established in real-time and within the real environment (Wirza et al., 2020). It is now being utilized in various fields, including education (Garzón et al., 2019; López-Belmonte et al., 2020), marketing (Vilkina & Klimovets, 2020; Rauschnabel et al., 2022; Sung, 2021), healthcare (Ara et al., 2021; Liang & Elliot, 2021; Lacey et al., 2022), tourism (Liang & Elliot, 2021; Rezaee et al., 2021; Wei, 2019), and other disciplines. In the field of education, the use of augmented Reality has been shown to help students with disabilities improve

their communication skills, particularly those who are deaf (Quintero et al., 2019). The use of augmented Reality in education can help students improve their behavior in the learning process (Hou & Keng, 2021). Based on this, it can be concluded that the presence of augmented Reality can have a positive impact on various sectors of life, particularly in education. AR has been extensively discussed and reported in the context of geometry education, including Geogebra-3D (Widada et al., 2021), ARSC (Sayed et al., 2011), IARBook (Bazzaza et al., 2014), AUGGO (Yuhana et al., 2020), GemAR (Husniah et al., 2020), DiedricAR (de Ravé et al., 2016). The experts emphasize that the design and implementation of AR systems are intended to teach abstract geometric concepts. This system presents students with interactive 3D scenes that can be explored from multiple perspectives, helping them enhance their spatial intuition. However, these studies have not yet fully integrated technology with local culture. For instance, older forms of cultural heritage can be combined with new technologies (Samuelsson, 2022).

UNESCO defines cultural heritage as the tangible and intangible artefacts originating from groups or communities, passed down from previous generations, cared for in the present, and preserved for future generations (Bonenberg, 2020). Cultural heritage is also defined as a symbol of a civilization's spiritual and intellectual wealth, encompassing intangible heritage associated with traditions and living expressions (Idris et al., 2016). Moreover, it represents a collection of unique customs, objects, places, values, and artworks originating from the past and found in various countries and regions (Janković, 2019). It can be interpreted as a legacy of human thought and creation, carrying profound meanings as symbols of human life (Huda & Feriandi, 2018). Thus, it can be concluded that cultural heritage is a collection of inheritances passed down from generation to generation, encompassing both tangible and intangible forms, serving as symbols of human life. Cultural heritage is divided into two forms: tangible and intangible cultural heritage (Doulamis et al., 2017; Heesom et al., 2021). Tangible cultural heritage comprises physical objects, artefacts, and monuments of cultural significance. Intangible cultural heritage, on the other hand, encompasses practices, expressions, knowledge, and skills transmitted orally through rituals, performances, and other forms of cultural expression.

This article aims to complement previous studies by focusing on how AR strategies can be integrated into the learning of geometry and cultural heritage. The following research questions guide this study: 1) What does ARUNG mean, and has the term ARUNG ever been researched before? 2) How are the elements of cultural heritage (Material Collecting) integrated into ARUNG? 3) How is the ARUNG system designed for geometry education? 4) What are the outcomes in terms of the competency in understanding geometric concepts achieved using ARUNG?. By exploring these questions, this article aims to provide comprehensive knowledge, both conceptual and practical, of ARUNG. Furthermore, this study is based on the argument that, in mathematics education, students often encounter difficulties or lose interest due to the subject's complexity. Geometry is a challenging subject for students, with abstract objects being one contributing factor. ARUNG facilitates the understanding of abstract concepts that cannot be adequately represented in 2D. The innovations found in ARUNG are as follows: Firstly, the integration of cultural heritage concepts into modelling geometric constructions, such as those found in the Jami Tua Mosque of Palopo (the pole of Soko Guru, the wall of Jami Tua Mosque of Palopo), Lokko'e Tomb, and PNIEL Church. Secondly, AR technology is marker-based, and the application runs on the Android platform, providing ease of both offline and online access. Thirdly, using ARUNG enhances understanding of geometric concepts. Therefore, ARUNG can serve as a solution to enrich geometry learning media by integrating cultural heritage.

METHODS

The design of the ARUNG application for learning geometry applies the IPO (Input-Process-Output) diagram (Pritami & Muhimmah, 2018). The IPO diagram helps understand the flow of apps from start to end of the app journey. The focus of this research is on designing, developing, and testing the effectiveness of an innovative AR-based Android learning media that integrates cultural heritage from South Sulawesi Province, Indonesia, into the application. The stages of the research process, which are divided into four main phases: input, process, output, and outcome. The input stage focuses on identifying user needs through Focus Group Discussions (FGDs) involving professors, multimedia experts, and geometry subject matter experts. This stage also includes material collection activities such as site visits to cultural heritage locations, obtaining access permits, conducting photo-taking sessions, and reviewing relevant literature. The process stage involves the development of the system, including system model design, interface model design, and virtual object design. It also covers technical implementation steps such as marker generation, Android processing, and testing. The output stage results in the development of ARUNG, an augmented reality (AR) application that integrates local wisdom. Finally, the outcome stage emphasizes the educational impact of the research, namely enhancing users' understanding of geometry concepts.

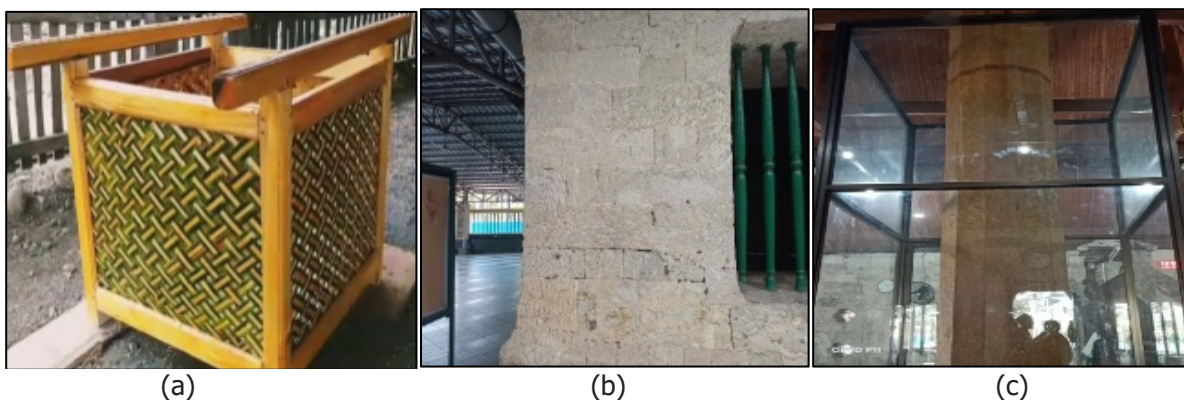
The data source for this research consists of 25 eighth-grade students from a junior high school, serving as the sample for the experimental application of ARUNG. The data collection techniques used are 1) interviews to gather data on cultural heritage history; 2) observation of the ARUNG prototype; 3) questionnaires to collect data on the validity of ARUNG, and 4) tests to collect data on the understanding of geometry concepts. The instruments used in this research are 1) interview guidelines; 2) Observation Sheet for Augmented Reality Product Testing (Marker testing, Mobile camera specification testing, distance, and angle camera testing); 3) Validity Questionnaire. The evaluation is conducted by two types of validators: media experts and content experts. Media experts focus on the technical and visual quality of the product, assessing the software and design aspects. The software evaluation includes indicators such as file size, smoothness and ease of operation, availability of a user guide, and the level of interactivity.

Meanwhile, the design aspect examines the interface design, clarity of texts, quality of images and sound, and the functionality of buttons. Content experts, on the other hand, evaluate the educational quality and usefulness of the product. Their assessment covers learning design, content, and function. The learning design aspect includes indicators such as the clarity of learning objectives, learning emphasis, flexibility, compatibility between the marker book and the AR application, and appropriate language structure. The content aspect focuses on the accuracy, sequence, and completeness of the material presented. Finally, the function aspect evaluates how useful the product is for both lecturers and students. Together, these criteria ensure that the educational media is technically sound, well-designed, pedagogically effective, and practical for teaching and learning, and 4) geometry concept comprehension test competencies measured is applying patterns and generalizations to make predictions and estimating and calculating the surface area and volume of a flat-sided shape, for questions indicators are determining the elements of geometric flat shapes, determining the nets of geometric flat-sided shapes, calculating the surface area of a geometric shape, and calculating the volume of a geometric shape.

The data analysis methodology employed in this study involves analyzing validation data provided by experts and assessing geometric concept understanding through quantitative and descriptive statistical analyses. The determination of the levels of validity (0-20) invalid, (21-40) less valid, (41-60) fairly valid, (61-80) valid, and (81-100) highly valid. The hypothesis in this study is H_0 : there is no difference in students' understanding of geometric concepts before and after using ARUNG media, H_1 : students' understanding of basic geometric concepts is higher after using ARUNG media. Data on the results of the conceptual understanding test were analyzed to answer the research hypothesis using a paired t-test, if $t_{table} \leq t_{count}$ then the research hypothesis (H_1) is accepted. To address ethical issues, this study was reviewed and approved by the ethical research committee of Institut Agama Islam Negeri Palopo to protect the privacy, rights, and confidentiality of all research subjects. Following [Sukirman and Kabilan \(2023\)](#), this study also obtained informed consent from all participants, who signed the consent form. The consent form stated clearly the research aims, clearly stating "the participants' rights and voluntary participation, including withdrawal from the study at any time" ([Sukirman & Kabilan, 2023](#)).

RESULT AND DISCUSSION

The process of collecting cultural heritage material includes site visits, access permits to sites or objects, and photo-taking sessions.



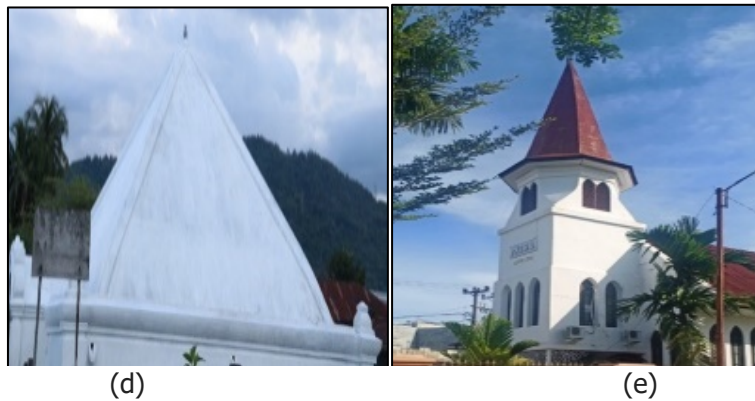


Figure 1. Marker Culture Heritage Palopo City

Figure 1a, known as "Wala Suji" or "Bala Suci," holds significant cultural value in South Sulawesi, particularly in Palopo city. It is considered a well-preserved cultural heritage and is frequently observed during wedding ceremonies. The term "Bala Suji" signifies a divider (*bala*) with sacred connotations (*suji*), constructed using bamboo weaving techniques to achieve various forms, depending on its intended purpose. It serves as a symbolic partition between the groom and the bride, as a vessel for presenting gifts from the groom, or as an embellishment of the wedding venue's entrance (Asis & Halip, 2020). The fabrication process of Wala Suji emphasizes congruence and parallelism in its structural components. The upper section of Wala Suji remains open, allowing offerings, such as agricultural produce and cattle for the bride, to be placed during the ceremony.

Figure 1b depicts a wall segment of the ancient Palopo Grand Mosque. This architectural masterpiece holds significant historical value as it was established in 1604 under the patronage of Andi Pattiware, a prominent figure in the region. The mosque's construction features durable materials, such as schist, which were meticulously joined with a mixture of egg white and lime. This meticulous construction technique ensures the mosque's longevity and structural stability, safeguarding its cultural and architectural heritage (Mutmainna et al., 2018). The use of schist stones, crafted into rectangular blocks measuring 0.92 cm thick, in the construction of the mosque walls demonstrates clear architectural influences reminiscent of Javanese temple designs. Notably, the mosque's structure is remarkable for its deliberate use of substantial natural stone, a characteristic feature of buildings in moderate or cold climates. This architectural decision aptly reflects a keen awareness of regional climatic conditions and exemplifies the design's adaptability to local environmental conditions (Duli et al., 2013; Siola, 2020).

Figure 1c depicts the principal pillar of the Jami Tua Mosque of Palopo, known as the "Soko Guru" pillar. It features five pillars, four on the left and right sides, while the central pillar, referred to as Soko Guru, occupies the center. The central pillar is currently adorned with glass. Standing at 784 cm and with a diameter of 950 cm, the Soko guru pillar distinguishes itself from the smaller pillars measuring 420 cm in height and 100 cm in diameter. The Soko guru pillar is skillfully crafted from cinaduri wood, whereas the remaining four pillars are constructed using *bitti* and *lelupan* wood, showcasing a meticulous selection of materials (Mansyur & Hasrianti, 2019). Figure 1d shows the Lokko'e tomb in Palopo city, an esteemed historical site in Luwu Regency. The local community attests that the construction of this tomb complex coincided with the establishment of the Jami Tua Mosque of Palopo in 1619. Remarkably, the Lokko'e tomb houses 37 tombs of the Luwu kings, forming a distinctive dome structure measuring 10m x 10m. Notably, the focal point lies within the *cungkup*, where the tombs of Datu Luwu and his family are interred. The *cungkup* exhibits a pyramid-shaped roof, with each side seamlessly merging with the four-sided walls. An intriguing aspect concerns the identification of 42 tombs within the *cungkup*, each characterized by diverse ornamental motifs, including beams, flat surfaces, menhirs, and cylindrical shapes (Duli et al., 2013).

Figure 1e depicts the Pniel Church, a venerable and historic structure located in the city of Palopo. Established in 1924, this church holds significant cultural value as a relic from the Dutch era and stands as both a place of worship and an iconic symbol of Palopo. The founding of Pniel Church can be traced back to the arrival of the first Zending envoy, Mr. Antonie Aris Van de Loosdrecht, and his wife Aida Patnella Sizoo, who embarked on a mission to spread Christianity. Upon their arrival in Palopo, they encountered a growing community of Christian believers. To accommodate the increasing congregation, the PNIEL church was constructed in the Dutch architectural style, providing a dedicated space for worship that replaced the previous practice of gathering in Dutch-built houses. As a cultural heritage site, Pniel Church exhibits distinct architectural features such as its roof and windows, which are reminiscent of other historic buildings in Palopo, including the Jami Tua Mosque of Palopo, the Datu Luwu Palace, the former Customs Office, the deputy mayor's office, the LVRI office, and the army office (Nurhijrah & Fisul, 2019). The unaltered roof shape serves as evidence of the building's antiquity. The church's structure follows a rectangular floor plan measuring 18.76 m by 8.25 m. Its roof, clad in zinc, features a gable design with two sloping sides. Positioned at the front is a tower featuring a

pyramid-style roof, serving as an external transitional area (Mansyur & Hasrianti, 2019). The ARUNG's proposed augmented reality (AR) system comprises a series of menus. The functional requirements encompass interconnected, mutually supportive key functions. These functions primarily involve users utilizing the AR media application on Android devices in conjunction with marker books.

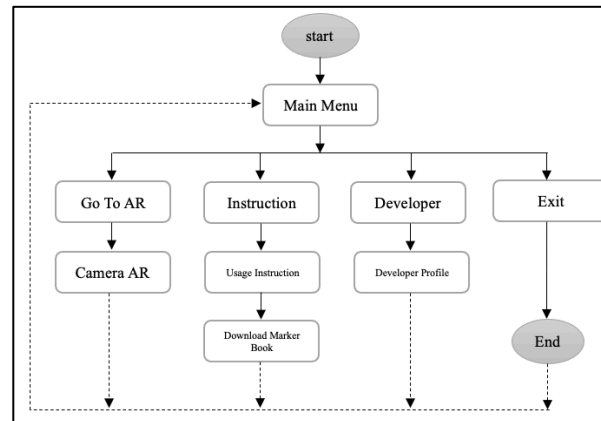


Figure 2. Design of System Model

The augmented Reality (AR) output is presented as an Android application named ARUNG, which includes a loading menu, start menu, instructions menu, and developer menu (Figure 3). Click Start AR and point the Android device at the Marker book, and the 3D object display will appear in real time (Figures 4).



Figure 3. ARUNG Application

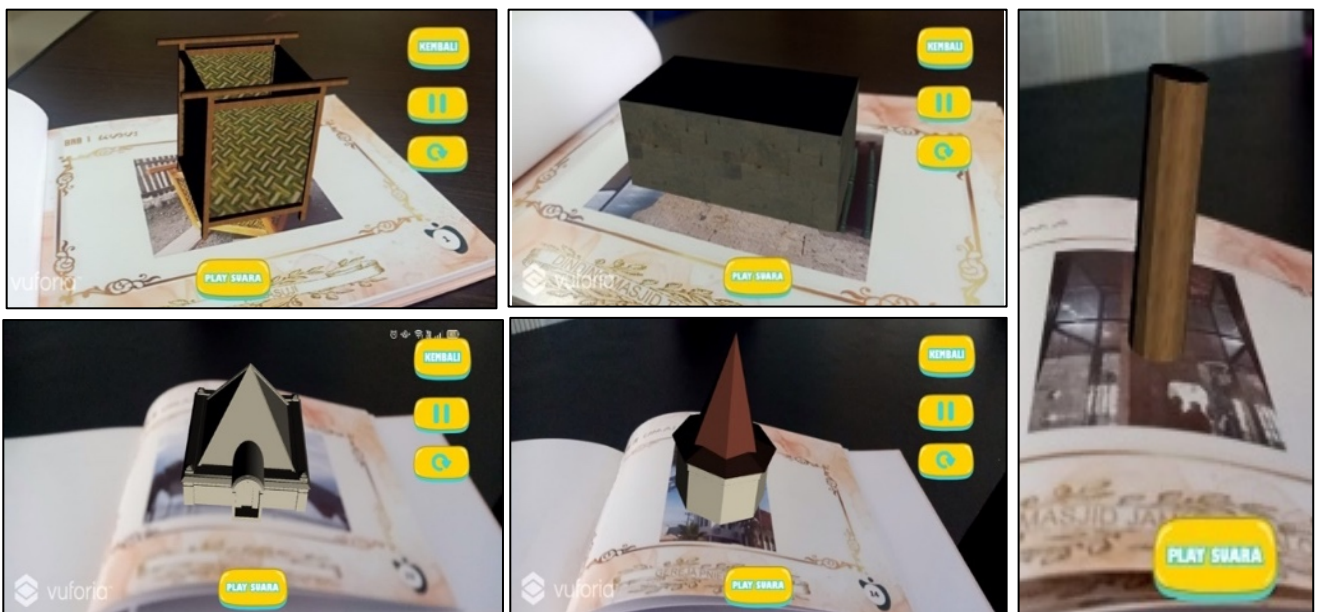


Figure 4. Display AR

The ARUNG application displays several markers, including: 1) Walasuji is a cube model for academic purposes; students can first explore its elements, such as vertices, edges, faces, diagonal lines, and diagonal planes. Secondly, calculate the surface area of a cube using the formula $6s^2$. Thirdly, calculate the volume of a

cube using the formula s^3 . 2) The walls of the grand mosque serve as a model for a rectangular prism. Students can first explore the elements of a rectangular prism, such as vertices, edges, faces, diagonal lines, and diagonal planes. Secondly, calculate the surface area of the rectangular prism using the formula $2(pl + pt + lt)$. Thirdly, calculate the volume of the rectangular prism using the formula $p \times l \times t$. 3) The pillars of the mosque Soko guru serve as a model for a twelve-sided prism. Students can explore, firstly, the elements of a prism, such as vertices, edges, faces, diagonal lines, and diagonal planes. Secondly, calculate the surface area of the prism using the formula: the total area of the upright side plus two times the area of the base. Thirdly, calculate the volume of the prism using the formula base area times height. 4) The royal tombs of Luwu Lokko'e serve as a model for a square pyramid. Students can explore, firstly, the elements of a square pyramid, such as vertices, edges, faces, diagonal lines, and diagonal planes. Secondly, calculate the surface area of the square pyramid using the formula: the Total area of the upright side plus the area of the base. Thirdly, calculate the volume of the pyramid using the formula $\frac{1}{3} La \times t$. and 5) The old PNIEL Church in Palopo serves as a model for an octagonal pyramid. Students can explore, firstly, the elements of an octagonal pyramid, such as vertices, edges, faces, and diagonal lines. Secondly, calculate the surface area of the octagonal pyramid using the formula: the Total area of the upright side plus the area of the base. Thirdly, calculate the volume of the pyramid using the formula $\frac{1}{3} La \times t$. The black-box testing process involves executing applications or programs and assessing whether errors occur. The testing encompasses various aspects, including marker testing and camera distance and angle testing. The paraphrased sentence maintains an academic tone, grammatical accuracy, and cohesion while effectively conveying the original meaning.

Table 1. Testing Marker

Marker	Descriptions	Results		
		3D	Texts	Sound
Walusuji	Marker Walusuji serves to display Palopo's AR local wisdom for modeling cubes	Successfully displayed	3D object and texts are matched	Matches the narration of the text
The wall of Jami Tua Mosque of Palopo	Marker "the wall of Jami Tua Mosque of Palopo" serves to display the local AR wisdom modelling blocks	Successfully displayed	3D object and texts are matched	Matches the narration of the text
Soko guru pole	The main pole marker displays the local AR wisdom, modelling a twelve-sided prism.	Successfully displayed	3D object and texts are matched	Matches the narration of the text
The tomb of Lokko'e	Marker Lokko'e serves to display the local AR wisdom modelling a rectangular pyramid	Successfully displayed	3D object and texts are matched	Matches the narration of the text
Gereja PNIEL Palopo	Marker "the roof of PNIEL church" serves to display the local AR wisdom modelling octagonal pyramid	Successfully displayed	3D object and texts are matched	Matches the narration of the text

Table 2 shows that the cultural heritage markers are in the form of 3D animation, text, and sound, indicating that all markers were successfully displayed and matched the text and sound.

Table 2. Test for Distance and Camera Angles

Distance between camera and marker (meters)	Tilt			Remarks
	0°	30°	60°	
2	-	-	-	Not successfully displayed
1,5	-	-	-	Not successfully displayed
1,25	√	√	-	Successfully displayed
1	√	√	√	Successfully displayed
0,5	√	√	√	Successfully displayed
0,25	√	√	√	Successfully displayed

Table 3 shows the results of testing camera distance and camera angles. The maximum distance for the Android camera to display the marker is 1.25 meters above that point. The Android camera angles are 60°, which are perfect up to a height of 1 meter. The validity of this media is validated by two content experts and two media experts. The content is rated for its significance, materials, and learning design. On the other hand, the media is rated for the design and software. The content validity of the learning material is rated at 91, placing it in the highly valid category. Similarly, the learning media experts' rating is 88, also indicating a highly valid category. ARUNG was subjected to an experimental study involving 25 eighth-grade students from a junior

high school. On the first day, a 40-minute pre-test was administered to assess students' understanding of concepts before engaging in learning activities using the ARUNG application. Subsequently, on the second day, the treatment was implemented, focusing on introductory lessons on geometric elements and geometric nets. The third day of the study focused on determining the surface area and volume of geometric shapes. The initial assessment of students' comprehension of geometric concepts yielded an average pre-test score of 52.8. However, after treatment, the post-test results showed an average score of 81.6 (Table 3). The hypothesis (H1) of this study posits that the utilization of ARUNG as a learning medium can enhance students' understanding of geometric concepts. The hypothesis test, presented in Table 8, demonstrates that the calculated t-value (12.039) exceeds the critical t-value (1.714) from the t-table, and the significance level (0.000) is lower than the predetermined alpha level of 0.005. Hence, H1 is accepted, and H₀ is rejected.

Table 3. Experimental Descriptive Data

N=25	Pre-test	Post-test
Mean	52,8	81,6
Standard Deviation	7,487	13,190
Minimum	41	50

Table 4. Paired Sample T-test

Table 11. Paired Sample T-test								
	Paired Differences					t	df	Sig
	Mean	St. Deviation	Std Eror Mean	95% Confidence Interval of The Difference				
				Lower	Upper			
Pair 1 Pretest-Posttest	28,40	11,978	2,396	33,784	23,896	12,039	23	0,000

The research, which aims to elucidate the developed ARUNG application, has yielded three significant findings. Firstly, Indonesia possesses numerous cultural heritages that can be seamlessly integrated into geometry education. Structures and architectural designs can serve as valuable resources for contextualizing abstract concepts. Secondly, in addition to its physical manifestation, the ARUNG application is also available on Android, providing users with convenient access both online and offline. The application offers user-friendly features, making it easy to use. Lastly, the utilization of ARUNG has demonstrated a positive impact on students' comprehension of geometric concepts. The presentation of real-time 3D visualizations fosters an interactive learning environment, facilitating students' self-guided exploration and understanding.

The ARUNG application, as depicted in this study, holds promising implications for the learning of geometry among junior high school students, particularly about conceptual comprehension and student knowledge (de Ravé et al., 2016). AR also facilitates the comprehension of abstract 3D concepts that cannot be adequately represented in 2D (İbili et al., 2020). In recent years, technological growth has begun to explore cultural heritage (Dagnino et al., 2017). Therefore, this study integrates cultural heritage into geometry learning to enhance cultural awareness. The use of AR in the Indonesian educational context is not yet widespread, partly due to teachers' influence. Insufficient technological literacy among teachers hinders the implementation of innovative approaches in the learning process, thereby hindering the effective achievement of learning objectives. The willingness of mathematics teachers to embrace change lays the foundation for transforming mathematics education, particularly in geometry.

This study presents findings that contrast with previous research. While many previous studies have highlighted the significant contribution of AR as an innovative approach to enhancing geometry learning, this study's results indicate differences in the observed outcomes (Buchori et al., 2017; Cahyono, 2018; Cruzado et al., 2020; Nurmawati & Suparman, 2017; Yuhana et al., 2020). Moreover, previous studies have also focused on exploring the impact of AR on students' conceptual understanding in the context of learning. This aspect was investigated by İbili et al. (2020), who developed the ARGTS application, specifically designed to enhance students' spatial reasoning skills through activities involving the arrangement of 3D cubes and the calculation of volumes and shapes. However, contrary to expectations, their study found no significant improvement in students' cognitive abilities or critical thinking skills from using the AR application. The findings of these studies reveal significant distinctions from previous research, as ARUNG stands out not only as an augmented reality (AR) application designed to facilitate learning, but also as a unique integration of cultural heritage elements. This feature sets it apart from numerous other AR applications. This distinctive aspect of ARUNG, incorporating cultural heritage, has not been widely explored in existing AR applications.

Furthermore, integrating the ARUNG application allows students to interact directly with culturally contextualized 3D Geometric models, making the learning process more visual, concrete, and engaging. Based on a preliminary trial conducted with eighth-grade students, approximately 87% reported that they found it easier to understand geometric concepts and felt more enthusiastic during lessons using the application than

with traditional methods. ARUNG has demonstrated a positive influence on learning, leading to enhanced comprehension of geometric concepts. Therefore, it is imperative to make concerted efforts to enhance educators' competence, particularly in technological literacy. By doing so, teachers can effectively embrace and implement ARUNG in geometry learning. The changing educational landscape necessitates educators to adapt and innovate their teaching approaches to cater to Generation Z students, who are the digital natives of the 4.0 era. Consequently, the transition from conventional learning materials to AR is expected to foster an engaging and enjoyable learning experience and to open a new direction for the development of technology-enhanced learning media. This research significantly advances educational technology and culturally responsive pedagogy in science education. By integrating Augmented Reality with local cultural heritage, ARUNG introduces a novel interdisciplinary approach that bridges mathematics, technology, and cultural studies.

CONCLUSION

ARUNG (Augmented Reality for Learning Geometry), an Android application that integrates cultural history into geometry learning, was developed because of this study. Originating in the Bugis and Makassar cultures of South Sulawesi, the name "Arung" is often used to describe a noble or traditional leader of great stature, often on par with a king. The app was given the moniker ARUNG to represent leadership in educational innovation and exploration, given its cultural relevance. To illustrate geometric shapes aligned with curricular material, traditional Indonesian items and architectural forms were modelled. The application supports interactive, contextualized learning by providing real-time 3D visualizations, easy-to-use navigation, and online and offline access. Students' comprehension of geometric ideas significantly improved after implementation, and validation revealed great efficacy. ARUNG links abstract mathematics to cultural identity and improves student engagement. ARUNG offers a model for technology-enhanced, culturally relevant learning, notwithstanding its existing limitations regarding flat-sided shapes and a single-site experiment. Its cultural reach and educational influence could expand further throughout Indonesia.

REFERENCES

- Ara, J., Karim, F. B., Alsubaie, M. S. A., Bhuiyan, Y. A., Bhuiyan, M. I., Bhyan, S. B., & Bhuiyan, H. (2021). Comprehensive Analysis of Augmented Reality Technology in Modern Healthcare System. *International Journal of Advanced Computer Science and Applications*, 12(6), 845–854.
- Asis, A., & Halip, M. F. (2020). Analisis Unsur Semiotika Penggunaan Bambu Pada Masyarakat Etnik Mandar. *Pepatudzu: Media Pendidikan Dan Sosial Kemasyarakatan*, 16(2), 142.
- Bazzaza, M. W., Al Delail, B., Zemerly, M. J., & Ng, J. W. (2014, December). iARBook: An Immersive Augmented Reality System for Education. In *2014 IEEE International Conference on Teaching, Assessment and Learning for Engineering (TALE)* (pp. 495–498). IEEE.
- Bonenberg, W. (2020). The Role of Cultural Heritage in Sustainable Development. Values and Valuation as Key Factors in Spatial Planning of Rural Areas. *Advances in Intelligent Systems and Computing*, 966.
- Bower, M., Howe, C., McCredie, N., Robinson, A., & Grover, D. (2014). Augmented Reality in Education - Cases, Places and Potentials. *Educational Media International*, 51(1), 1–15.
- Buchori, A., Setyosari, P., Dasna, I. W., & Ulfa, S. (2017). Mobile Augmented Reality Media Design With Waterfall Model for Learning Geometry in College. *International Journal of Applied Engineering Research*, 12(13), 3773–3780.
- Cahyono, B. (2018). Augmented Reality Applied to Geometry Education. In *Proceedings - 2nd East Indonesia Conference on Computer and Information Technology: Internet of Things for Industry, EIConCIT 2018* (pp. 299–303).
- Cruzado, J. P., Céspedes, T. L., Coria, G. P. B., & Salazar, J. L. H. (2020, October). Geobook: Mobile App With Augmented Reality for Learning Geometry. In *2020 IEEE Engineering International Research Conference (EIRCON)* (pp. 1–4). IEEE.
- Dagnino, F. M., Pozzi, F., Cozzani, G., & Bernava, L. (2017, February). Using Serious Games for Intangible Cultural Heritage (ICH) Education: A Journey Into the Canto a Tenore Singing Style. In *Special Session on Computer Vision, Imaging and Computer Graphics for Cultural Applications* (Vol. 6, pp. 429–435). SCITEPRESS.
- de Ravé, E. G., Jiménez-Hornero, F. J., Ariza-Villaverde, A. B., & Taguas-Ruiz, J. (2016). DiedricAR: A Mobile Augmented Reality System Designed for the Ubiquitous Descriptive Geometry Learning. *Multimedia Tools and Applications*, 75(16), 9641–9663.

- Doulamis, N., Doulamis, A., Ioannidis, C., Klein, M., & Ioannides, M. (2017). Modelling of Static and Moving Objects: Digitizing Tangible and Intangible Cultural Heritage. In *Mixed Reality and Gamification for Cultural Heritage* (pp. 567–589). Springer International Publishing.
- Duli, A., Rahman, A., Sulisty, B., Muhaeminah, M., Raodah, R., Rosmawati, R., & Sumalyo, Y. (2013). *Monumen Islam di Sulawesi Selatan*. Direktorat Jenderal Kebudayaan.
- Firmansyahputra, B., & Cherid, A. (2020). Aplikasi Multimedia Pengenalan Huruf Alfabet, Buah dan Hewan Menggunakan Teknologi Augmented Reality. *Jurnal Telekomunikasi Dan Komputer*, 9(3), 173.
- Garzón, J., Pavón, J., & Baldiris, S. (2019). Systematic review and meta-analysis of augmented reality in educational settings. *Virtual Reality*, 23(4), 447–459.
- Heesom, D., Boden, P., Hatfield, A., Rooble, S., Andrews, K., & Berwari, H. (2021). Developing a Collaborative HBIM to Integrate Tangible and Intangible Cultural Heritage. *International Journal of Building Pathology and Adaptation*, 39(1), 72–95.
- Hou, H. T., & Keng, S. H. (2021). A Dual-Scaffolding Framework Integrating Peer-Scaffolding and Cognitive-Scaffolding for an Augmented Reality-Based Educational Board Game: An Analysis of Learners' Collective Flow State and Collaborative Learning Behavioral Patterns. *Journal of Educational Computing Research*, 59(3), 547–573.
- Huda, K., & Feriandi, Y. A. (2018). Pendidikan Konservasi Perspektif Warisan Budaya untuk Membangun History for Life. *Aristo*, 6(2), 329–343.
- Husniah, L., Nugraha, Y. B. S., Kholimi, A. S., Yuhana, U. L., Yuniarno, E. M., & Purnomo, M. H. (2020, November). Gemar: Geometry Augmented Reality Application for Elementary School Students. In *2020 IEEE Graphics and Multimedia (GAME)* (pp. 25–30). IEEE.
- İbili, E., Çat, M., Resnyansky, D., Şahin, S., & Billinghamurst, M. (2020). An Assessment of Geometry Teaching Supported With Augmented Reality Teaching Materials to Enhance Students' 3D Geometry Thinking Skills. *International Journal of Mathematical Education in Science and Technology*, 51(2), 224–246.
- Idris, M. Z., Mustaffa, N. B., & Yusoff, S. O. S. (2016). Preservation of Intangible Cultural Heritage Using Advance Digital Technology: Issues and Challenges. *Harmonia: Journal of Arts Research and Education*, 16(1), 1–13.
- Janković, R. (2019). Machine Learning Models for Cultural Heritage Image Classification: Comparison Based on Attribute Selection. *Information*, 11(1), 1–13.
- Kerr, J. (2020). Augmented Reality in Design Education: Landscape Architecture Studies as AR Experience. *International Journal of Art and Design Education*, 39(1), 6–21.
- Lacey, G., Gozdzielewska, L., McAloney-Kocaman, K., Ruttle, J., Cronin, S., & Price, L. (2022). Psychomotor Learning Theory Informing the Design and Evaluation of an Interactive Augmented Reality Hand Hygiene Training App for Healthcare Workers. *Education and Information Technologies*, 27(3), 3813–3832.
- Liang, L. J., & Elliot, S. (2021). A Systematic Review of Augmented Reality Tourism Research. *Tourism and Hospitality Research*, 21(1), 15–30.
- López-Belmonte, J., Moreno-Guerrero, A. J., López-Núñez, J. A., & Hinojo-Lucena, F. J. (2023). Augmented Reality in Education. A Scientific Mapping in Web of Science. *Interactive Learning Environments*, 31(4).
- Mansyur, S., & Hasrianti, H. (2019). Perkembangan Arsitektur Masa Kolonial di Kota Palopo (1908-1940). *Jurnal Tumotowa*, 2(2), 92–105.
- Moreno-Guerrero, A. J. (2020). Augmented Reality as a Resource for Improving Learning in the Physical Education Classroom. *International Journal of Environmental Research and Public Health*, 17(10).
- Munir, N. P., Anas, A., Sunarti, S., Mursalin, N. R., & Natsir, I. (2021). Development of Mathematics Student Worksheets Through the Approach Model Eliciting Activities (MEAs) on the Triangle Material. *Journal of Physics: Conference Series*, 1940(1), 012097.
- Mutmainna, M., Ridha, M. R., & Najamuddin, N. (2018). Masjid Agung Luwu: Pusat Sejarah dan Pengembangan Islam di Palopo. *Jurnal Pattingalloang*, 5(2), 76–81.
- Nurhijrah, N., & Fisru, A. A. (2019). Place Memory Masyarakat Pada Bangunan Cagar Budaya di Kota Palopo. *Review of Urbanism and Architectural Studies*, 17(2), 63–70.
- Nurmawati, & Suparman. (2017). Development of E-Book With Augmented Reality on Analytical Geometry Course. *Man in India*, 97(24), 359–368.

- OECD. (2023). *PISA 2022 Results*. In *Factsheets* (Vol. 1).
- Pritami, F. A., & Muhimmah, I. (2018, February). Digital Game Based Learning Using Augmented Reality for Mathematics Learning. In *Proceedings of the 2018 7th International Conference on Software and Computer Applications* (pp. 254–258).
- Quintero, J., Baldiris, S., Rubira, R., Cerón, J., & Velez, G. (2019). Augmented Reality in Educational Inclusion. A Systematic Review on the Last Decade. *Frontiers in Psychology*, 10(8), 1–14.
- Rauschnabel, P. A., Babin, B. J., tom Dieck, M. C., Krey, N., & Jung, T. (2022). What is augmented reality marketing? Its definition, complexity, and future. In *Journal of Business Research* (Vol. 142, pp. 1140–1150).
- Rezaee, S., Sadeghi-Niaraki, A., Shakeri, M., & Choi, S. M. (2021). Personalized Augmented Reality Based Tourism System: Big Data and User Demographic Contexts. *Applied Sciences*, 11(13).
- Richardo, R., Abdullah, A. A., Rochmadi, T., Wijaya, A., & Nurkhamid. (2023, January). Ethnomatematics Learning Media Based on Augmented Reality for Learning Geometry: A Needs Analysis. In *AIP Conference Proceedings* (Vol. 2540, No. 1, p. 070018). AIP Publishing LLC.
- Samuelsson, R. (2022, June). Cultural Heritage Through Educational Robots: Using a Ukrainian Folk Tale With a Programmable Robot in Early Childhood Education. In *International Conference on Human-Computer Interaction* (pp. 336–343). Springer Nature Switzerland.
- Sayed, N. E., Zayed, H. H., & Sharawy, M. I. (2011). ARSC: Augmented Reality Student Card an Augmented Reality Solution for the Education Field. *Computers & Education*, 56(4), 1045–1061.
- Siola, A. (2018). Pengaruh Ketebalan Dinding Terhadap Time Lag Masjid Jami' Kota Palopo. *LOSARI: Jurnal Arsitektur Kota dan Pemukiman*, 19–26.
- Sukirman, S., & Kabilan, M. K. (2023). Indonesian Researchers' Scholarly Publishing: An Activity Theory Perspective. *Higher Education Research & Development*, 42(8), 2030–2047.
- Sung, E. C. (2021). The Effects of Augmented Reality Mobile App Advertising: Viral Marketing Via Shared Social Experience. *Journal of Business Research*, 122, 75–87.
- Tresnawati, D., & Albani, I. M. (2021). Pengenalan Komponen Komputer Menggunakan Teknologi Augmented Reality. *Jurnal Algoritma*, 17(2), 457–552.
- Tzima, S. (2019). Augmented Reality Applications in Education: Teachers Point of View. *Education Sciences*, 9(2).
- Vilkina, M. V., & Klimovets, O. V. (2020). Augmented Reality as Marketing Strategy in the Global Competition. In *Lecture Notes in Networks and Systems* (Vol. 91, pp. 54–60).
- Wei, W. (2019). Research Progress on Virtual Reality (VR) and Augmented Reality (AR) in Tourism and Hospitality: A Critical Review of Publications From 2000 to 2018. *Journal of Hospitality and Tourism Technology*, 10(4), 539–570.
- Widada, W., Herawaty, D., Nugroho, K. U. Z., & Anggoro, A. F. D. (2021). Augmented Reality Assisted by GeoGebra 3-D for Geometry Learning. *Journal of Physics: Conference Series*, 1731(1), 012034.
- Wirza, R., Nazir, S., Khan, H. U., García-Magariño, I., & Amin, R. (2020). Augmented Reality Interface for Complex Anatomy Learning in the Central Nervous System: A Systematic Review. *Journal of Healthcare Engineering*, 2020(1), 1–15.
- Yuhana, U. L., Hariadi, R. R., Mukramin, M., Fabroyir, H., & Arifiani, S. (2020). AUGGO: Augmented Reality and Marker-Based Application for Learning Geometry in Elementary Schools. *2020 International Conference on Computer Engineering, Network, and Intelligent Multimedia (CENIM)*, 116–120.