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GEOMETRY LEARNING BASED ON THE ETHNOMATHEMATICS METAVERSE OF *TUGU JOGJA* TO DEVELOP STUDENTS' COGNITIVE LEVELS

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Abstract: This study focused on analyzing the implementation of metaverse-based ethnomathematics in geometry learning for 9th-grade junior high school students. The aim of this research is to explore the concept of three-dimensional shapes in the *Tugu Jogja* monument as part of local culture using metaverse technology. The study sought to enhance the cognitive level of 9th-grade students in understanding the concepts of solid geometry, including both flat and curved surfaces, with the metaverse centered on Tugu Jogja. The method employed is purposive sampling, involving 29 ninth-grade students, with pre-tests and post-tests administered to measure the improvement in students' cognitive levels. The data analysis results show a significant difference in students' understanding after applying this approach, with a p-value of $0.00019 < 0.05$. This proves that metaverse-based ethnomathematics geometry learning is effective in developing the cognitive levels of 9th-grade students. The exploration of *Tugu Jogja* through the metaverse medium contains mathematical elements such as flat-sided and curved-sided three-dimensional shapes. Through this learning media, it is possible to develop innovative learning methods that integrate technology and local culture to create more interactive and meaningful learning experiences.

Keywords: ethnomathematics, metaverse, geometry

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INTRODUCTION

Education and culture are two inseparable elements in daily life. Culture encompasses various aspects within society, while education is a basic need for every individual. Indonesia is known for its rich cultural heritage that must be preserved by future generations to ensure that the values of wisdom within it remain intact. Education, meanwhile, plays a crucial role in ensuring the transfer of knowledge and cultural values from one generation to the next, thus shaping culturally aware individuals, as stated by Normina (2017).

PISA questions require students to have basic skills in finding various solutions for a wide variety of problems. One of the objectives of PISA is to evaluate students' mathematical knowledge in dealing with everyday issues, including scenario-based questions. Therefore, there is a need to enhance students' creative thinking skills, especially in solving real-life problems. In order to achieve this, new innovations in mathematics teaching methods in schools are necessary. This is because Conventional methods that are less relevant to real-life contexts and tend to be monotonous may contribute to students' negative perceptions of learning mathematics. Approaches such as one-way lectures that focus on memorization of formulas and formal calculations often fail to connect abstract mathematical concepts with real-world applications. The use of such conventional methods is often chosen by educators due to the ease of implementation. In this method, the main focus of the teacher is to deliver the material, while students are expected to understand the concepts and solve problems based on the given explanations. Although using this method is not inherently wrong, educators should strive to relate learning to its application in daily life. This way, students can perceive more tangible benefits from learning mathematics. Thus, the teachers' creativity is crucial in determining the appropriate approach so that students can comprehend the learning materials more clearly and meaningfully.

Furthermore, mathematics instruction that focuses solely on formulas and formal calculations often fails to bridge the gap between abstract concepts and real-life applications. As a result, students struggle to see the relevance of mathematics to their own experiences, leading to low motivation to learn. On the other hand, the ethnomathematics approach offers a way to connect mathematics learning with cultural practices familiar to students. For instance, batik art, weaving patterns, and traditional house construction contain mathematical elements such as geometry, symmetry, and measurement that can be integrated into the learning process. Therefore, ethnomathematics not only helps students understand mathematical concepts more concretely but also fosters a sense of pride in their local culture.

Mathematics has a significant relevance to everyday life. Mathematical concepts can be found in various aspects of daily activities. For example, buying and selling activities involve algebra, traditional food shapes reflect geometric concepts, and residential structures are applications of geometry in mathematics. Many activities, habits, and other cultural elements can be explained through mathematical concepts. Therefore, a learning approach that can connect students with mathematical concepts in a more concrete and socially and culturally relevant way is needed. One approach considered effective in achieving this goal is ethnomathematics.

Ethnomathematics is the study of how different cultures develop and apply mathematical concepts in their daily lives. It is also an approach to mathematics education that aims to help students understand, articulate, and apply mathematical concepts in real-life situations. Its main goal is to recognize the diversity of ways of thinking and using mathematics across cultures, as well as to understand the different ways these cultures practice mathematics in their everyday activities (d'Ambrosio, U, 1985).

Culture itself is a collection of habits, beliefs, arts, and social practices passed down within a group or society. Culture is closely tied to daily life because it influences how individuals think, learn, and interact with their environment. By integrating culture into mathematics learning, students can enhance their confidence in their identity, appreciate local culture, and develop an open-minded attitude and respect for different cultures around them. Indonesia has a high level of cultural diversity with 38 provinces, each with its own unique cultural traits. This diversity offers great opportunities to apply ethnomathematics in education. From traditional foods, customs, norms, and languages to arts, each region has its own uniqueness that can be utilized in teaching mathematics. The ethnomathematics approach enables the integration of culture and mathematics, making learning more meaningful and relevant for students.

The implementation of ethnomathematics can bring new hope to the field of mathematics education by offering educators a way to deliver more interactive, contextual, and relevant learning experiences for students. For instance, some cultures have traditional measurement practices related to the creation of handicrafts. In this context, geometric and measurement concepts can be introduced through practices that are familiar within the students' cultural contexts. Through such approach, students not only comprehend mathematical concepts but also realize that this knowledge has long been applied by their ancestors in daily life. This makes mathematics more integrated with real life, rather than just a subject to be memorized or used solely for exams.

Moreover, Ethnomathematics encourages students to learn about and explore the various cultures around them. For example, students can learn about the structures of temples or other historical buildings to deepen their understanding of mathematics. Ethnomathematics also fosters greater appreciation for local culture. Culture-based mathematics learning allows students to understand and internalize that the values and cultural practices passed down through generations remain relevant in modern science, including mathematics. For example, geometric patterns and symmetry found in batik or woven textiles are applied with technical precision. When these patterns are taught within the context of geometry, students not only learn mathematical concepts but also develop a sense of pride in their cultural heritage. Thus, ethnomathematics serves to strengthen cultural identity through the learning process.

Additionally, ethnomathematics also stimulates the development of critical thinking skills by simultaneously connecting mathematics and culture. Students are invited to explore how mathematical concepts can be applied in real life through cultural practices they are familiar with. This approach gives them the opportunity not only to memorize theories or formulas but also to understand their applications in various situations. For example, traditional games such as *congklak* or *dakon* involve mathematical aspects like strategy, calculation, and distribution, which can be systematically analyzed. These activities challenge students to link theory with practice, thereby enhancing their analytical abilities in a meaningful context.

Through ethnomathematics, educators can create a more engaging and interactive learning environment. By using culturally familiar objects as learning media, the learning process becomes more dynamic and less monotonous. Students feel more involved because they can see that mathematics has real-world applications in their daily lives. The use of cultural elements allows for deeper interaction between students and the learning material. In this process, students are not just listening or solving problems, but also actively observing, analyzing, and discussing the relevance of mathematical concepts to their culture.

Finaly, ethnomathematics not only teaches mathematical concepts but also helps students understand the importance of culture in their lives. Through this approach, students are expected to view mathematics from a broader and more humanistic perspective, where mathematics is not just an exact science but also a part of their identity and culture. In this manner, students are trained not only to become skilled in logic and calculation but also to become individuals who appreciate and understand the uniqueness of their own culture.

In addition, ethnomathematics has the potential to enrich students' analytical and critical thinking skills by simultaneously connecting mathematics and culture. Through this exploration, students not only learn mathematics as an exact science but also as an integral part of their social and cultural lives. By using this approach, mathematics education can become more inclusive and relevant, ultimately fostering more holistic character development in students. A previous study entitled "The *Kawung* Motif in Traditional Yogyakarta Batik: An Inquisitive Semantic Study" by Hermandra (2022) explained that the *Kawung* batik motif was chosen because it reflects the sugar palm tree, from which the motif originates, whose entire body parts are useful in daily life. The message behind this motif is that wearing it will bring benefits to many people and the surrounding environment. The *Kawung* motif symbolizes values of purity, perfection, and sanctity, which are significant in Javanese society. This is reflected in the regular pattern of kawung, consisting of four *kawung* seeds arranged symmetrically.

One way to bridge the gap between school learning and real life is through ethnomathematics (Eryandi, Somakim, & Hartono, 2016). Integrating ethnomathematics into the learning process is considered a solution to this problem while also bringing innovation to mathematics teaching (Abi, 2017; Chahine & Naresh, 2015). In practice, ethnomathematics can also be combined with various teaching methods and strategies. A study by Ashari (2024), published under the title "Ethnomathematics Integration in Mathematics Education: A Case Study of Fort Rotterdam in Makassar", discusses how presenting mathematics within a socio-cultural context can facilitate students in grasping basic mathematical concepts.

Alongside the use of culture as a bridge for mathematics education, technology also plays a crucial role in this Society 5.0 era in enhancing human quality, particularly that of students. Schools and teachers play a role in transforming education, which no longer relies solely on textbooks but also utilizes various sources of information such as the internet and social media. As educators in this era, digital skills and creative thinking abilities are essential. In general, learning activities nowadays often utilize audio, visual, and audiovisual media, as well as printed materials and e-learning platforms (Rahmi, 2021). There are three key aspects that educators must utilize in the Society 5.0 era: the Internet of Things (IoT) in education, virtual/augmented reality (VR/AR), and Artificial Intelligence (AI) to identify students' learning needs. One of the technologies frequently mentioned in this context is the metaverse.

Metaverse is a technology that offers educators the opportunity to explore, experience new things, and interact with others through a network (Hwang & Chien, 2022). It is a computer-controlled 3D technology that presents environments as if they were in real life and allows users to interact within them. This technology seeks to simulate the real world into a 3D environment and visual displays (Kaminska et al., 2019). It can provide students with new experiences in the learning process. The internet is manifested into something that can be felt by humans not just seen, but experienced directly by users.

Considering the importance of improving students' comprehension, learning interest, and the overall quality of education in Indonesia, the metaverse can be utilized in education. To enhance educational quality through the metaverse, an in-depth study of that technology is necessary. However, in Indonesia, metaverse-based education is still relatively unpopular. Therefore, the introduction of the metaverse in Indonesian education is needed, as the technology offers a wide range of advantages. The metaverse allows students to engage in global learning without being limited by geographical boundaries (Paul, 2024).

Furthermore, the metaverse can also reduce the need for educational infrastructure and learning resources (Mukherjee, 2024). Infrastructure that would normally exist in the real world can be created in the metaverse and observed by students. For example, when a laboratory or a sample building is needed for geometry learning in mathematics, the metaverse can host such a laboratory or building in the virtual world. With metaverse, Students can observe and experience an online interaction that closely resembles real-life experiences. The level of details offered in the metaverse is also highly capable of enriching students' learning experience. Therefore, the metaverse greatly helps reduce costs associated with building educational infrastructure.

In addition, the metaverse also offers other benefits for the field of education. For instance, the metaverse can drive new innovations in educational methodologies and the development of educational support tools (Akbar et al., 2024) As a result, innovative ideas for utilizing the metaverse in learning activities will emerge. Furthermore, learning support tools will inevitably keep up with this development. Since the metaverse requires internet access, it will also prompt the emergence of developers and providers of tools that support access to the metaverse.

In the context of ethnomathematics, students are taught not only mathematics but also culture. For example, the iconic Tugu Jogja becomes part of the learning experience. Therefore, ethnomathematics is considered highly relevant in today's education, as it can increase students' motivation to learn mathematics and enhance the *Pancasila Student Profile*. This study carried out spatial geometry learning for 9th-grade students through a metaverse-based ethnomathematics medium featuring Tugu Jogja, aiming to improve students' cognitive levels. The purpose of this research is to determine the effectiveness of metaverse-based ethnomathematics learning using Tugu Jogja to develop the cognitive level of 9th-grade junior high school students.

METHODOLOGY

In this study, the data was collected using a quantitative approach with a pre-experimental method in the form of a one-group pretest-posttest design. In this design, two measurements were conducted: a pretest and a posttest. The pretest was administered before the research subjects received the treatment, while the posttest was conducted after the treatment. In this way, the effect of the treatment could be observed by comparing the conditions before and after it is applied. This method involves measuring students' cognitive levels before and after the implementation of ethnomathematics-based learning using the metaverse. The participants of this study were 29 ninth-grade students. The learning model used was the Realistic Mathematics Education (RME) model, carried out over four lesson periods. RME is a mathematics teaching approach based on the idea that mathematics is a human activity that must be meaningful to students, so learning starts from real-life situations familiar to them or from contexts within mathematics itself (Primasari, 2021). The object of this research involved conducting ethnomathematics-based learning activities in class interactively using metaverse-based media, enabling students to explore mathematical concepts more deeply through engaging and immersive virtual experiences.

The study was carried out in five stages. The first stage was identifying ethnomathematical elements in *Tugu Jogja* that were relevant to geometry learning. The second stage involved developing metaverse-based learning materials with visualizations of *Tugu Jogja*. Stage three consisted of designing metaverse learning media through *spatial.io* and *Sketchfab* in the form of virtual rooms that allowed students to learn conveniently. In the fourth stage, the learning was implemented with ninth-grade junior high school students. The final stage involved measuring students' cognitive levels before and after implementation using the pretest and posttest.

In the teaching and learning activities, students were given a pretest to determine their initial understanding of the material to be taught. Then, geometry lessons on three-dimensional shapes with flat and curved surfaces were delivered through exploration of the metaverse. Students were asked to form groups of four to work on worksheets (LKPD) and engage in discussions to promote mutual understanding during the learning process. After the group discussions and completion of the worksheets, students were given a posttest to measure their cognitive abilities after the metaverse exploration. Observations during the lessons were also conducted to assess student engagement. Data analysis used statistical tests to compare the pretest and posttest results.

The data was processed using descriptive analysis by creating graphs comparing the pretest and posttest results among groups. Then, a one-way ANOVA test was conducted to determine whether H_0 is accepted or rejected, using a 95% confidence level to observe the significance between the independent and dependent variables using RStudio. The decision rule for this test is: H_0 is rejected and H_a accepted if the significance probability < 0.05; H_0 is accepted if the significance probability > 0.05. The hypotheses used in this study are as follows:

- **Null hypothesis (H_0):** The Tugu Jogja ethnomathematics metaverse-based learning is effective in developing the cognitive level of junior high school students.
- **Alternative hypothesis (H_a):** The Tugu Jogja ethnomathematics metaverse-based learning is not effective in developing the cognitive level of junior high school students.

Table 1. Categorization of Students' Cognitive Level

Score Percentage	Category
≥ 80	Very High
60 - 79	High
40 - 59	Average
20 - 39	Low
< 20	Very Low

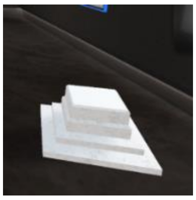
The success criterion in this study is considered to indicate cognitive level development when students obtain a score of ≥ 70, which falls into the high category (Himawan & Purwanto, 2014), as shown in Table 1.

RESULT AND DISCUSSION

Based on the results of the geometry learning activities in the 9th-grade class, students engaged in various explorations using the metaverse as a medium. Students were divided into groups of four to collaboratively study and complete the student worksheet. In this learning process, students explored and observed the Tugu Jogja monument, focusing on its three parts: the lower, middle, and upper sections. At this stage, students attempted to identify the 3D shapes present in Tugu Jogja according to the characteristics of each shape. The structure of Tugu Jogja contains mathematical elements that can be integrated into the school mathematics curriculum. Ethnomathematics found or developed within communities includes cultural heritage such as temples and inscriptions, pottery and traditional tools, local entities, batik and embroidery motifs, traditional games, and settlement patterns, all of which are the results of various mathematical activities (Zayyadi, 2017).

Ethnomathematics also provides insights into how culture is connected to mathematics and helps cultivate national character values among students (Widiantari & Suparta, 2022). Tugu Jogja is a monument frequently used as a symbol of Yogyakarta, located at the intersection of Jendral Sudirman and Margo Utomo street. The application of ethnomathematics enables students to connect mathematical concepts with their real-life experiences (see Table 2), ultimately increasing their motivation and participation in the learning process (Turmuzi et al., 2024).

Tabel 2. Mathematical Concepts in Tugu Jogja

No	Etno-mathematics	Mathematical Concept
1		The lower part of *Tugu Jogja* is designed like a staircase, with each step having a different size. Upon closer observation, the structure has 6 faces, 12 edges, 12 face diagonals, 8 vertices, 4 space diagonals, and 6 diagonal planes. These characteristics indicate that the shape belongs to the category of three-dimensional flat-sided shapes, specifically a rectangular prism (cuboid).
2		The second lower part of *Tugu Jogja* is designed in the shape of a truncated square pyramid. This section of the structure contains mathematical elements, including 6 square faces, 12 equal-length edges, 8 equal angles, and 6 diagonal planes. Upon closer observation, the structure resembles a three-dimensional flat-sided shape, specifically a cube. Additionally, at the base, there is a square pyramid structure, but only the base and the middle part are visible, and it does not extend all the way to the apex.
3		In the middle section of *Tugu Jogja*, the design features a square base with a partially formed square pyramid (not reaching the apex) and a square structure on top. The lower part of the building exhibits mathematical elements: it has 6 faces, 12 edges, 12 face diagonals, 8 vertices, 4 space diagonals, and 6 diagonal planes. Upon observation, this part resembles a three-dimensional flat-sided shape, specifically a rectangular prism. In the middle, there is a square pyramid structure, but only its base and middle portion are present, not extending to an apex. At the top, there is a square structure whose characteristics are the same as a three-dimensional flat-sided shape, namely a rectangular prism.
4		At the top section of *Tugu Jogja*, the structure is designed with a square base, a partially formed square pyramid (not reaching the apex), and on top of it is a structure that tapers upward like a cone. The lower part of this section contains mathematical elements: it has 6 faces, 12 edges, 12 face diagonals, 8 vertices, 4 space diagonals, and 6 diagonal planes. Upon observation, this resembles a three-dimensional flat-sided shape, namely a rectangular prism. In the middle and on each side, there are square pyramid structures, but only the base and middle parts are present, not extending to the apex. At the top, there is a structure with characteristics such as having 2 circular and curved surfaces, with the circular side as the base and the curved surface as the lateral face, 1 rounded edge, and 1 vertex at the tip of the cone. Therefore, it can be identified as a curved-sided solid shape, namely a cone.

No	Etno-mathematics	Mathematical Concept
5		Students can explore and observe the entire *Tugu Jogja* in 3D to validate the three-dimensional shapes identified in each of its parts. In this case, students who do not live in Yogyakarta can still study the ethnomathematics of *Tugu Jogja* without having to see it in person.

After having an enjoyable journey in the metaverse, students were given a posttest to measure their level of understanding. The ethnomathematical exploration of *Tugu Jogja* monument, as discussed earlier, revealed the presence of mathematical elements integrated into the ornaments of the monument. These elements align with the mathematical concepts taught in school. Kusuma et al. (2024) stated that ethnomathematics enriches learning by linking students' cultural experiences with formal mathematical concepts, thus enhancing their understanding of the subject matter. Learning the application of mathematical concepts in local culture can be an effective learning resource in connecting mathematical theory with students' real-life experiences. Furthermore, culturally based learning approaches can reduce the gap in mathematical understanding among students from diverse cultural backgrounds. Integrating cultural aspects into mathematics learning can help students understand the relevance of mathematics in daily life.

The data collected are the pretest and posttest scores of students' mathematics learning outcomes after being given treatment using the Realistic Mathematics Education (RME) approach, conducted in only one class. The descriptive statistical summary to determine the cognitive improvement of students in geometry learning with the ethnomathematics-based metaverse treatment can be seen in Table 3.

Table 3. Summary of Cognitive Scores of Students' Geometry Learning Outcomes

Score Range	Category	*Pretest*		*Posttest*	
		Frequency	%	Frequency	%
90-100	Very High	9	31	10	34
80-89	High	7	24	17	59
65-79	Average	7	24	2	7
55-64	Low	5	17	0	0
<55	Very Low	1	3	0	0

The results of the quantitative data analysis indicate that learning ethnomathematics using the Tugu Jogja with metaverse as the media increases the number of students in the very high cognitive category by one compared to before the treatment. In the high cognitive category, there was an increase of 10 students. In the average cognitive category, there was a decrease of 5 students. In low and very low cognitive category, there were no students. Based on this data, it can be seen that geometry learning with ethnomathematics-based metaverse treatment is effective in improving students' mathematical understanding.

Tabel 4. Summary of the Test of Normality using Shapiro-Wilk for Pretest and Posttest

Data	W	p-value	Description
Learning Outcome Cognitive Score	0.93181	0.00289	Normal

Based on the analysis results (Table 4) which used the Shapiro-Wilk test (because the data is < 50), a W value of 0.93181 was obtained with a p-value of 0.00289, where the p-value < 0.05, so H_0 is accepted, meaning the residuals do not follow a normal distribution. Since the residuals do not follow a normal distribution, the ANOVA test with R Studio does not meet the normality assumption.

Tabel 5. Summary of Homogenity Test for Pretest and Posttest

Data	F Value	p-value	Description
Learning Outcome Cognitive Score	18,53	6.789e-05 *** or equivalent to 0,00006789	Not Homogenous

The Levene Test result (Table 5) shows a p-value of 0.00006789 where the p-value <0.05, thus H_0 is accepted. This means that the variance between groups does not meet the assumption of homogeneity. Since the data is not homogeneous, a robust ANOVA test in R (Table 6), which is resistant to violations of the homogeneity assumption, was used. This was then followed by a post hoc test after the ANOVA, corrected using a robust post hoc analysis that is also resistant to violations of the homogeneity assumption.

Tabel 6. Summary of ANOVA Robust

Data	F	Num df	Denom df	p-value
Mathematics and Methods	17.154	1	36.705	0.0001938

The results ANOVA test above show that the DF, or degrees of freedom, is as follows: the numerator DF is the number of groups minus 1, which is 2 – 1 = 1. The adjusted denominator DF is 17.154. The calculated F-value is 17.154, and the significance value or p-value of the F-test is 0.0001938, which is less than 0.05. Since the p-value < 0.05, it can be concluded that H0 is rejected. This means that using metaverse as a media for teaching ethnomathematics to 9th-grade junior high school students has a significant effect in developing the students' mathematical cognitive skills.

Summary of Robust Post Hoc Analysis on Homogeneity Assumption

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Pairwise comparisons using t tests with non-pooled SD data:
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The difference in students' cognitive levels after participating in metaverse-based learning between the experimental group and the control group showed a p-value of 0.00019, which is less than 0.05, thus rejecting H_0. The results of the study indicate a significant improvement in students' cognitive levels after engaging in ethnomathematics-based metaverse learning, showing that this learning method is effective in enhancing students' understanding of geometric concepts.

Based on the results of the ethnomathematics learning using the *Tugu Jogja* as context through metaverse media for 9th-grade students, it was discovered that it can develop students' cognitive levels in understanding geometry material. This aligns with Bloom's Taxonomy, which was later revised and refined by Anderson and Krathwohl in 2001, where the knowledge level reaches level C4 (analyzing). Students are able to carry out cognitive processes by applying learned skills to previously unknown information. This is done by grouping the information and determining the relationship between pieces of information.

Students find it easier to understand concepts when those concepts are related to their own social environment. Since students already have prior understanding of things from their surroundings, learning activities that utilize this approach help them grasp the knowledge more quickly. Ethnomathematics learning is in line with the nature of school mathematics, which includes: a) mathematics as an activity to explore patterns and relationships, b) mathematics as a form of creativity that requires imagination, c) mathematics as an effort to solve problems, and d) mathematics as a tool of communication (Marsigit, Setiana, & Hardiarti, 2018). Through ethnomathematics, students are presented with mathematics in a simpler communicative way, with more concrete patterns, thereby enhancing their understanding of the subject. Moreover, this new approach also tends to increase students' interest and enthusiasm during the learning process.

CONCLUSION

The findings of this study show that metaverse-based ethnomathematics learning on the Tugu Jogja context is not only effective in improving students' cognitive performance but also indicates meaningful cognitive engagement at the C4 (analyzing) level of Bloom's taxonomy. Students were able to deconstruct cultural artifacts into geometric components, identify relationships among shapes, and apply conceptual understanding to classify solid figures. Beyond descriptive identification of geometric forms, this learning approach provides insight into how cultural integration supports students' analytical thinking. By embedding local cultural values, such as the symbolic structure of Tugu Jogja, into virtual learning spaces, students engage with mathematical concepts in a context that aligns with their cultural cognition. This reinforces the reciprocal relationship between cultural awareness and mathematical reasoning, showing that the metaverse can serve as a bridge between intangible heritage and formal school mathematics. Despite the demonstrated improvement, the long-term potential of this approach warrants further exploration, especially in understanding how immersive cultural environments shape higher-order thinking across broader mathematical domains. Limitations related to the scope of content, sample size, and duration of implementation indicate the need for follow-up studies that examine retention, transferability of skills, and broader cultural integration within STEM learning. Practically, this study contributes to the development of culturally responsive digital learning tools that can guide educators in designing immersive, context-rich mathematics instruction. Future implementations may serve as models for integrating local wisdom into technology-enhanced learning ecosystems, ensuring that innovation in mathematics education remains culturally grounded and pedagogically impactful.

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