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Augmented Reality-Based Ethnomathematics Learning Media to Enhance Spatial Ability in 3D Geometry for Fifth Grade Elementary Students

Devi Maya Gustina*
Master's of Elementary Education, State University of Surabaya, Surabaya, Indonesia

Neni Mariana
Master's of Elementary Education, State University of Surabaya, Surabaya, Indonesia

Wiryanto
Master's of Elementary Education, State University of Surabaya, Surabaya, Indonesia

***Corresponding Author:** 24010855087@mhs.unesa.ac.id

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Abstract
This study explores the potential of Augmented Reality (AR)-based learning media integrated with ethnomathematics to enhance students' spatial ability in the context of teaching 3D geometry to fifth-grade elementary students. Spatial ability, which includes spatial perception, mental rotation, spatial visualization, spatial relations, and spatial orientation, is a critical cognitive skill for understanding geometric concepts. A Systematic Literature Review (SLR) method was employed to identify, evaluate, and synthesize findings from 15 studies related to the use of AR and ethnomathematics in mathematics education. The review reveals that AR offers significant advantages in presenting three-dimensional geometric objects interactively, visually, and concretely, which improves students' comprehension of abstract spatial relationships and enhances mental manipulation of objects. Additionally, the integration of ethnomathematics provides contextual learning experiences by linking mathematical content to students' cultural backgrounds, thereby increasing engagement and motivation. These findings support the Van Hiele theory, emphasizing the importance of gradual stages in geometric understanding. The combination of AR and ethnomathematics not only deepens spatial reasoning but also promotes meaningful and culturally relevant learning experiences. Future studies should further explore the impact of AR-based ethnomathematical media through empirical classroom-based research and assess its long-term effects on students' mathematical thinking and spatial abilities. The 21 students selected for the classroom trials were chosen through purposive sampling, ensuring the sample's relevance to the study context.

INTRODUCTION

The rapid advancement of technology, particularly in the fields of multimedia and Augmented Reality (AR), has significantly influenced various aspects of life, including education (Telussa et al., 2022). AR, as a technology that merges virtual elements into the real world, offers an interactive and engaging learning experience for students (Supli & Yan, 2024). In the context of mathematics education especially in geometry and three-dimensional (3D) shapes AR has immense potential to aid students in understanding abstract concepts. These concepts are often difficult to explain using only traditional tools like textbooks or chalkboards. Through AR, 3D objects such as cubes, spheres, and pyramids can be visualized more realistically and interactively. This enables students to better grasp the properties and relationships between geometric objects (Fachril et al., 2024). Despite AR's potential, there are several challenges that need to be addressed. Barriers like device availability, costs, and teacher training can limit the widespread adoption of AR in classrooms. Moreover, AR-based learning must be aligned with the curriculum to be truly effective, which requires careful

planning and integration. Nevertheless, these challenges do not diminish the transformative potential of AR in education.

Although AR presents several advantages in mathematics learning, the challenge lies in making the technology contextually relevant for elementary students (Setiawati & Zainil, 2024). A promising approach to bridge this gap is the integration of ethnomathematics. Ethnomathematics is a field that explores the connection between mathematics and local culture (Rosa & Orey, 2011). This approach helps students relate mathematical concepts to their everyday lives and environments. For example, traditional houses, local musical instruments, or familiar cultural structures can serve as meaningful references. This relevance not only improves comprehension but also increases student motivation and engagement in learning geometry (Solihin & Rahmawati, 2024).

The integration of AR with ethnomathematics offers a powerful solution to enhance students' understanding of geometric concepts, particularly 3D shapes. AR can present culturally relevant 3D representations of geometric objects, making the learning experience more contextual and relatable. These interactive models allow students to manipulate and explore objects from multiple perspectives. Through such interactions, students can learn concepts like volume, surface area, and geometric properties in a more intuitive way. Additionally, these representations help bridge the gap between abstract mathematical ideas and concrete real-world applications. This makes learning not only more enjoyable but also more meaningful (Zulmaulida et al., 2021).

AR-based learning environments provide students with hands-on experiences that traditional methods often lack. With the ability to rotate, zoom, and deconstruct 3D shapes, students develop a deeper understanding of how geometric objects behave in space. These experiences foster critical spatial reasoning skills. For example, students learn to see how a 3D figure looks from different angles or how multiple shapes can combine to form a structure. Such skills are crucial for succeeding in geometry and other STEM disciplines. The use of AR empowers students to become active participants in their learning process (Dinarti, 2024).

Mathematics education should not solely focus on formulas and procedures but also prioritize the development of spatial ability. Spatial ability involves understanding the position, shape, and orientation of objects in space, as well as their relationships to each other (Harris, 2022). This cognitive skill is essential for mastering geometry concepts. Research shows that students with strong spatial skills perform better in geometry and related subjects (Simbolon & Sapri, 2022). Therefore, educators must adopt instructional methods that support the progressive development of this ability. AR and ethnomathematics combined create such a method by blending visual, interactive, and cultural learning.

Dahal et al. (2022) posits that students progress through levels of geometric understanding, from basic shape recognition to higher levels of analysis and deduction. Effective instruction must align with these stages to facilitate meaningful learning. Using AR-based media allows students to visualize and interact with shapes at each developmental level. When integrated with ethnomathematics, this progression becomes even more grounded in students' lived experiences. Learning becomes a gradual journey that respects students' cognitive readiness and cultural identity. This ensures that geometric understanding is built step-by-step, rather than imposed prematurely (Andriliani et al., 2022).

In the context of primary school education, where concrete and contextual learning is most effective, AR-based ethnomathematical tools show great promise. These tools can help young learners relate abstract concepts to familiar cultural elements, which aids in retention and comprehension. For example, a student might better understand a cone when seeing it as part of a traditional hat or instrument from their culture. The visual and tactile nature of AR enhances such connections. At the same time, it introduces students to essential mathematical ideas in a fun, dynamic, and engaging way. This approach addresses both cognitive and affective aspects of learning (Hamzah et al., 2024).

In light of these considerations, the use of ethnomathematics-based AR in teaching 3D geometry at the elementary level holds significant potential to enhance students' spatial abilities. By

leveraging available technology, educators can create learning experiences that are interactive, culturally relevant, and cognitively enriching. This study aims to explore how AR integrated with ethnomathematics can effectively develop spatial ability among fifth-grade students. Additionally, it seeks to contribute to the advancement of more effective and contextual mathematics education practices. Ultimately, the goal is to help students not only understand geometric concepts better but also apply them meaningfully in their daily lives. The findings of this study are expected to provide valuable insights for educators, curriculum developers, and researchers.

METHODS

This study employed a Systematic Literature Review (SLR) method to identify, evaluate, and synthesize relevant research on the use of ethnomathematics-based Augmented Reality (AR) to enhance students' spatial abilities, particularly in learning 3D geometry in fifth-grade elementary education. SLR is a structured method used to collect, assess, and summarize evidence from existing studies to generate comprehensive and evidence-based findings. The review process began with the identification of relevant articles through academic databases such as Google Scholar, ERIC, SpringerLink, and JSTOR. Keywords used in the search included: "Augmented Reality in Education," "Spatial Ability," "Ethnomathematics," "Spatial Perception," "Mental Rotation," "Van Hiele Theory," "Solid Geometry," and "Elementary School Mathematics Learning." To ensure the relevance and currency of data, the search was limited to publications from the last ten years. Only peer-reviewed journal articles and indexed conference papers were considered for inclusion.

The selected articles were then filtered based on inclusion and exclusion criteria, focusing on studies involving the use of AR in mathematics education at the elementary level, particularly those aimed at developing spatial skills and integrating ethnomathematics in geometry learning. Each study was evaluated for quality based on its research design, validity of findings, and its contribution to understanding AR's effectiveness in enhancing spatial ability. Studies with strong methodologies whether qualitative or quantitative and reliable instruments for measuring spatial skills were prioritized. The key findings from the selected studies were synthesized by identifying patterns, trends, and the extent to which AR supported the development of spatial aspects such as spatial perception, mental rotation, visualization, and orientation. Additionally, elements like student motivation and the cultural relevance of AR applications were analyzed. Results were presented in summary tables to clearly display each study's focus, authorship, publication year, and key findings, followed by conclusions and recommendations for future teaching practices and research directions.

RESULTS AND DISCUSSION

Results

The following section presents the analysis results of the selected and evaluated articles. The table below summarizes nine relevant studies that explore the influence of using Augmented Reality (AR) and ethnomathematics in mathematics education, particularly in enhancing students' spatial abilities in learning 3D geometry.

Table 1. Summary of Relevant Studies on the Use of Augmented Reality and Ethnomathematics to Enhance Students' Spatial Abilities in Geometry Learning

No	Author(s), Title of Study	Key Findings
1	(Nadzeri et al., 2024)	The use of AR enhances students' mental rotation and spatial visualization abilities. Students using AR showed a better understanding of spatial relationships among geometric shapes. AR also supported learning of geometric transformations such as reflection and rotation.
2	(Zuhri et al., 2023)	Ethnomathematics helps students relate geometric concepts to their daily lives, improving comprehension and increasing interest. Students became more engaged and were able to associate geometric forms

		with cultural artifacts such as traditional buildings and local crafts.
3	(del Cerro Velázquez & Morales Méndez, 2021)	AR effectively improved students' understanding of spatial relationships between 3D and 2D objects. It enhanced their ability to comprehend projections, cross-sections, and the relationships among edges and angles of solid figures.
4	(Supli & Yan, 2024)	The use of an AR-based pocket book significantly improved students' understanding of 3D geometry and their spatial skills. AR created a more interactive and enjoyable learning experience.
5	(Tarng et al., 2024)	AR helped students concretely visualize 3D shapes, enhancing spatial visualization and understanding of volume and surface area.
6	(Triwahyuningtyas et al., 2022)	Ethnomathematics-based AR learning media effectively improved spatial ability in learning cube and cuboid geometry.
7	(Sultan, 2023)	The integration of technology and culture in math learning had a positive impact. However, successful implementation requires attention to technology accessibility, teacher training, and the development of culturally relevant content.
8	(Utami & Irawati, 2024)	The study revealed a significant difference in critical thinking skills between students taught with ethnomathematics-based media and those taught using conventional methods.
9	(Anam et al., 2024)	The validation process confirmed that the video met quality standards. It was considered appropriate and feasible for use as a learning tool in vocational school mathematics.

From the analysis of the selected studies, it can be concluded that the use of Augmented Reality (AR) in mathematics education, particularly in the context of solid geometry, holds great potential in enhancing various aspects of students' spatial ability. One of the key strengths of AR lies in its ability to present three-dimensional objects in an interactive and realistic manner, allowing students to engage directly with the material. This hands-on experience significantly aids in understanding abstract geometric concepts, particularly for students who learn more effectively through concrete visualizations. Furthermore, integrating ethnomathematics into AR-based learning provides cultural relevance, which enhances student motivation and contextual understanding. The combination of cultural elements with immersive technology not only deepens comprehension but also fosters a stronger connection between mathematics and students' everyday lives. Overall, these findings underscore the effectiveness of ethnomathematics-based AR media in improving spatial ability and promoting meaningful learning experiences in elementary geometry education.

Discussion

The findings from the reviewed literature clearly demonstrate that Augmented Reality (AR) has a significant impact on improving students' spatial abilities in geometry learning. Spatial ability includes various components such as mental rotation, spatial visualization, spatial perception, and spatial orientation, all of which are crucial in understanding geometric concepts. According to Nadzeri et al. (2024), students who used AR applications showed better performance in tasks involving mental rotation and geometric transformations. This is because AR allows students to interact with three-dimensional (3D) models, making abstract concepts more tangible and visually accessible. As a result, learners are better able to manipulate shapes mentally and understand their properties. The immersive and interactive nature of AR supports the development of cognitive processes involved in spatial thinking. Thus, AR proves to be a promising tool for facilitating deeper understanding of geometry in elementary classrooms.

The integration of ethnomathematics into AR-based learning media further strengthens students' comprehension by connecting abstract mathematical concepts to their cultural backgrounds. Ethnomathematics enables students to see the relevance of geometry in real-life contexts, such as traditional architecture, local crafts, and cultural symbols (Zuhri et al., 2023). This contextualization not only enhances understanding but also increases student engagement and motivation in learning

mathematics. When students recognize familiar patterns or shapes from their culture, their cognitive connection to the material becomes stronger. According to D'Ambrosio (1985), ethnomathematics supports a more inclusive and meaningful approach to mathematics education by acknowledging the cultural dimensions of mathematical knowledge. Therefore, combining AR and ethnomathematics can bridge the gap between formal school mathematics and students' lived experiences. This approach supports equity and relevance in teaching, especially in culturally diverse classrooms.

Several studies highlight the importance of visualization in learning geometry, where AR plays a pivotal role. AR helps students perceive and analyze spatial relationships between different geometric components, such as vertices, edges, faces, and angles (del Cerro Velázquez & Morales Méndez, 2021). By enabling real-time manipulation and observation from multiple angles, AR enhances learners' ability to grasp the structure and properties of 3D figures. This leads to improved understanding of concepts like volume, surface area, and the relationship between two-dimensional and three-dimensional representations. Students who struggle with spatial reasoning often benefit from such tools, as they offer a concrete and interactive alternative to traditional textbooks and diagrams. As supported by Supli & Yan (2024), AR-based instructional materials such as pocket books or mobile apps can effectively support learning in both individual and group settings. Thus, AR serves as an effective scaffold for developing students' spatial thinking skills.

In addition to improving spatial ability, AR-based learning environments foster student motivation and engagement. Interactive technologies have been shown to capture learners' attention and sustain interest in subjects that are often perceived as challenging, such as mathematics (Tarng et al., 2024). When students are actively engaged in exploring geometric shapes using AR, they are more likely to retain the concepts being taught. The novelty of AR also contributes to students' willingness to experiment and explore, which is essential in constructivist learning environments. According to Clark & Mayer (2023), multimedia learning experiences that involve visual and kinesthetic interaction lead to better cognitive processing and knowledge retention. AR creates such a multimedia environment by blending real-world experiences with virtual objects. As a result, students develop a more intuitive and lasting understanding of geometry concepts.

While the benefits of AR in learning are evident, successful implementation requires careful planning and resource allocation. Issues such as access to technology, teacher readiness, and curriculum integration must be addressed to ensure equity and effectiveness (Sultan, 2023). Teachers need adequate training to use AR tools effectively and to design culturally relevant content that aligns with educational goals. Without proper support and infrastructure, even the most innovative tools may fail to produce desired outcomes. Moreover, it is essential that AR content reflects the local cultural context to enhance relevance and student identity. According to Triwahyuningtyas et al. (2022), AR media that incorporates ethnomathematics is more effective when it includes visual representations of cultural elements familiar to students. Therefore, investment in both technological and pedagogical aspects is crucial for maximizing the impact of AR in education. Collaboration between educators, developers, and cultural experts is key to achieving this goal.

The Van Hiele theory of geometric thinking provides a theoretical foundation for understanding how AR supports spatial learning. This theory suggests that students progress through hierarchical levels of understanding in geometry, from visualization to informal deduction (Chairunnisa et al., 2021). AR can facilitate movement through these levels by providing visual and interactive experiences that align with students' cognitive development stages. For example, at the visualization level, students recognize shapes by their appearance, which is enhanced by AR's 3D models. At higher levels, students begin to analyze properties and make logical connections, supported by AR simulations and guided tasks. According to Solihin et al. (2024), tools that match students' developmental stages help in scaffolding learning and reducing misconceptions. Thus, AR serves as a cognitive bridge that supports the sequential progression of geometric understanding.

In addition to supporting individual learning, AR and ethnomathematics also promote collaborative learning and social interaction. When students work together to explore AR models and

discuss their cultural significance, they engage in meaningful mathematical discourse (Utami & Irawati, 2024). This collaborative process fosters critical thinking, communication, and problem-solving skills, which are essential in 21st-century education. Moreover, cultural content embedded in learning activities encourages respect for diversity and shared understanding among peers. According to Anam et al. (2024), ethnomathematics-based learning media, such as educational videos, also serve as accessible tools for broader student populations. They can be adapted for use across various educational levels, from primary to vocational schools. Thus, AR and ethnomathematics offer flexible and inclusive approaches to improving spatial ability and overall learning outcomes.

Overall, the synthesis of these studies confirms that the integration of AR and ethnomathematics in mathematics education offers a highly effective strategy for enhancing students' spatial ability, particularly in learning 3D geometry. This dual approach not only enriches students' conceptual understanding but also aligns with their cultural experiences, thereby increasing engagement and motivation. However, the success of this approach relies on the readiness of teachers, availability of technological infrastructure, and development of culturally contextualized materials. As educational environments continue to evolve, embracing innovations like AR while honoring local knowledge systems becomes increasingly important. Future research should explore the long-term effects of AR-based ethnomathematics learning on students' cognitive development and academic achievement. Additionally, studies should examine how this approach can be adapted to diverse educational contexts. With appropriate support and innovation, AR and ethnomathematics can transform how geometry is taught and understood in schools.

CONCLUSION

This study critically examined the integration of Augmented Reality (AR) and ethnomathematics as a pedagogical approach to enhance spatial ability in teaching solid geometry to fifth-grade elementary students. Through a systematic literature review, the findings consistently highlighted that AR significantly improves students' spatial skills, such as mental rotation, spatial visualization, and spatial orientation. When embedded with ethnomathematical elements, AR not only aids comprehension of abstract geometric concepts but also contextualizes learning by linking it to students' cultural backgrounds. This approach enriches mathematical understanding by making learning both meaningful and relevant. Furthermore, it aligns with the Van Hiele theory of geometric learning, offering learners a scaffolded, developmentally appropriate pathway to higher-order thinking in geometry. However, it is important to acknowledge that the findings are based on a synthesis of prior studies and not on direct experimental implementation; therefore, generalizations should be made cautiously. Despite this limitation, the study contributes to the growing body of knowledge on the use of technology and culturally responsive pedagogy in elementary mathematics education.

Based on the findings, it is recommended that future research include empirical classroom-based studies to further validate the effectiveness of AR-based ethnomathematics in improving spatial abilities. Researchers should also explore longitudinal impacts to understand how sustained exposure to this approach influences students' conceptual understanding and mathematical reasoning over time. In addition, the development of AR learning media should involve collaboration among educators, technologists, and cultural experts to ensure both pedagogical soundness and cultural relevance. Teachers must be provided with adequate training to effectively integrate AR tools into their instructional practices. Policy-makers and school administrators should also consider investing in technological infrastructure to ensure equitable access across different educational settings. Further investigation is needed to adapt this approach across various grade levels and cultural contexts, especially in rural and underserved schools. Finally, future studies could explore how this integration influences other cognitive domains such as problem-solving, critical thinking, and mathematical creativity.

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