Advance Sustainable Science, Engineering and Technology (ASSET)
Vol. 8, No.1, January 2026, pp. 02601014-01 ~ 02601014-014
ISSN: 2715-4211 DOI: https://doi.org/10.26877/asset.v8i1.2372

Developing a Trigonometry AR Book Using an Ethnomathematics Approach to Improve International Collage Students' Motivation and Learning Outcomes

Achmad Buchori[1*], Farida Nursyahidah[1], Dina Prasetyowati[1], Sharifah Osman[2]

[1]Faculty of Mathematics Education Natural Sciences, Information Technology, Universitas Persatuan Guru Republik Indonesia Semarang, Jl. Sidodadi-Timur No.24 Semarang, Central Java 50232, Indonesia

[2]Faculty of Sains Sosial dan Kemanusiaan, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100, Kuala Lumpur

*achmadbuchori@upgris.ac.id

Abstract. This study presents the development of an Augmented Reality (AR)-based trigonometry learning media integrating ethnomathematics to enhance students' conceptual understanding and engagement. The AR system was designed using the ADDIE framework, emphasizing the design and development stages, with validation conducted through expert review and limited user trials at Universitas PGRI Semarang (UPGRIS) and Universiti Teknologi Malaysia (UTM). The AR Book integrates local cultural geometries such as traditional architectural patterns and ornaments into interactive 3D visualizations to contextualize trigonometric concepts. The system was developed using Unity 3D and Vuforia SDK, optimized for Android devices. Validation results indicated high content validity (92%) and strong media practicality (88%), while small-scale implementation showed improved student motivation and learning outcomes. Beyond educational outcomes, the research contributes to the advancement of culturally adaptive AR learning media design and demonstrates the potential scalability of ethnomathematics-based AR systems in STEM education.

Keywords: trigonometry augmented reality systems, ethnomathematics integration, trigonometry media design, educational technology, interactive learning tools

(Received 2025-07-15, Revised 2025-12-05, Accepted 2025-12-06, Available Online by 2025-12-26)

1. Introduction

With today's rapid technological developments, teachers and lecturers are required to design learning that is engaging, interactive, and technologically adaptive [1]. At Universitas PGRI Semarang (UPGRIS), particularly within the Mathematics Education study program, very few textbooks produced by lecturers are integrated with Augmented Reality (AR)-based learning technology. Similarly, in the

Mathematics Education study program at Universiti Teknologi Malaysia (UTM), the development of AR-based teaching materials remains limited. Therefore, breakthroughs are needed to modernize learning resources, especially for the Trigonometry course. In the context of engineering-oriented education, integrating AR technology into mathematics instruction represents not only a pedagogical innovation but also a technological advancement supporting interactive system design and user-centered learning environments. This aligns with ASSET's mission of promoting sustainable science and engineering education through digital transformation.

Trigonometry, a fundamental branch of mathematics, is essential for solving problems involving angles and dimensions in two- and three-dimensional spaces. Its applications span diverse domains such as engineering, physics, architecture, computer graphics, and economics [2]. Mastery of trigonometry equips students with important analytical skills, enabling them to engage in advanced mathematical concepts and interdisciplinary applications [3]. [4] emphasizes that students proficient in trigonometry demonstrate stronger applied mathematics performance, while [5], notes that integrating real-world contexts enhances motivation and bridges the gap between theory and practice. To progress beyond pedagogical applications, AR media design must incorporate structured system architecture, usability validation, and adaptive visualization mechanisms that optimize user interaction efficiency. These elements transform conventional learning materials into measurable technological systems with clear engineering value. In this study, the AR architecture is designed as a modular system, enabling scalability and future integration with cloud-based or mobile learning platforms

Despite its importance, trigonometry learning in both Indonesia and Malaysia still encounters persistent challenges, as reflected by low student performance. Interviews with course lecturers revealed that the average final examination score in 2023 remained below 75. This highlights a systemic gap that can be addressed through immersive technologies capable of supporting spatial reasoning and contextual visualization capabilities that static two-dimensional media fail to achieve effectively. To overcome these issues, this study proposes the development of an innovative trigonometry textbook that integrates ethnomathematics and AR in every chapter. AR provides immersive 3D experiences that allow learners to concretely visualize abstract trigonometric concepts [6–9], improving motivation and learning outcomes [10,11], while fostering engagement through interactive media [12]. The novelty of this research is the combination of augmented reality (AR) features with ethnomathematical elements through the development of 3D visual models, marker-based object detection, and real-time interactive visualization implemented using Unity 3D and the Vuforia SDK platform. This technological approach contributes to AR system engineering while promoting cultural adaptability as a design principle.

Ethnomathematics explores the cultural roots of mathematical ideas, linking abstract principles to tangible traditions and practices. While this approach has been applied in other mathematical topics, its integration with AR tools for trigonometry remains underexplored [13,14]. Ethnomathematics supports students' conceptual understanding [15,16], problem-solving [17], and numeracy [18]. By embedding local cultural geometries such as Indonesian and Malaysian traditional architectures and ornaments into AR visualizations, this study fosters cultural contextualization while advancing the design of culturally adaptive AR-based learning systems.

Accordingly, this research aims to develop an Augmented Reality Book (AR Book) for trigonometry integrated with ethnomathematics that is valid, practical, and effective for enhancing student motivation and learning outcomes at UPGRIS and UTM. Specifically, the study contributes to the design and validation of a scalable AR-based learning system that combines pedagogical effectiveness with engineering functionality, positioning it as a potential framework for future STEM education innovations.

2. **Methods**

This research adopts a Research and Development (R&D) methodology guided by the ADDIE framework, which encompasses five structured phases: Analysis, Design, Development, Implementation, and Evaluation [19]. However, since this study represents the basic research phase of a multi-year project conducted in 2025, only the first three stagesAnalysis, Design, and Development were implemented. These stages focused on designing, constructing, and validating an Augmented Reality (AR)-based Trigonometry Textbook integrated with ethnomathematics. The ADDIE framework was selected because it provides a structured, iterative, and user-centered process that bridges instructional design and engineering-oriented media development [20].

The research began by identifying the learning performance problems faced by students in trigonometry courses at Universitas PGRI Semarang (UPGRIS) and Universiti Teknologi Malaysia (UTM). During this preliminary stage, data were collected through literature reviews, field observations, and semi-structured interviews with lecturers and students. The findings showed consistent issues: students had difficulty visualizing trigonometric relationships, low engagement with abstract concepts, and limited exposure to technology-based learning. These challenges became the foundation for designing an AR-enhanced learning solution.

The use of augmented reality in mathematics education has previously been demonstrated by Buchori et al. [13], who developed interactive AR-based learning media using Unity and Vuforia for geometry learning, proving its ability to enhance engagement and conceptual understanding. Similarly, Buchori and Istiyaningsih [1] emphasized that AR-integrated textbook design promotes contextual learning by combining digital visualization with ethnomathematical content, a framework adopted and expanded upon in this study. Technically, the AR-based Trigonometry Book was developed using Unity 3D as the main platform, Vuforia SDK for marker-based recognition, and Blender for 3D ethnomathematical modeling, in line with earlier frameworks by Buchori et al. [21] that integrated AR-Geogebra for geometric visualization in primary education. These systems were validated through expert review and internal consistency testing to ensure usability, accuracy, and accessibility in real classroom contexts.

The following is a flowchart of the research using ADDIE.

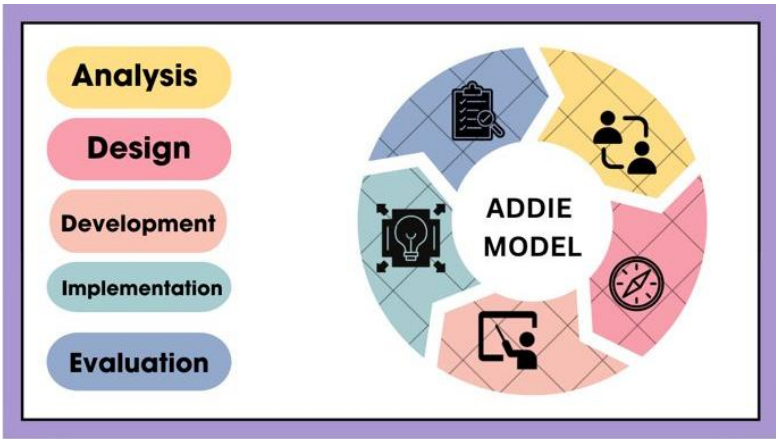


Figure 1. ADDIE Model

In the analysis stage, four main activities were conducted to establish the foundation of the AR-based trigonometry textbook design. The learning gap analysis identified students' conceptual weaknesses and motivational barriers based on exam results and interviews. The resource and curriculum analysis examined the availability of digital infrastructure and its alignment with AR-supported pedagogy. The material analysis determined trigonometric topics suitable for contextualization through ethnomathematical representations, such as traditional architecture, local ornaments, and cultural measurement systems [22,23]. Lastly, the learning outcome analysis ensured the designed content and AR elements were aligned with national curriculum standards and course objectives. Findings from this stage informed the product blueprint, emphasizing both pedagogical relevance and technological structure.

The design stage focused on developing the conceptual and technical framework of the AR textbook. A discourse analysis refined the language and clarity of mathematical explanations to improve comprehension. A flowchart and storyboard were created to visualize interactions between text, AR elements, and ethnomathematical components. Technically, the system was built using Unity 3D as the primary platform, Vuforia SDK for marker-based tracking, and Blender for 3D modeling of ethnomathematical objects. The design followed user-centered principles, ensuring intuitive interfaces, balanced cognitive load, and harmony between cultural aesthetics and mathematical content [24]. The AR system was also designed for cross-platform interoperability across Android and Windows devices, aligning with ASSET's emphasis on sustainable digital innovation in STEM education [25].

The development stage covered the production, validation, and refinement of the textbook prototype. Three experts a linguist, a mathematics content specialist, and a media expert validated the product's language, content, usability, and system performance using a Likert-scale validation sheet. Revisions were made based on expert feedback, improving AR interaction flow, synchronization, and 3D accuracy. Afterward, a one-to-one trial and small-group trial involving 20 students from UPGRIS and UTM were conducted using purposive sampling to assess practicality and usability.

The data were obtained through a combination of tests, questionnaires, interviews, and classroom observations, and subsequently analyzed using descriptive statistical techniques including the mean, percentage, and standard deviation along with qualitative triangulation to ensure the validity and reliability of the findings. A mean expert validation score above 80% indicated *very valid*, while a student response score above 85% indicated *very practical*. These results confirmed that the AR-based trigonometry textbook integrated with ethnomathematics is pedagogically effective and technologically viable for broader STEM learning implementation.

3. **Results and Discussion**

The development of the Augmented Reality (AR)-assisted Trigonometry Textbook in this study applied the ADDIE model as the systematic instructional framework, emphasizing both pedagogical design and technological implementation. The process covered three main stages Analysis, Design, and Development since this study represents the first phase of a multi-year R&D project. Each stage was executed iteratively to ensure both content validity and system reliability.

3.1 Analysis

During the analysis phase of developing the Augmented Reality (AR)-based Trigonometry Book integrated with an ethnomathematics approach, several comprehensive analyses were conducted to ensure both pedagogical and technological readiness. The initial stage involved identifying gaps between students' learning outcomes and expected competencies in trigonometry. Interviews with lecturers and preliminary tests revealed that students often struggled to understand trigonometric concepts abstractly, particularly when connecting them to real-world contexts and local cultural representations. This indicated the need for an interactive and contextually grounded medium capable of bridging conceptual understanding through visual and cultural dimensions.

A diagnostic test confirmed that while most students demonstrated adequate procedural knowledge, their ability to interpret contextual problems, visualize geometric forms, and relate mathematical principles to cultural applications remained limited. These findings emphasized the need to develop AR-assisted instructional materials that could enhance mathematical literacy through cultural contextualization. Infrastructure analysis showed that students at Universitas PGRI Semarang (UPGRIS) and Universiti Teknologi Malaysia (UTM) possessed the technological readiness for AR-based learning—most owned Android smartphones supporting ARCore with a minimum of 4GB RAM and stable internet connectivity. Furthermore, both institutions provided computer laboratories and lecturer support systems suitable for AR deployment.

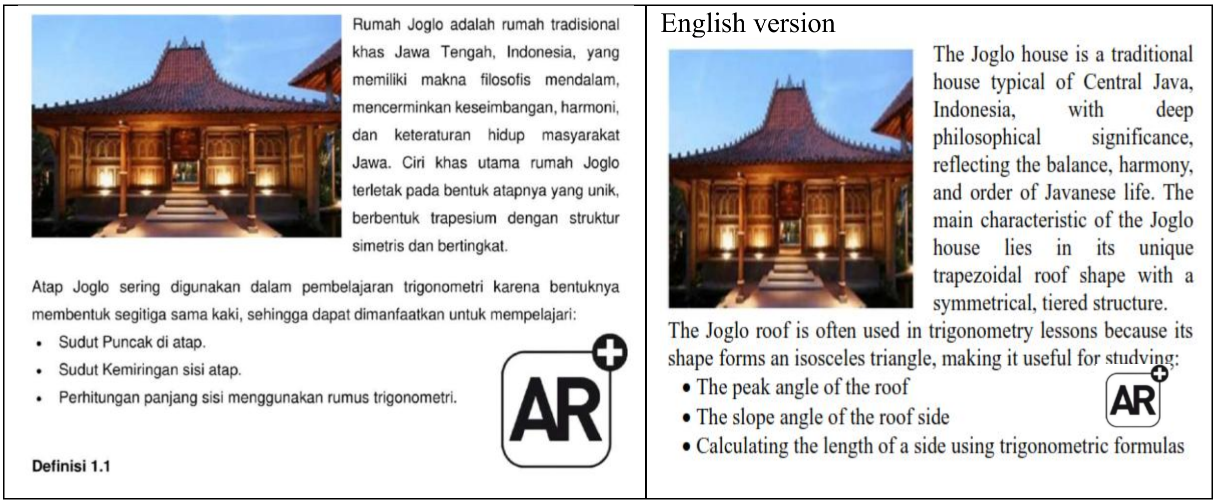
An analysis of the curriculum and learning resources was carried out with reference to the Mathematics Education study program syllabus, which identifies trigonometry as a fundamental component aimed at fostering students' critical thinking, creativity, and problem-solving abilities. The analysis confirmed that AR-based ethnomathematical learning aligns with program learning outcomes and 21st-century STEM education goals. Cultural components were mapped to trigonometric concepts Indonesian examples included the *Joglo* house roof and *Batik* ornaments, while Malaysian examples featured the *Kampung Laut Mosque* tower and the traditional Malay house roof each reflecting the geometric relationships of angles, triangles, and proportional lengths. These cultural contexts formed the foundation for designing AR-based visualizations, ensuring that the AR Book supported both conceptual learning and the preservation of cultural identity. This stage established the pedagogical and technical specifications necessary for effective AR integration.

3.2 *Design*

In the design stage, researchers developed a detailed framework for the AR-based Trigonometry Book integrating ethnomathematics, focusing on both instructional and engineering aspects. The process began with the creation of key development instruments, including expert validation sheets, student questionnaires, observation checklists, and interview guides. The validation sheet assessed material accuracy, media display clarity, AR system performance, and ethnomathematical relevance. The student questionnaire measured practicality, engagement, and ease of use, while observation sheets tracked interaction behavior during AR-based learning. The interview guide was used to collect qualitative feedback on user experience and usability.

To guide the learning workflow, a system flowchart was designed illustrating the complete learning interaction—from reading introductory trigonometry material, exploring cultural contexts (e.g., traditional roofs, mosque minarets, ornamental patterns), scanning AR markers, and visualizing 3D models, to solving contextual problems. Each flow segment was mapped to user interaction data, ensuring smooth navigation and minimizing cognitive load. The storyboard, developed using *Adobe XD* and *Figma*, visualized page layouts, text structure, and AR marker placement. It detailed how students would engage with content, trigger AR visualization, and complete high-order thinking (HOTS) exercises based on ethnomathematical contexts.

From a technical perspective, the AR system was developed using Unity 3D (version 2022.3) as the main development engine, Vuforia SDK (v10.14) for marker-based recognition, and Blender 3.6 for 3D object modeling. The system architecture supports Android (ARCore-enabled) and Windows devices, ensuring cross-platform interoperability. Design principles followed a user-centered and usability-driven approach, guided by the System Usability Scale (SUS) framework and heuristic evaluation to ensure accessibility, interface clarity, and efficient AR marker detection. Visual elements were optimized for contrast and cultural relevance, maintaining harmony between mathematical symbols and ethnomathematical illustrations. The draft AR Book design consisted of eight chapters, covering topics such as an introduction to trigonometry, special angles, trigonometric ratios, applications in Indonesian and Malaysian architecture, and ethnomathematical-based evaluation tasks. Each chapter integrates AR markers linked to interactive 3D models and contextual practice questions. The book layout was structured for both print and digital formats, including instructions for AR operation and QR code access to the learning platform. This dual-format design supports scalability and LMS integration, allowing the AR Book to be used in hybrid and online learning settings. Figure 2 illustrates an example of the AR Trigonometry Book interface and AR-based visualization workflow.



Rumah Joglo adalah rumah tradisional khas Jawa Tengah, Indonesia, yang memiliki makna filosofis mendalam, mencerminkan keseimbangan, harmoni, dan keteraturan hidup masyarakat Jawa. Ciri khas utama rumah Joglo terletak pada bentuk atapnya yang unik, berbentuk trapesium dengan struktur simetris dan bertingkat.

Atap Joglo sering digunakan dalam pembelajaran trigonometri karena bentuknya membentuk segitiga sama kaki, sehingga dapat dimanfaatkan untuk mempelajari:

- Sudut Puncak di atap.
- Sudut Kemiringan sisi atap.
- Perhitungan panjang sisi menggunakan rumus trigonometri.

AR

Definisi 1.1

English version

The Joglo house is a traditional house typical of Central Java, Indonesia, with deep philosophical significance, reflecting the balance, harmony, and order of Javanese life. The main characteristic of the Joglo house lies in its unique trapezoidal roof shape with a symmetrical, tiered structure.

The Joglo roof is often used in trigonometry lessons because its shape forms an isosceles triangle, making it useful for studying:

- The peak angle of the roof
- The slope angle of the roof side
- Calculating the length of a side using trigonometric formulas

AR

Figure 2. Example of AR Book Trigonometry Content

3.3 *Development*

During the development phase, the Augmented Reality (AR)-based Trigonometry Book integrated with ethnomathematics was systematically constructed and validated to ensure its pedagogical and technological feasibility. The development process focused on testing content accuracy, linguistic clarity, usability, and system performance. Technically, the AR system was built using Unity 3D (version 2022.3) as the main development engine, integrated with Vuforia SDK (v10.14) for marker-based tracking and recognition, and Blender (v3.6) for 3D object modeling of ethnomathematical elements such as *Joglo* roofs, *Batik* ornaments, and *Kampung Laut Mosque* towers. The AR application was optimized for Android-based devices supporting ARCore (minimum 4 GB RAM, Snapdragon 720G or higher) and Windows 10/11 systems for testing and development.

Expert validation was conducted to determine the validity and functionality of the developed learning media. Three validators participated in this stage: a mathematics content expert, a learning media expert, and a language expert. The content expert evaluated the appropriateness of trigonometric materials and the integration of cultural elements; the media expert reviewed visual design, interface readability, and AR marker stability; while the language expert assessed grammatical accuracy and instructional clarity. The validation instrument employed a five-point Likert scale adapted from the System Usability Scale (SUS) and heuristic usability principles to measure clarity, interactivity, functionality, and aesthetic consistency.

The validation results showed that the average score from material experts reached 92% (very valid) and from media experts 88% (valid). Some revisions were suggested, including the refinement of contextual examples for angle calculations, improving AR marker positioning for stability during scanning, and enhancing user guidance icons for smoother navigation. These recommendations were implemented, followed by limited revalidation, confirming that the revised AR Book prototype met the required validity standards and was ready for user testing. Subsequently, internal consistency and usability testing were conducted on a small group of 30 undergraduate mathematics education students (15 from Universitas PGRI Semarang and 15 from Universiti Teknologi Malaysia). The sampling used a purposive sampling technique, appropriate for the early-stage prototype evaluation phase as recommended by media development guidelines. During this stage, students accessed the AR Trigonometry Book via smartphones, scanned AR markers, visualized 3D objects, and solved contextual problems linking trigonometry to local cultural contexts. Data were collected using questionnaires, observation sheets, and brief interviews to assess practicality, usability, and comprehension. The usability analysis based on the System Usability Scale (SUS) produced a mean score of 84.6, categorized as *excellent usability*. Students responded positively to the clarity of material presentation, ease of AR activation, and the cultural relevance of contextual examples. Minor issues such as marker instability under low-light conditions and occasional lag on older devices were noted for improvement in future iterations.

In general, the findings from this stage indicated that the AR-integrated Trigonometry Textbook met the criteria of validity, practicality, and technical stability. The results also revealed that the developed media holds significant potential to foster learners' motivation, deepen conceptual comprehension, and increase active participation in trigonometry learning activities supported by an ethnomathematics-based AR environment.

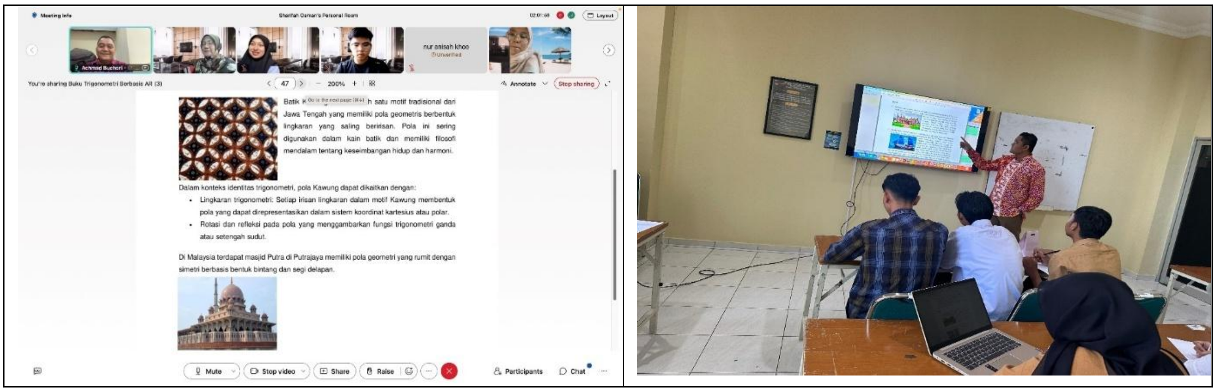


Figure 3. Implementation of AR book in Indonesian and Malaysian classrooms

The analysis of the internal consistency and usability test results demonstrated that students provided positive responses toward the AR-based Trigonometry Book. Most participants reported that the learning materials were clear, the AR activation process was easy to perform, and the integration of ethnomathematical cultural elements—such as traditional architecture and local ornaments—enhanced their conceptual understanding of trigonometric principles. Quantitative data from the System Usability Scale (SUS) yielded an average score of 84.6, categorized as *excellent usability*, while the mean practicality rating reached 88%, falling into the *very practical* category. These findings indicate that the developed AR system and instructional content were well-aligned and effectively supported motivation and conceptual engagement.

Despite these positive outcomes, several minor technical limitations were observed, including marker tracking instability under low-light conditions and occasional lag on lower-end Android devices, which the researchers documented as part of the iterative improvement plan for subsequent prototype versions. The internal consistency coefficient (Cronbach's $\alpha = 0.87$) also indicated strong reliability of the questionnaire instruments used to measure practicality and user experience. Overall, the internal validation confirmed that the AR-based Trigonometry Book was valid, practical, and user-centered, meeting the technological readiness level for experimental implementation. These results emphasize that combining AR features developed using Unity 3D and Vuforia SDK with ethnomathematical contextualization provides an effective digital learning tool that fosters active, culturally meaningful, and technology-enhanced trigonometry learning across both Universiti Teknologi Malaysia (UTM) and Universitas PGRI Semarang (UPGRIS) environments.

Table 1. Independent Samples Test

		Levene's Test for Equality of Variances		t-test for equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Score	Equal variances assumed	.011	.417	11.89	34	.000	27.778	2.336	23.03	32.525
	Equal variances not assumed			11.89	33.74	.000	27.778	2.336	23.03	35.526

According to the results presented in Table 1, the *t*-test for the Equality of Means yielded a significance value of 0.000, which corresponds to 0%. Because this value is below the 5% significance threshold, the null hypothesis (H_0) is rejected, and the alternative hypothesis (H_1) is accepted. This finding suggests that students who participated in mathematics learning using the AR-based textbook with an ethnomathematics approach achieved significantly higher outcomes than those taught through conventional instructional methods. Furthermore, to identify which group—between the UTM experimental and control classes obtained a superior mean score, a Group Statistics analysis was conducted, as illustrated in Table 2.

Table 2. Group Statistics

	Class	N	Mean	Std. Deviation	Std. Error Mean
Score	UTM experiment class	18	91.94	7.304	1.722
	UTM control class	18	65.17	6.697	1.579

Table 2 presents the descriptive statistics of students' learning outcomes, showing that the mean score of the UTM experimental class reached 91.94, whereas the control class obtained an average score of 65.17. This substantial difference in mean values demonstrates that students in the experimental group who learned through the AR-based textbook with an ethnomathematics approach achieved notably higher mathematics learning outcomes compared to those in the control group taught using conventional methods.

Moreover, the result of the regression test is shown in Table 3.

Table 3. Coefficients

	Model	Unstandardized Coefficients		Standardized Coefficients Beta	t	Sig.
		B	Std. Error			
1	(Constant)	70.163		91.94	7.304	1.722
	Motivation	.921		65.17	6.697	1.579

a. Dependent Variable : Learning Outcomes

Based on the Coefficients table, the regression model obtained is expressed as Y = 70.163 + 0.921X. The constant value of 70.163 indicates that when motivation (X) is absent, the predicted learning outcome (Y) remains at 70.163. The positive regression coefficient of 0.921 signifies that motivation contributes positively to students' learning performance, meaning that an increase in motivation corresponds with an improvement in learning outcomes. The obtained significance level of 0.012 (equivalent to 1.2%) is below the 5% significance threshold, leading to the rejection of the null hypothesis (H_0) and the acceptance of the alternative hypothesis (H_1). This confirms that motivation has a statistically significant influence on learning outcomes. The extent of this influence is further illustrated in Table 4, which details the strength and direction of the relationship between the two variables.

Table 4. Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.895[a]	.785	.622	2.385

a. Predictors (Constant), Motivation

From the output in Table 4, the R Square value obtained is 0.785 = 78.5%, which means that the influence of motivation (X) on learning outcomes (Y) is 78.5% and the remainder is influenced by other variables that were not studied.

Furthermore, the result of the independent samples test from the implementation in UPGRIS is shown in Table 5.

Table 5. Independent Samples Test

		Levene's Test for Equality of Variances		**t-test for equality of Means**						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Score	Equal variances	.02	.32	15.3	48	.000	48.889	2.005	27.09	35.83

assumed	7	6	4						7
Equal variances not assumed			15.34	47.52	.000	48.889	2.005	27.09	35.837

As presented in Table 5, the results of the *t*-test for Equality of Means show a significance value of 0.000, equivalent to 0%. Since this value is lower than the 5% level of significance, the null hypothesis (H_0) is rejected, and the alternative hypothesis (H_1) is accepted. This finding indicates that students who engaged in mathematics learning using the AR Book integrated with an ethnomathematics approach achieved significantly higher learning outcomes compared to those who were taught using traditional instructional methods. Furthermore, to determine which group—between the UPGRIS experimental and control classes—obtained a higher mean score, a Group Statistics analysis was performed, as presented in Table 6.

Table 6. Group Statistics

	Class	N	Mean	Std. Deviation	Std. Error Mean
Score	UPGRIS experiment class	25	90.73	6.924	1.429
	UPGRIS control class	25	64.71	5.714	1.318

Based on the mean scores presented in Table 4, the UPGRIS experimental group achieved an average score of 90.73, whereas the control group obtained an average of 64.71. This suggests that students in the experimental group demonstrated superior mathematics learning outcomes compared to those in the control group.

Moreover, the result of the regression test is shown in Table 7.

Table 7. Coefficients

	Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	69.875	11.534		7.813	.000
	Motivation	.793	.103	.159	.813	0.29

a. Dependent Variable : Learning Outcomes

From the Coefficients table above, the regression equation is Y = 69.875 + 0.793 X. The constant number 69.875 means that if there is no motivation, the consistent value of learning outcomes is 69.875. While the regression coefficient value is positive at 0.793, it can be said that motivation (X) has a positive effect on learning outcomes (Y). Then, seen from the significance value of 0.029 = 2.9%. Because 2.9% <5%, H0 is rejected. This means that we accept H1, which means there is an influence of motivation (X) on learning outcomes (Y). To find out the magnitude of the influence of motivation (X) on learning outcomes (Y) in the regression analysis, it can be seen in Table 8.

Table 8. Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.871[a]	.816	.787	1.904

a. Predictors (Constant), Motivation

The coefficient of determination (R^2) obtained from the analysis is 0.816, indicating that motivation (X) accounts for 81.6% of the variance in learning outcomes (Y). The remaining 18.4% is attributed to other factors beyond the scope of this study that may also contribute to students' performance.

Overall, the data processing results prove that the development of an AR-based trigonometry textbook with an ethnomathematics approach is valid in terms of content, practical to use, and proven effective in improving student learning outcomes at two universities with different cultural backgrounds. Furthermore, this medium also supports increased student learning motivation, which has been shown to be a significant factor influencing learning outcomes. Thus, it can be concluded that the use of the AR Book Trigonometry with an ethnomathematics approach significantly improves student learning outcomes compared to conventional learning models, with learning motivation being a strong supporting factor. The development of a Trigonometry AR Book using an ethnomathematics approach has demonstrated significant potential to enhance both students' motivation and their learning outcomes at Universitas PGRI Semarang (UPGRIS) and Universiti Teknologi Malaysia (UTM). The integration of Augmented Reality technology into mathematics learning aligns with previous findings that AR can provide interactive and engaging learning experiences, resulting in higher student motivation and better understanding of abstract concepts [19,20].

In this study, the use of ethnomathematics elements such as local cultural patterns and traditional architectural designs serves to contextualize trigonometric concepts within students' cultural backgrounds. This supports the assertion by [13,14] that ethnomathematics can bridge students' real-life experiences and mathematical concepts. In addition, ethnomathematics can also foster concept understanding [15,16], problem solving [17], support numeracy and meaningful learning [18]. The cultural relevance embedded in the AR book likely contributed to the increased intrinsic motivation observed among the students, which is consistent with the self-determination theory perspective [22].

Furthermore, the positive impact on students' learning outcomes aligns with research indicating that AR-based learning media can improve students' spatial abilities and conceptual understanding in mathematics [24]. The visual and interactive features of AR help students grasp trigonometric relationships that are often difficult to visualize in traditional instruction [26]. The findings corroborate [25], who highlighted that AR enhances motivation by providing a more immersive learning environment. In this study, the AR-integrated textbook goes beyond offering static 3D models but also integrates contextual problems rooted in local culture, encouraging students to relate mathematical concepts to their daily lives. This reflects the importance of culturally responsive pedagogy, which has been shown to positively affect students' engagement and achievement [26–28]. Additionally, the collaborative implementation involving students from two different universities, UPGRIS and UTM, demonstrates the versatility of the AR book across diverse educational settings.

However, the findings also indicate that successful integration of AR and ethnomathematics requires careful instructional design. Teachers must be adequately trained to facilitate AR-based lessons effectively and connect cultural contexts with mathematical content. This resonates with previous recommendations that teacher readiness is crucial for the successful adoption of AR in classrooms [29–31].

4. Conclusion

Based on the research findings, the development of an Augmented Reality (AR)-based Trigonometry textbook integrated with an ethnomathematics approach using the ADDIE model was successfully implemented in a systematic and iterative manner, from needs analysis, flowchart, and storyboard design to expert validation and small-group testing. The validation results indicated that the trigonometric content, cultural integration, and media design were highly valid, with only minor revisions to AR marker placement and user instructions. Internal consistency tests confirmed that the AR Book was practical, accessible, and enhanced students' engagement and understanding through interactive and immersive learning experiences.Implementation tests showed that students using the AR Book achieved significantly higher learning outcomes and motivation levels than those taught through conventional methods at both UPGRIS and UTM, with regression analysis revealing a strong positive influence of motivation on learning outcomes (78.5% at UTM and 81.6% at UPGRIS). These results demonstrate that the AR-based ethnomathematics approach effectively improves conceptual understanding, spatial reasoning, and learning motivation.

Technologically, this study highlights that the integration of Unity 3D, Vuforia SDK, and 3D ethnomathematical modeling contributes to sustainable educational innovation, aligning with ASSET's vision of digital transformation in STEM education. It is recommended that lecturers adopt this AR textbook within classroom instruction and Learning Management Systems (LMS) to foster contextual, interactive, and inclusive learning environments. Future investigations are encouraged to explore the scalability of this approach and its adaptability across diverse cultural and exploring AI-driven adaptive learning and AR Cloud technologies to build intelligent, collaborative, and culturally responsive STEM learning ecosystems.

Acknowledgements

The authors sincerely acknowledge Universiti Teknologi Malaysia and the LPPM of Universitas PGRI Semarang for their generous financial support provided through the Joint Research Program.

References

[1] Buchori A, Istiyaningsih R. Design of Augmented Reality Book for Economic Mathematics Course. Dinamika Pendidikan 2018;13:130–42. https://doi.org/10.15294/dp.v13i2.15319.

[2] Zhao L, Chen W. Trigonometry in data visualization and analysis: A modern perspective. Computational Mathematics and Modeling 2021;34:287–300. https://doi.org/https://doi.org/10.1007/s10598-021-09603-2.

[3] Kim H. Correlating trigonometric mastery with success in higher mathematics. Mathematics and Science Education 2022;37:25–39.

[4] Y W, X L. Enhancing problem-solving skills through trigonometric applications. Mathematics Education Research Journal 2020;32:575–90. https://doi.org/https://doi.org/10.1007/s13394-019-00307-2.

[5] H L. Bridging theory and practice: The impact of real-life applications in trigonometry education. Journal of Educational Research and Practice 2022;45:122–40.

[6] Wu J, Jiang H, Long L, Zhang X. Effects of AR mathematical picture books on primary school students' geometric thinking, cognitive load and flow experience. Education and Information Technologies 2024;29:24627–52. https://doi.org/10.1007/s10639-024-12768-y.

[7] Bertrand MG, Sezer HB, Namukasa IK. Exploring AR and VR Tools in Mathematics Education Through Culturally Responsive Pedagogies. Digital Experiences in Mathematics Education 2024;10:462–86. https://doi.org/10.1007/s40751-024-00152-x.
[8] Supriyadi E, Juandi D, Turmudi T, Pebrianti A. Augmented Reality in Mathematics Education: A Bibliometric Analysis Utilizing the Scopus Database. Journal on Mathematics Education Research (J-MER) 2023;4:113–24. https://doi.org/10.17509/j-mer.v4i2.65081.
[9] Cevikbas M, Bulut N, Kaiser G. Exploring the Benefits and Drawbacks of AR and VR Technologies for Learners of Mathematics: Recent Developments. Systems 2023;11. https://doi.org/10.3390/systems11050244.
[10] Park H, Kim S. Ethnomathematics in trigonometry education: Bridging culture and pedagogy. Ethnographic Studies in Mathematics Education 2020;33:91–109.
[11] Erşen ZB, Alp Y. A Systematic Review of Augmented Reality In Mathematics Education In The Last Decade. Malaysian Online Journal of Educational Technology 2024;12:15–31. https://doi.org/10.52380/mojet.2024.12.1.476.
[12] Bulut M, Ferri RB. A systematic literature review on augmented reality in mathematics education. European Journal of Science and Mathematics Education 2023;11:556–72.
[13] Buchori A, Prasetyowati D, Wijayanto W. The effectiveness of using magic book Math in Mathematics learning during the Covid-19 pandemic in Senior High School. Journal of Physics: Conference Series 2021;1869:012114. https://doi.org/10.1088/1742-6596/1869/1/012114.
[14] Buchori A, Sulianto J, Osman S. Interactive Learning Media With Augmented Reality (AR) Geogebra for Teaching Geometry in Elementary School. Profesi Pendidikan Dasar 2023:190–203. https://doi.org/10.23917/ppd.v10i3.4469.
[15] Nursyahidah F, Saputro BA, Rubowo MR. Supporting second grade lower secondary school students' understanding of linear equation system in two variables using ethnomathematics. Journal of Physics: Conference Series 2018;983. https://doi.org/10.1088/1742-6596/983/1/012119.
[16] Nursyahidah F, Wardono W, Mariani S, Wijayanti K. Integrating technology, ethnomathematics, and realistic mathematics education in learning statistics: A learning trajectory. Infinity Journal 2025;14:633–54. https://doi.org/10.22460/infinity.v14i3.p633-654.
[17] Nursyahidah F, Albab IU. Learning Design on Surface Area and Volume of Cylinder Using Indonesian Ethno-mathematics of Traditional Cookie maker Assisted by GeoGebra. Mathematics Teaching-Research Journal 2021;13:79–98.
[18] Nursyahidah F, Wardono, Mariani S, Wijayanti K. Integrating technology, Javanese ethnomathematics, and realistic mathematics education in supporting prospective mathematics teachers' numeracy skills: A learning trajectory. Journal on Mathematics Education 2025;16:671–88. https://doi.org/10.22342/jme.v16i2.pp671-688.
[19] Bacca J, Baldiris S, Fabregat R, Graf S, Kinshuk. International Forum of Educational Technology & Society Augmented Reality Trends in Education : A Systematic Review of Research and Applications. Educational Technology & Society 2014;17:133–49.
[20] Akçayır M, Akçayır G. Advantages and challenges associated with augmented reality for education: A systematic review of the literature. Educational Research Review 2017;20:1–11. https://doi.org/10.1016/j.edurev.2016.11.002.
[21] Rosa M, Orey DC. State of the Art in Ethnomathematics. Current and Future Perspectives of Ethnomathematics as a Program, Cham: Springer; 2016, p. 11–37. https://doi.org/10.1007/978-3-319-30120-4_3.
[22] D'Ambrosio U, Almeida MC. Ethnomathematics and the Emergence of Mathematics. The Nature and Development of Mathematics: Cross Disciplinary Perspectives on Cognition, Learning and Culture, Routledge; 2017.
[23] Rosa M, Orey DC. An Ethnomathematical Perspective of STEM Education in a Glocalized World. Bolema: Boletim de Educação Matemática 2021;35:840–76. https://doi.org/10.1590/1980-4415v35n70a14.

[24] Deci EL, Ryan RM. The "What" and "Why" of Goal Pursuits: Human Needs and the Self-Determination of Behavior. Psychological Inquiry 2000;11:227–68. https://doi.org/10.1207/S15327965PLI1104_01.
[25] Ibáñez M-B, Delgado-Kloos C. Augmented reality for STEM learning: A systematic review. Computers & Education 2018;123:109–23. https://doi.org/10.1016/j.compedu.2018.05.002.
[26] Garzón J, Acevedo J. Meta-analysis of the impact of Augmented Reality on students' learning gains. Educational Research Review 2019;27:244–60. https://doi.org/10.1016/j.edurev.2019.04.001.
[27] Gay G. Culturally Responsive Teaching: Theory, Research, and Practice. Third Edition. Multicultural Education Series, New York: Teachers College Press; 2018.
[28] Cai S, Liu E, Shen Y, Liu C, Li S, Shen Y. Probability learning in mathematics using augmented reality: impact on student's learning gains and attitudes. Interactive Learning Environments 2020;28:560–73. https://doi.org/10.1080/10494820.2019.1696839.
[29] Kounlaxay K, Shim Y, Kang SJ, Kwak HY, Kim SK. Learning Media on Mathematical Education based on Augmented Reality. KSII Transactions on Internet and Information Systems 2021;15:1015–29. https://doi.org/10.3837/tiis.2021.03.011.
[30] Radu I. Augmented reality in education: a meta-review and cross-media analysis. Personal and Ubiquitous Computing 2014;18:1533–43. https://doi.org/10.1007/s00779-013-0747-y.
[31] Kellems RO, Cacciatore G, Osborne K. Using an Augmented Reality–Based Teaching Strategy to Teach Mathematics to Secondary Students With Disabilities. Career Development and Transition for Exceptional Individuals 2019;42:253–8. https://doi.org/10.1177/2165143418822800.