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Development of Augmented Reality (AR) Based Learning Media for Geometry

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Abstract: Students' limited understanding of surface area and volume in three-dimensional geometry is influenced by insufficient instructional time and a lack of innovative learning media. This development research aims to produce an augmented reality (AR)–based learning application that is valid and practical for geometry instruction. The study employed the ADDIE development model, which consists of Analysis, Design, Development, Implementation, and Evaluation stages. During the implementation phase, peer teaching was conducted involving 17 graduate students from the Mathematics Education Department at Universitas Negeri Malang. The results indicate that the AR learning application was successfully developed for three-dimensional geometry topics. Data analysis shows that the average validity score of the developed media was 3.35, while the average practicality score was 3.87. These findings suggest that the AR-based learning media are valid and practical for supporting students' understanding of surface area, volume, and geometric elements.

Keywords: Augmented reality, Geometry, Learning media, Educational software

Introduction

Mathematics is an essential discipline that students must master, as it develops logical thinking skills and supports problem-solving in everyday life (Lestari & Annizar, 2020). In formal education, mathematics also plays a foundational role in supporting the development of other scientific disciplines (Septiadi et al., 2022). Annizar et al. (2020) emphasized that mathematics functions as a foundational science that facilitates the growth and operational development of other fields of knowledge.

One important branch of mathematics is geometry, particularly three-dimensional geometry, which requires students to visualize and reason about objects in space. Students' understanding of geometry is closely related to their spatial abilities and spatial perception. Several studies have reported a positive relationship between mathematical achievement and spatial thinking ability (Yu et al., 2022). Spatial reasoning plays a crucial role in solving geometry-related problems (Cahyono, 2021), and it is considered an essential skill for students when learning three-dimensional concepts (Listiwikono, 2022).

In fact, results from the 2015 TIMSS assessment revealed that Indonesia's average score in geometry was 394, which falls below the international benchmark (Listiwikono, 2022). According to TIMSS standards, this score indicates that Indonesian students are generally limited to basic geometric understanding and have difficulty visualizing or interpreting geometric representations (Prasetyo & Qohar, 2023). Similarly, the 2022 PISA results showed a decline in Indonesia's mathematics score to 366, with geometry-related components included in the Space and Shape domain (Putra & Rahmawati, 2022). These findings highlight the need to improve students' spatial and geometric understanding through more innovative instructional approaches.

Augmented Reality in Geometry Learning

One effective approach to improving students' spatial understanding is to transform abstract geometric concepts into more concrete and interactive representations. Augmented Reality (AR) technology allows digital objects to be integrated into the real environment, creating interactive learning experiences that combine physical and virtual elements (Richardo et al., 2023). Sukriadi et al. (2023) defined AR as a technology that overlays digital information onto the real world in real time and can be effectively implemented through mobile devices.

This study aims to develop an AR-based geometry learning application using Unity that can be installed on Android devices. The application enables students to explore three-dimensional geometric objects, including nets, edges, faces, angles, formulas, and calculations related to surface area and volume. This research addresses limitations identified in previous studies, such as the reliance on external applications (e.g., GeoGebra and Google AR) and the absence of integrated problem-solving features (Pakaya & MacHmud, 2021). Additionally, unlike digital learning media that primarily present static content (Aditya & Hiltrimartin, 2024), the developed AR application provides interactive 3D visualizations combined with evaluative tasks.

Method

This study employed a research and development (R&D) approach aimed at producing AR-based learning media for three-dimensional geometry instruction. The development process followed the ADDIE model, which includes five stages: Analysis, Design, Development, Implementation, and Evaluation (Qohar et al., 2021). The trial implementation was conducted through peer teaching involving 17 graduate students from the Mathematics Education program at Universitas Negeri Malang. Data were collected using validation sheets and practical questionnaires. The validation instrument assessed four aspects: content, usability, display, and language. The practicality questionnaire evaluated media usability, material presentation, and visual appearance. Quantitative data were analyzed using descriptive statistics, while qualitative feedback from validators and participants was analyzed descriptively.

Validity Test

The validity of the learning media was determined by calculating the average validation score (Vr) from expert validators. The validation instrument used a four-point Likert scale ranging from 1 (Very Unsuitable) to 4 (Very Suitable) (Silwana & Qohar, 2022). The validity criteria are presented in Table 1.

Table 1. Validity level

Average Validity Score (Vr)	Validity Level
$1 \leq Vr < 2$	Invalid
$2 \leq Vr < 3$	Less Valid
$3 \leq Vr < 4$	Valid
$Vr = 4$	Very Valid

Based on Table 1, the validity level is determined by the average validity score (Vr). A score of $1 \leq Vr < 2$ indicates the instrument is Invalid, $2 \leq Vr < 3$ means Less Valid, $3 \leq Vr < 4$ shows it is Valid, and $Vr = 4$ signifies Very Valid. In other words, the higher the Vr value, the more appropriate and reliable the instrument is for use.

Practicality Test

The practicality of the AR learning media was evaluated using a questionnaire completed by peer teaching participants. The instrument employed a four-point Likert scale (Fahmi & Qohar, 2023). The practicality level was determined by comparing the average practicality score (Pr) with the criteria shown in Table 2.

Table 2. Practicality level

Rata-rata Skor Kepraktisan (Pr)	Practicality level
$1 \leq Pr < 2$	Not Practical
$2 \leq Pr < 3$	Less Practical
$3 \leq Pr < 4$	Practical
$Pr = 4$	Very Practical

Based on Table 2, the practicality level is determined by the average practicality score (Pr). A score of $1 \leq Pr < 2$ indicates the media is Not Practical, $2 \leq Pr < 3$ means Less Practical, $3 \leq Pr < 4$ shows it is Practical, and $Pr = 4$ signifies Very Practical. Thus, a higher Pr value reflects greater efficiency, ease of use, and suitability of the learning media for classroom implementation.

Results and Discussion

This section presents and discusses the results of the development and evaluation of the augmented realit (AR) based learning media for three-dimensional geometry. The discussion focuses on the validity and practicality of the developed media based on expert validation and peer-teaching implementation. The results are presented in relation to the research objectives and supported by relevant previous studies.

Analysis Stage

The analysis stage consisted of performance analysis and needs analysis. The performance analysis revealed that students experienced difficulties in understanding surface area and volume concepts in three-dimensional geometry, particularly in identifying geometric elements such as edges, faces, angles, and nets. The needs analysis focused on determining learning objectives aligned with the curriculum (Putra & Rahmawati, 2022). Based on this analysis, the primary competency targeted in this study was students' conceptual understanding of surface area and volume in three-dimensional geometry.

Design Stage

At the design stage, the structure of the AR based learning media and the lesson plan were systematically developed in accordance with the learning objectives of three-dimensional geometry. The design components included learning objectives, application usage scenarios, media format, student worksheets (LKPD), and evaluation instruments. All components were aligned with the curriculum to support students' conceptual understanding of surface area, volume, and geometric elements in three-dimensional geometry.

Development Stage

The development stage followed the ADDIE framework and consisted of three phases: pre-production, production, and post-production.

a. Pre-production stage

The pre-production phase focused on preparing the tools and materials required for developing the AR-based learning media. The development utilized Unity software, AR markers, and learning materials adapted from the Grade 8 Merdeka Curriculum mathematics textbook published by the Ministry of Education and Culture (2022/2023). Media scripts were prepared to ensure consistency between learning objectives, content presentation, and application feature.

b. Production Stage

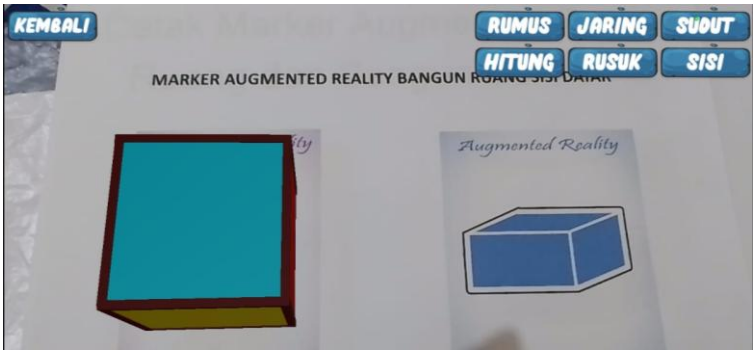

Figure 1. Button display

At this stage, the Augmented Reality (AR) learning media was developed for three-dimensional geometry (solid geometry). The application consists of a main menu that appears after the start button is selected and provides four primary feature options, namely introductory material on geometric nets, angles, edges, and faces. These features are designed to support students' understanding of fundamental elements of three-dimensional shapes through interactive visualization.

Figure 1. illustrates the main interface of the AR application, which consists of several interactive buttons. The *Formula* button displays the formulas for surface area and volume of three-dimensional solids. The *Net* button presents the geometric nets of the solids, while the *Angle*, *Edge*, and *Face* buttons display the corresponding geometric elements based on the detected AR marker. In addition, the *Calculate* button functions as a calculator for computing the surface area and volume of three-dimensional shapes. This feature is activated when the camera is directed at the selected AR marker, including markers for cubes, rectangular prisms, prisms, and pyramid.

Figure 2. Shape of the Spacecraft Net

Figure 2 shows the visualization of geometric nets that appears when the *Net* button is selected. Each face of the net is displayed in a different color to help students distinguish between adjacent surfaces and to facilitate clearer visual understanding of the structure of the three-dimensional solid.

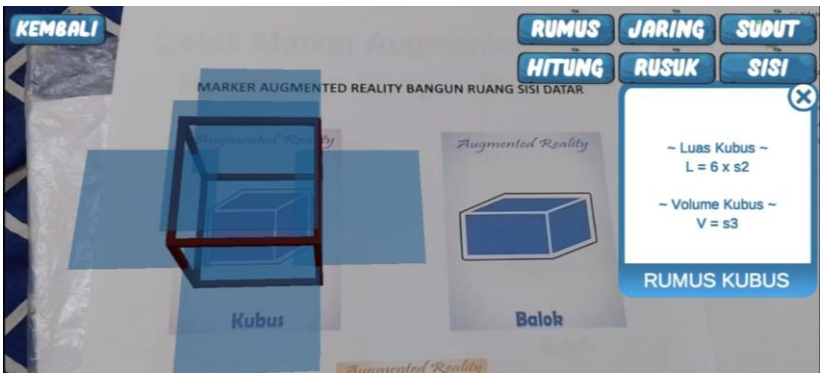

Figure 3. Formula for building spaces

Figure 3 presents information on the formulas for surface area and volume that appears after the *Formula* button is selected, once the camera is directed at the appropriate AR marker. The formulas provided in the AR application are intended to support students in verifying their solutions when determining the surface area and volume of three-dimensional solids.

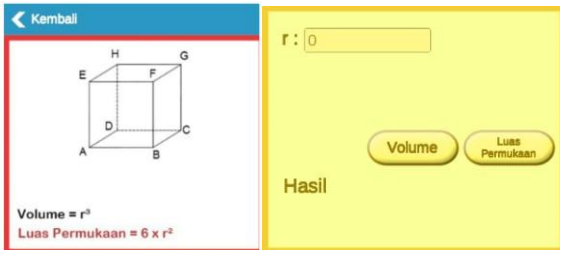

Figure 4. Calculator of building spaces

Figure 4 displays the calculator feature for computing the surface area and volume of three-dimensional solids, which appears after selecting the *Calculate* button. This feature allows students to check the accuracy of their calculations and serves as a tool for reflection and self-evaluation in learning three-dimensional geometry. In the introductory material section, students are presented with three-dimensional visualizations by directing the camera at the AR markers provided in the initial menu. Once the marker is detected, the main buttons appear, allowing students to explore the 3D representations of nets, faces, angles, and edges of the selected solid.

In the justification and evaluation section, students are provided with facilities to verify the correctness of surface area and volume formulas after completing worksheets designed to guide them toward conceptual understanding. Furthermore, students can compare their problem-solving results related to surface area and volume using the calculator feature accessed through the *Calculate* button.

c. Post-production stage

At this stage, the developed learning media were validated by material experts and media experts to evaluate the suitability of the content in relation to the established learning indicators. The validator in this study was a postgraduate lecturer in mathematics education who also serves as a professor specializing in mathematics learning media. The results of the validation of the Augmented Reality based learning application for three-dimensional geometry are presented below.

Table 3. Media validation results

Criteria Assessed	Average score
Content Aspect	
The suitability of the content in helping students recognize the material easily	4
The suitability of the content in helping students build an understanding of the concept of the material	4
The suitability of positive interactive activities	3
The suitability of the content of the activities with the learning objectives	3
Clarity of learning media content	3
Usability Aspect	
Usability in helping students achieve learning objectives	4
Usability in supporting the learning process	3
Usability in encouraging student activeness in learning	4
Display Aspect	
Display according to the material or concepts discussed	3
Images clarify the material	3
Display of interesting learning media	3
Display in accordance with the characteristics of junior high school students	4
Language	
Ease of reading and understanding sentences (communicative)	3
Appropriateness of colors, fonts, and font sizes used	3
Average Validity Score	3.35

Based on Table 3, the average validity score of the AR-based learning media was 3.35, indicating that the media is categorized as valid. This result suggests that the developed media meets essential criteria in terms of content accuracy, usability, visual design, and language clarity. The highest scores were obtained in the content and usability aspects, indicating that the media effectively supports conceptual understanding of three-dimensional geometry. These findings are consistent with previous studies highlighting that well-designed digital learning media should integrate accurate content, interactive features, and clear instructional language to support meaningful learning (Richmasari et al., 2023).

Implemetation Stage

The implementation stage aimed to evaluate the practicality of the developed AR learning media through a preliminary trial. The trial was conducted using a peer-teaching approach involving **17 graduate students** from the Mathematics Education program at Universitas Negeri Malang. This approach was employed to assess media usability, clarity of content, and functionality prior to classroom implementation. Participants accessed the AR application via an APK file installed on Android smartphones.

Evaluation

At this stage, after the peer-teaching activities were completed, participants were asked to complete a questionnaire to evaluate the practicality of the Augmented Reality (AR) learning media for three-dimensional geometry. The questionnaire aimed to assess the ease of use, usefulness, and visual appeal of the developed application during the trial implementation. The results of the practicality questionnaire completed by peer-teaching participants are presented in Table 4.

Table 4. Response questionnaire analysis results

Criteria Assessed	Average score
Content Aspects	
Ease of use of the media	4
Its usefulness in helping students build an understanding of the concept of the material	4
Its usefulness in helping students get excited about learning math	4
Benefits in learning for students	4
Helps students to play an active role	4
Bring up a sense of wanting to understand more math	4
Language and Display	
Instructions and information are easy to understand	3
The appearance of learning media is interesting	4
Average Validity Score	3.87

Based on Table 4, the average practicality score of the AR-based learning media is 3.87, which falls into the practical category. The average score was obtained by summing the scores of all indicators and dividing them by the total number of indicators. This result indicates that the developed AR application is easy to use, visually engaging, and beneficial in supporting learning activities. The developed learning media takes the form of an Android-based application (APK), enabling installation and use on Android smartphones. Referring to the validation results (see Table 3), the AR-based learning media was also categorized as valid, with an average validity score of 3.35, which meets the criterion of $3 \leq Vr < 4$. These findings indicate that the content, design, and functionality of the AR application are aligned with established principles of instructional media development. The validity results are consistent with previous studies suggesting that learning media can be considered valid when aspects such as content accuracy, usability, animation, language, and symbols are appropriately designed (Richmasari et al., 2023). This confirms that the developed AR application meets theoretical and practical requirements for instructional use.

Furthermore, the practicality test results demonstrate that the AR-based learning media is feasible for classroom implementation. The practicality score of $3 \leq Pr < 4$ indicates that the media is easy to operate, interactive, and understandable according to the indicators assessed in the questionnaire. Participants gave positive responses across all assessed aspects, particularly regarding media interactivity.Interactivity between learners and AR media plays an important role in supporting digital learning environments. Positive responses to the interactivity of the AR application suggest that such media can contribute to the success of digital learning initiatives in schools (Khotimah et al., 2022). This finding aligns with Cevikbas et al. (2023), who stated that technology-based learning media can encourage students to become more active and support meaningful learning through interactive visualizations.

In this study, learning activities were designed following constructivist approach. Students were initially provided with brief explanations of three-dimensional geometry concepts as a stimulus. They then engaged in interactive activities using student worksheets (LKPD), which required them to explore geometric elements through the AR application. Through these activities, students were guided to identify surface area and volume formulas by observing the geometric properties of three-dimensional solids and solving contextual problems related to everyday situations. Such activities support students' conceptual understanding of surface area and volume (Soeprianto et al., 2023) and help them recognize the relationship between these two concepts. Understanding the relationship between surface area and volume requires a relatively high level of conceptual comprehension, particularly in three-dimensional geometry (Putra & Rahmawati, 2022).

In the final stage, students were provided with justification and evaluation features to verify the correctness of the formulas they derived and the solutions they obtained. This process was intended to foster students' mathematical reasoning skills. Reasoning is a fundamental component of mathematical learning and is essential for developing

conceptual understanding, problem-solving abilities, and justification skills (Heldi Nur Setiawan et al., n.d.; Yu et al., 2022).

Conclusion

This study successfully developed an Augmented Reality–based learning media application for three-dimensional geometry. The validation results showed an average score of 3.35, indicating that the developed AR application is valid. Meanwhile, the practicality test results showed an average score of 3.87, indicating that the AR-based learning media is practical. The validity and practicality findings suggest that the AR application is ready for use and can serve as a supportive learning medium for understanding surface area, volume, and geometric elements of three-dimensional solids. However, this study was limited to evaluating validity and practicality and did not examine the effectiveness of the media in improving students' learning outcomes. Therefore, future research is recommended to investigate the effectiveness of AR-based learning media on students' mathematical abilities.

Recommendations

Based on the findings of this study, future research is encouraged to further develop Augmented Reality–based learning media for a wider range of mathematical topics beyond geometry. Expanding the integration of AR technology may provide more immersive and interactive learning experiences to support students' understanding of abstract mathematical concepts. Teachers and curriculum designers are encouraged to adopt AR media as a complementary tool to conventional instructional materials. Additionally, future studies should involve broader classroom trials to evaluate long-term learning outcomes and user experience. Collaboration among educators, researchers, and software developers is essential to ensure the sustainability and effectiveness of AR learning applications in mathematics education.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPESS journal belongs to the authors.

* The authors declare that all research procedures were conducted in accordance with scientific, ethical, and legal standards. The study did not involve activities that posed risks to participants, and informed consent was obtained prior to data collection. Ethical and legal responsibility for the content of this article lies entirely with the authors.

Conflict of Interest

* The authors declare that there are no conflicts of interest related to the research, authorship, or publication of this article.

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