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Analysis of the Needs Augmented Reality-Based Learning Media: Spatial Structure Material in Junior High Schools

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ABSTRACT

Acquiring knowledge in geometry, especially three-dimensional geometry, necessitates robust visualization and spatial reasoning abilities. In practice, students frequently encounter challenges in perceiving three-dimensional shapes when solely provided through two-dimensional representations in textbooks or on classroom boards. This study aims to examine the preliminary requirements for creating Augmented Reality (AR)-based educational resources for three-dimensional geometry at the junior high school level, as a component of the Analysis phase of the ADDIE development model. The research employed a descriptive qualitative approach, with data collected through semi-structured interviews involving one mathematics teacher and two eighth-grade students at Junior High School 7 Tarakan. Data analysis was conducted through data reduction, data display, and conclusion drawing. The results demonstrate that students have challenges in visualizing three-dimensional structures, especially in tasks involving composite solids and spatial perspectives. Traditional learning media are deemed inadequate in delivering sufficient visual experiences and are restricted in their application. Simultaneously, both educators and learners articulated a want for interactive, flexible, and smartphone-accessible technology-based learning resources. Augmented reality media are considered to have the capacity to enhance students' comprehension of three-dimensional geometric topics by providing tangible learning experiences through manipulable three-dimensional visuals. These findings lay a crucial foundation for the future design and development of AR-based educational media.

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1. INTRODUCTION

Three-dimensional geometry is a crucial aspect of mathematics education in junior high school, as it is intimately connected to students' visualization and spatial reasoning skills (Fujita et al., 2022; Molle & Sabandar, 2025). Numerous studies indicate that pupils frequently have challenges in comprehending three-dimensional geometry ideas when their learning is exclusively based on two-dimensional representations from textbooks or board illustrations (Andini & Cahyaningsih, 2024; Saralar et al., 2018;

Stieff et al., 2005). The constraints in visualization adversely impact students' conceptual comprehension, particularly in difficulties related to composite solids, spatial perspectives, and the interrelationships among the faces of solids (Kim et al., 2017; Saralar, 2018).

The advancement of digital technology provides the potential to establish more tangible and engaging learning experiences (Alam & Mohanty, 2023; Hasbi et al., 2025; Wekerle et al., 2022). Augmented Reality (AR) has garnered significant interest in the realm of education (AlGerafi et al., 2023; Harnal et al., 2024). Augmented reality facilitates the real-time presentation and integration of three-dimensional virtual objects with the physical world, thus aiding pupils in cultivating a more profound spatial comprehension (Kamińska et al., 2023; Koumpouros, 2024). Augmented reality (AR) and virtual reality (VR) technologies in education possess significant potential to improve students' conceptual comprehension through enhanced visualization and interactivity relative to traditional media (Al-Ansi et al., 2023; Papanastasiou et al., 2019; Radianti et al., 2020).

Additional research has shown that the application of augmented reality in mathematics and science education enhances spatial reasoning abilities, learning motivation, and student engagement (Cetintav & Yilmaz, 2023; Supli & Yan, 2024; Wang et al., 2025). Garzón et al. (2020) stated in their meta-analysis that augmented reality significantly enhances students' learning outcomes, especially in abstract areas necessitating advanced visualization skills. Recent research corroborates these findings, demonstrating that augmented reality (AR) is significantly pertinent to geometry education, since it enables pupils to immediately examine, rotate, and manipulate three-dimensional objects (Gjoka & Pireva Nuci, 2025; Tarng et al., 2024).

In the realm of mathematics education in Indonesia, the advancement of technology-based learning media has demonstrated its efficacy in enhancing students' comprehension of abstract concepts (Hidayat & Chao, 2025; Ulya et al., 2024). Research by Mucti (2025) demonstrated that animation-based learning media enhances students' comprehension of challenging mathematical ideas and boosts student engagement and motivation for learning. These findings underscore the significance of robust imagery and tangible representations in facilitating effective mathematics learning.

Most research on augmented reality focuses on the development phase and the evaluation of educational media's effectiveness, often neglecting the needs analysis phase, which is essential for media production. Within the ADDIE development model, the analysis stage is essential for identifying learning challenges, student characteristics, and the requirements of both educators and learners concerning the media to be created (Adeoye et al., 2024; Li & Sun, 2024; Spatioti et al., 2022).

This study aims to analyze the foundational requirements for creating Augmented Reality (AR)-based educational material for three-dimensional geometry at the junior high school level. The research utilized a qualitative methodology, conducting in-depth interviews with one mathematics instructor and two eighth-grade students at Junior High School 7 Tarakan. The outcomes of this needs analysis aim to deliver a thorough comprehension of learning challenges and users' genuine requirements, forming a foundation for the design of AR-based educational media in future development phases.

2. METHOD

This study adopted a descriptive qualitative approach to identify learning needs in three-dimensional geometry at the junior high school level as a foundation for developing Augmented Reality (AR)-based learning media. The qualitative approach was selected to explore in depth teachers' and students' experiences, perceptions, and needs related to the learning of solid geometry.

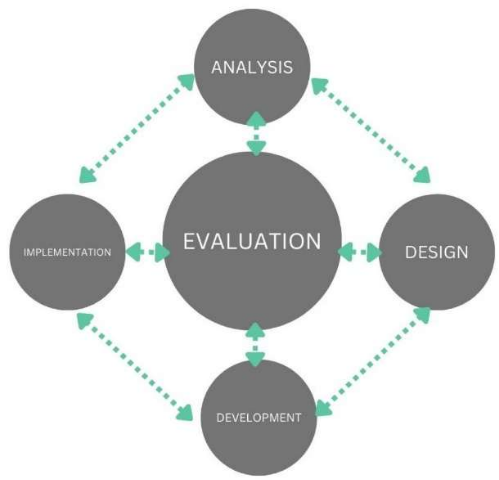

Figure 1. ADDIE model and was limited to the Analysis phase

The study was conducted as part of a development research framework using the ADDIE model and was limited to the Analysis phase. This phase aimed to identify learning difficulties, student characteristics, instructional problems, and media requirements relevant to the development of AR-based learning media. Specifically, the analysis focused on: (1) students' difficulties in understanding three-dimensional geometry, (2) students' visualization and spatial thinking abilities, (3) limitations of existing instructional media, and (4) expectations of teachers and students regarding technology-based learning media.

The research was carried out at Junior High School 7 Tarakan. Participants were selected through purposive sampling based on their direct involvement in teaching and learning three-dimensional geometry. The participants consisted of one eighth-grade mathematics teacher (G1) and two eighth-grade students with different academic levels, including one student with moderate ability (S1) and one student with high ability (S2). This selection was intended to capture diverse perspectives from both instructional and learner viewpoints.

Data were collected through semi-structured interviews, which allowed flexibility in probing participants' responses while maintaining focus on the research objectives. The interviews explored students' learning difficulties, teachers' instructional experiences, limitations of current learning media, and expectations for AR-based instructional media. All interviews were conducted face-to-face in a natural setting to encourage open and authentic responses.

Data analysis followed the interactive model of Miles and Huberman, encompassing data reduction, data display, and conclusion drawing. To enhance trustworthiness, source triangulation was applied by comparing data obtained from teachers and students, and the findings were interpreted in relation to relevant previous studies.

3. RESULTS AND DISCUSSION

Results

An examination of interview data with one mathematics teacher and two eighth-grade students at Junior High School 7 Tarakan revealed numerous key themes that highlight learning needs in three-dimensional geometry, serving as a basis for the development of Augmented Reality (AR)-based educational media.

Students' Difficulties in Visualization and Spatial Thinking

The interviews revealed that students experienced difficulties in visualizing three-dimensional objects when they were presented only through two-dimensional representations in textbooks or on the board. The teacher explicitly described this challenge:

"*When students face problems involving composite shapes or are asked to imagine hidden faces, they immediately get stuck*." (G1)

The main problem identified was students' inability to visualize spatially. When multiple geometric shapes were combined, students often failed to "decompose," or break down complex objects into their basic forms. They saw the objects as a confusing whole, rather than as an organized structure. Furthermore, this problem is related to mental rotation skills. Students who "got stuck" when visualizing the back or inside sides indicated that their mental representation of 3D objects was still two-dimensional (flat).

G1's comment implied that traditional methods—such as static images in textbooks or whiteboards—were insufficient to bridge the abstraction gap. 2D images on paper forced students to rely purely on imagination without a physical reference to manipulate. Without the ability to "see through" or actually rotate an object, students lost the structural context of the geometric shape.

This interpretation supports the use of AR as scaffolding. AR media allows students to directly see hidden sides (as if the object were transparent) and rotate objects with hand gestures. AR transforms the abstract concept of "space" into a concrete visual-spatial experience. This reduces students' cognitive load because they no longer need to expend all their mental energy simply imagining shapes but can instead focus on solving geometry problems.

These results indicate that geometry education cannot depend exclusively on the memorization of volume or surface area formulas. Students' difficulties with composite objects and hidden sides are a manifestation of their low mental manipulation abilities. The use of AR serves not only as a visual aid but also as a cognitive instrument that allows students to "interact" with dimensions previously unreachable by their perception.

Limitations of Conventional Learning Media

The teacher stated that traditional learning media tend to be static and insufficient in supporting students' need for dynamic visual exploration:

> *"Physical teaching aids help, but only for a short time. Students have to take turns, some tools get damaged, and students sitting at the back cannot see clearly."* (G1)

Informant G1's statement revealed the practical and logistical aspects that often hinder geometry learning in the classroom. The main issue raised was unequal access within the classroom. Students sitting in the back rows experience "visual marginalization." Small physical props cannot effectively reach the entire classroom, so conceptual understanding is dominated by students closest to the teacher. The culture of "queuing," or taking turns using props, creates pauses in the thinking process. When a student is in a moment of understanding (flow), they are interrupted to hand the prop to another classmate.

This interpretation positions AR as a medium capable of overcoming the physical limitations mentioned by G1. With AR, each student has a "personal prop" at their desk via a mobile device or tablet. No longer are students "unable to see" due to distance. AR digital objects cannot be damaged, broken, or lost. Students can conduct experiments repeatedly—dissecting nets of geometric shapes, resizing them, or viewing their structures from within—without risk of damaging the props. G1's findings indicate that physical props have a very short effective "expiration" within a learning session due to logistical constraints. AR integration not only replaces the role of physical teaching aids but also increases the level of learning by providing equal access, more accurate visualization (mathematical precision), and interactive experiences that inanimate objects cannot provide.

The Need for Interactive Technology-Based Media

The interview results also indicated a strong demand from both teachers and students for learning media that can present three-dimensional objects in a realistic and interactive manner:

> *"If the solid shapes could appear on the desk and be assembled and disassembled, I think I would understand better."* (S1)

The student statements reflect their aspirations for a tactile-digital learning experience. The phrases "appeared on the table" and "disassembled" reflect students' need for complete control over the objects they study. Students' desire to "assemble and disassemble" demonstrates that deep geometric understanding occurs not simply through viewing, but through manipulation. In traditional geometry, nets are often viewed as static 2D images. With AR, students want to see the transition process of how a net folds into a geometric shape in real time. This desire aligns with constructivist theory, where students construct their knowledge by manipulating the objects of their study.

The phrase "appeared on the table" indicates the importance of contextualizing learning. AR transforms students' personal space (their desks) into personal math laboratories. This creates a sense of ownership over the learning material. When objects appear in students' real-world environments, the boundaries between abstract theory and reality blur, making learning feel more relevant and less intimidating. Psychologically, students' desire to interact with "magical" digital objects on their desks triggers dopamine, which increases engagement.

The findings from S1 confirm that the effectiveness of AR lies not only in its cool appearance but also in the agency it gives students. The ability to independently control, dissect, and reassemble geometric objects on their desks transforms mathematical abstractions into tangible, physical experiences, significantly strengthening the foundation of their conceptual understanding.

Time Efficiency and Instructional Support for Teachers

In addition to supporting students' understanding, the interviews revealed that interactive media could help teachers deliver instructional content more efficiently:

"Sometimes one entire lesson is spent just on visualization, and even then not all students understand." (G1)

This statement from informant G1 highlights the time-consuming and pedagogical ineffectiveness of conventional geometry teaching methods. The comment that "a whole class hour is spent just on visualization" indicates a deadlock in the teaching and learning process. The initial stage or "entry point" to problem-solving and formula application should be visualization. However, because students struggle to visualize 3D objects, teachers remain stuck at the introductory stage, resulting in core material (such as calculating volume or surface area) being rushed or missed. This inefficiency creates a domino effect on the curriculum schedule, where subsequent topics are forced to be compressed due to the lack of time devoted to spatial geometry.

The statement that "not all students understand" despite the maximum amount of time devoted demonstrates that traditional media fail to accommodate diverse learning styles. Every student has different levels of spatial intelligence. Verbal explanations or 2D drawings on the board may be sufficient for a small number of students, but for the majority, they remain confusing abstractions. Without interactive tools, teachers struggle to provide individualized guidance to students who are lagging behind in visualization. This interpretation positions Augmented Reality (AR) not simply as a supplementary medium, but as a tool for accelerating understanding. With the help of AR, the burden on teachers to become "illustrators" is reduced. Teachers can redirect time typically spent on basic visualizations to more meaningful discussions, such as analyzing relationships between geometric shapes, proving formulas, or solving more complex contextual problems. Teachers can use AR to precisely show specific parts of a shape (e.g., a diagonal or a diagonal) that are difficult to achieve with a static physical model.

Findings from G1 indicate a "time crunch" in geometry learning due to the low absorption of conventional visualizations. The use of AR significantly improves classroom time efficiency by transforming the visualization process from a time-consuming and tedious activity into an instant and accurate digital experience. This allows all students—without exception—to achieve the same standard of understanding in a shorter time.

Discussion

Research at Junior High School 7 Tarakan identified a significant gap between conventional geometry learning methods and students' cognitive needs in understanding spatial structures. Based on this data, four key points underlie the urgency of developing Augmented Reality (AR)-based media.

Cognitive Barriers in Spatial Visualization

Students' primary difficulty lies in the limitations of transforming 2D representations (textbooks) into a comprehensive 3D understanding. When students are asked to process composite shapes or hidden edges, cognitive barriers occur that cause them to get stuck. Spatial thinking skills involve more than simply seeing objects, but also mentally manipulating them. This finding confirms that static media fails to bridge the transition from the concrete operational stage to the formal stage in geometry. AR offers a solution because it offers an interactive visualization experience that has been proven effective in improving students' spatial reasoning (Shaghaghian et al., 2024; Supli & Yan, 2024; Yanuarto & Iqbal, 2025).

Failure of Conventional Media in Classroom Inclusivity

Although physical teaching aids have been used, their effectiveness is limited by logistical and accessibility factors, including (1) Spacing and Durability Issues: Students in the back rows often lack a clear visualization, and physical teaching aids are susceptible to damage. (2) AR Solutions: Unlike physical teaching aids that must be shared, AR allows each student to have their own "digital object" on their desk. This technique creates equity in receiving precise and engaging visual information.

Personalization and Interactive Exploration

The desire of students to be able to "disassemble" geometric objects on their desks demonstrates the need for active learning. The use of AR allows abstract concepts to become more concrete. With object manipulation features (such as rotation and dissection of geometric shapes), AR not only provides a richer visual experience but also increases students' emotional and intellectual engagement in the learning process (AlGerafi et al., 2023; Ji et al., 2025).

Optimizing Instructional Time Management

One crucial finding is the time inefficiency, where an entire lesson hour is often spent simply explaining basic visualizations. With the help of AR, teachers can reduce the time spent on convoluted theoretical explanations. This medium helps teachers deliver instructional content more efficiently because abstract concepts are automatically visualized by the technology (Carrera et al., 2018; Hung et al., 2017). This provides more space for teachers to focus on higher-level discussions or problem-solving (HOTS) (Ansori et al., 2025).

This research demonstrates that the transition from static learning media to augmented reality-based media is no longer just a technological trend but rather an urgent need to address students' spatial barriers and logistical limitations in mathematics classes. AR can transform geometric concepts that are difficult to grasp mentally into real-life experiences that are interactive and easy to understand (Dargan et al., 2023; Gargrish et al., 2020).

Overall, the findings of this study indicate that learning three-dimensional geometry faces significant challenges related to students' visualization and spatial thinking abilities. These challenges cannot be optimally addressed using conventional learning media and require more interactive and contextualized instructional support. The results are consistent with previous studies demonstrating that AR-based learning media effectively enhance students' spatial reasoning and conceptual understanding through concrete and engaging three-dimensional visualizations (Hafis et al., 2024; Parandreni, 2024; Supli & Yan, 2024). The integration of AR not only enables students to interact visually with geometric objects but also supports teachers in delivering abstract concepts in a more efficient and meaningful manner.

4. CONCLUSION

Learning three-dimensional geometry at the junior high school level continues to face major challenges related to students' visualization and spatial thinking abilities. These difficulties are experienced by students across different levels of academic ability and result in low levels of conceptual understanding, particularly in topics involving composite solids and the identification of non-visible components of three-dimensional objects. The results also indicate that conventional learning media currently used in classrooms have not adequately supported students' visualization needs. Two-dimensional representations and physical manipulatives have limitations in providing interactive, flexible, and sustained learning experiences. This condition illustrates the importance of technology-based learning media that are capable of presenting three-dimensional representations in a realistic and contextualized manner. Furthermore, the interview findings reveal a strong demand for the development of Augmented Reality (AR)-based learning media. AR is thought to be able to help students better understand three-dimensional geometry concepts, improve their spatial thinking skills, and make teaching more effective for teachers. These findings provide a solid foundation for the development of innovative learning media aligned with students' characteristics and classroom learning needs. In conclusion, this study contributes not only to the identification of learning challenges in three-dimensional geometry but also serves as a conceptual and empirical foundation for the development and evaluation of augmented reality-based learning media at the junior high school level.

As a suggestion, future research will proceed to the Design and Development stages of the ADDIE model by designing and developing AR-based learning media for three-dimensional geometry in accordance with the identified needs. Subsequent stages will also include expert validation, practicality testing involving teachers and students, and effectiveness testing to examine the impact of the developed media on students' spatial thinking abilities and conceptual understanding. These evaluations may be conducted using quantitative or mixed-methods approaches.

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