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DEVELOPMENT OF AN AUGMENTED REALITY APPLICATION FOR LEARNING THE VOLUME AND SURFACE AREA OF THREE-DIMENSIONAL SHAPES

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Abstract: This study focuses on the development of an Augmented Reality (AR)–based learning application designed to assist students in understanding the mathematical concepts of volume and surface area of three-dimensional geometric shapes. The development process adopted the Multimedia Development Life Cycle (MDLC) model, which consists of six systematic stages: concept, design, material collecting, assembly, testing, and distribution. The research concentrated on the development and expert validation stages. Validation results from content and media experts indicate that the application meets pedagogical and technical feasibility standards. The content expert confirmed that the materials align with the national mathematics curriculum and are presented in a clear, contextual, and accurate manner, while the media expert highlighted the user-friendly interface, interactive features, and visual appeal of the application. Theoretically, this AR-based medium bridges the gap between abstract mathematical concepts and concrete visualization by enabling students to interact directly with virtual 3D objects. Practically, the application enhances learning motivation and engagement by providing dynamic, interactive experiences. Overall, this research contributes to the advancement of educational technology by offering a systematic model for developing AR-based learning media that support active and meaningful learning in the digital era.

Keywords: Augmented Reality; geometry learning; surface area ; volume

Abstrak: Penelitian ini berfokus pada pengembangan aplikasi pembelajaran berbasis *Augmented Reality* (AR) yang dirancang untuk membantu siswa memahami konsep volume dan luas permukaan bangun ruang tiga dimensi. Proses pengembangan dilakukan menggunakan model *Multimedia Development Life Cycle* (MDLC) yang terdiri atas enam tahap sistematis, yaitu konsep, perancangan, pengumpulan materi, perakitan, pengujian, dan distribusi. Penelitian ini difokuskan pada tahap pengembangan dan validasi oleh para ahli. Hasil validasi dari ahli materi dan ahli media menunjukkan bahwa aplikasi memenuhi kriteria kelayakan pedagogis dan teknis. Ahli materi menilai bahwa isi aplikasi telah sesuai dengan kurikulum matematika nasional, disusun dengan bahasa yang komunikatif, serta disertai contoh kontekstual yang relevan. Sementara itu, ahli media menilai tampilan antarmuka mudah digunakan, elemen interaktif menarik, dan desain visual konsisten. Secara teoretis, media berbasis AR ini menjembatani kesenjangan antara konsep matematika yang abstrak dan pengalaman visual yang konkret, memungkinkan siswa berinteraksi langsung dengan objek 3D virtual. Secara praktis, aplikasi ini dapat meningkatkan motivasi dan keterlibatan belajar melalui pengalaman interaktif yang dinamis. Secara keseluruhan, penelitian ini berkontribusi pada pengembangan teknologi pendidikan dengan menawarkan model sistematis dalam pengembangan media pembelajaran berbasis AR yang mendukung pembelajaran aktif dan bermakna di era digital.

Kata kunci: *Augmented Reality*; pembelajaran geometri; luas permukaan; volume

INTRODUCTION

Geometry represents one of the fundamental branches of mathematics that require advanced levels of abstract and spatial reasoning [1], [2]. Concepts related to three-dimensional figures such as cubes, rectangular prisms, pyramids, cylinders, cones, and spheres often pose considerable challenges for students because they demand a strong ability to visualize objects in three dimensions [3]. In practice, many learners struggle to connect the visual form of these solids with the corresponding formulas for volume and surface area [4], [5]. This difficulty largely stems from the limitations of conventional learning media, which typically provide only two-dimensional illustrations through text-books or chalkboard drawings [6]. As a result, abstract geometric concepts become harder to grasp in depth, ultimately influencing students' overall performance in mathematics [7].

The rapid advancement of digital technology today offers significant opportunities for education to create learning experiences that are more interactive, contextual, and meaningful. One emerging technology that has gained increasing attention in educational research is Augmented Reality (AR) [8], [9]. AR technology enables the integration of virtual three-dimensional objects into real-world environments in real time, allowing learners to directly interact with digital representations of instructional materials. Within the context of geometry learning, AR provides a highly visual approach that helps students understand the shape, size, and spatial relationships of geometric solids in a more concrete manner [10]. Such interactive visuali-zation not only strengthens conceptual understanding but also promotes active learner engagement throughout the learning process .

A growing body of research has demonstrated that the use of Augmented Reality (AR) in mathematics education can enhance students' motivation, conceptual understanding, and know-ledge retention [10]. Nevertheless, most of these studies have primarily focused on introducing two-dimensional shapes or presenting three-dimensional objects merely as visual aids, without integrating more complex mathematical computa-tions such as volume and surface area. Furthermore, there remains a limited number of AR applications specifically designed to align with the Indonesian national curriculum and the learning needs of local students. This gap highlights the need for research that develops AR-based learning tools capable of not only visualizing geometric solids interactively but also facilitating a deeper comprehension of the underlying mathematical principles.

In response to this gap, the present study aims to develop an Augmented Reality application that assists students in understanding the concepts of volume and surface area of three-dimensional figures in an intuitive and interactive manner. The development process followed a Research and Development (R&D) approach encom-passing stages of needs analysis, design, and application development. The resulting product was evaluated by both content and media experts to assess its feasibility in terms of accuracy, pre-sentation quality, and usability. Rather than conducting classroom trials, this study concentrated on expert validation to ensure the quality and suitability of the learning medium prior to broader implementation.

METHOD

This study employs a Research and Development (R&D) approach, focusing on the design and validation of an Augmented Reality (AR) application developed to support the learning of volume and surface area of three-dimensional shapes. The primary goal of this research is to produce a learning medium that meets the standards of feasibility based on expert evaluations, including both content and media specialists. The development process follows the Multimedia Development Life Cycle (MDLC) model proposed by Luther (1994) and later adapted by Sutopo (2003). This model was chosen because it provides a systematic and structured framework for multimedia product development, encompassing stages from initial concept formulation to final evaluation.

The MDLC model comprises six major stages: concept, design, material collecting, assembly, testing, and distribution. In this study, the development process was carried out only up to the testing stage, as the product has not yet been distributed to end users. Expert validation was conducted to assess the content accuracy and media quality, ensuring that the learning application meets pedagogical and usability standards before broader implementation in educational settings.

RESULT AND DISCUSSION

Concept Stage

The first stage involved formulating the fundamental concept for developing the AR-based application, grounded in a thorough needs analysis. At this stage, the researchers identified learning challenges in geometry, particularly students' difficulties in understanding three-dimensional shapes both visually and mathematically. Based on a review of relevant literature and curriculum analysis, it was determined that the application would focus on seven commonly taught geometric solids at the secondary school level: the cube, cuboid, prism, pyramid, cylinder, cone, and sphere. The primary aim of the application is to help students visualize three-dimensional forms and comprehend the calculations of volume and surface area through interactive exploration.

The learning concept is rooted in a constructivist approach, allowing learners to acquire knowledge through active exploration and direct interaction with digital objects. In addition, the user experience (UX) aspect was carefully considered to ensure that the application is intuitive and accessible for both students and teachers.

Design Stage

The design stage involved developing the overall structure of the application, navigation flow, user interface (UI), and the visual design of three-dimensional objects. Storyboards and flowcharts were used to illustrate the relationships among pages, user interactions, and the integration of AR functionalities. The user interface was designed to be simple and intuitive, considering the characteristics of the primary users, secondary school students. Additionally, multimedia elements such as text, images, audio, animations, and 3D objects were carefully selected to ensure that each component effectively supports the delivery of learning concepts.

This stage resulted in a comprehensive blueprint design consisting of the interface layout, navigation flow, and application menu structure. The design was visualized using storyboards and flowcharts to depict the interaction between screens and user pathways. The principles of user-friendliness and interactivity served as the main design guidelines. Color schemes, typography, and layout arrangements were adapted to suit students' preferences and cognitive characteristics, aiming to sustain attention and enhance conceptual understanding throughout the learning process.

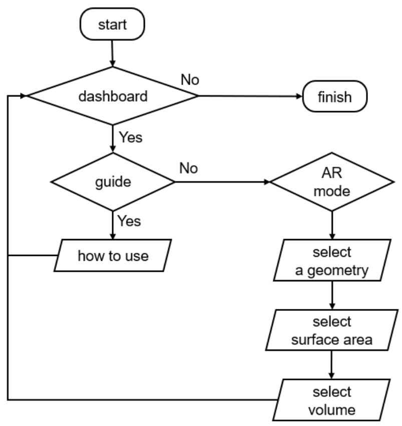

Figure 1. Application Development Process

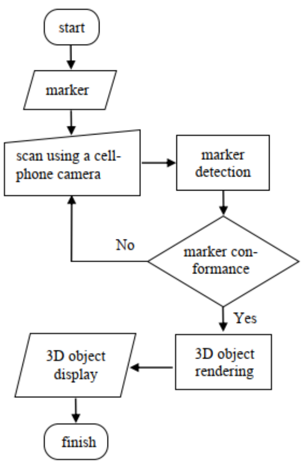

Figure 2. Application Workflow Diagram

Material Collecting Stage

The material collecting stage focused on assembling all instructional and multimedia resources required to support the development of the AR-based learning application. This process began with a comprehensive review of the national mathematics curriculum and textbooks commonly used at the secondary school level to ensure that the content was pedagogically relevant and aligned with educational standards. The selected learning materials covered essential concepts of three-dimensional geometry, including the identification of shapes, properties of solids, and the computation of volume and surface area.

Visual resources were developed to enhance conceptual clarity and engagement. Illustrations and 3D models of geometric solids. such as cubes, cuboids, prisms, pyramids, cylinders, cones, and spheres, were designed using Blender and SketchUp. These tools enabled the creation of realistic and manipulable models that could be integrated seamlessly into the AR environment. Each visual element was designed to help learners move from abstract understanding to concrete visualization, allowing them to interact with and explore spatial relationships dynamically.

In parallel, audio elements were recorded and refined using professional voice recording and editing software. Narrations were created to accompany visual explanations, offering verbal reinforcement that supports auditory learners and promotes multimodal engagement. These audio components were carefully scripted in simple yet precise language to ensure clarity and alignment with students' comprehension levels.

Before being incorporated into the

development phase, all materials underwent an expert validation process. Subject matter experts reviewed the accuracy, consistency, and relevance of the content, while media experts evaluated the visual and auditory elements for clarity, appeal, and pedagogical effectiveness. The validation process ensured that every component met both academic and usability standards, providing a solid foundation for the subsequent stages of application assembly.

Assembly Stage

The assembly stage represented the core phase of development, during which all multimedia components were integrated into a cohesive and interactive AR-based learning application. This process was carried out using Unity 3D as the primary game engine, supported by the Vuforia SDK platform to enable Augmented Reality functionality. Within this stage, the focus was on translating the conceptual and design blueprints into a functional prototype that could deliver an engaging and pedagogically sound learning experience.

The development process included the creation of the user interface, placement of 3D models, and integration of various interactive features such as rotation, zooming, and on-demand display of information related to the volume and surface area of geometric solids. These features were designed to promote exploration and active engagement, allowing learners to manipulate objects virtually and observe geometric properties from multiple perspectives. Initial testing was conducted on Android devices to ensure that the AR tracking, marker recognition, and rendering functions operated smoothly.

In this application, users can point their smartphone camera at specific AR markers to visualize geometric solids in three-dimensional form. The displayed objects can be rotated, enlarged, or minimized according to the user's needs, offering a dynamic visualization that supports the understanding of abstract mathematical concepts. The interactive nature of the system encourages experiential learning, in which students can construct their own understanding through direct manipulation of virtual models.

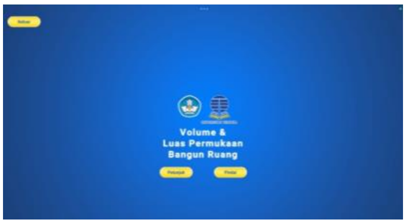

Figure 3. Augmented Reality Home Screen Display

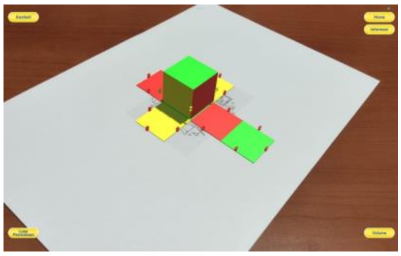

Figure 4. 3D View of Surface Area

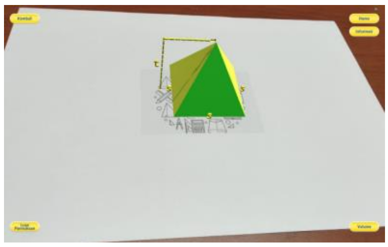

Figure 5. 3D Volume Display

During the assembly process, all multimedia elements, including text, images, animations, audio narrations, and 3D objects, were combined using development tools such as Adobe

Animate and Unity. Each element was carefully synchronized to maintain logical flow and instructional coherence. This stage resulted in a functional prototype of the AR learning application, which incorporated complete navigation features, cross-page transitions, and built-in evaluation components. The final prototype provided a seamless and immersive learning experience, integrating cognitive, visual, and interactive dimensions to support effective understanding of geometric concepts.

Testing Stage

The testing stage focused on expert validation to ensure that the developed application met the required standards of educational media feasibility. The validation process employed a Likert-scale questionnaire ranging from 1 to 5, designed to assess three key dimensions: content appropriateness, visual and interface design, and technical functionality. The collected scores were then averaged and converted into qualitative categories, very feasible, feasible, fairly feasible, less feasible, and not feasible. In addition to quantitative ratings, experts were encouraged to provide written comments and suggestions for improvement, which served as valuable input for refining the application before its implementation in future field testing. Two categories of experts participated in this validation process:

(1) Content Experts, who evaluated the accuracy and appropriateness of the instructional materials, particularly the representation of geometric concepts such as volume and surface area, as well as their alignment with the national mathematics curriculum. The evaluation results indicated that the application achieved an average score of 87.4, placing it in the “very feasible” category.
(2) Media Experts, who assessed the application’s visual appeal, interactivity, navigational ease, audiovisual clarity, and overall technical quality. Their evaluation yielded an average score of 82.6, categorized as “feasible for use”.

The results of both expert evaluations demonstrate that the AR-based learning application meets the pedagogical, aesthetic, and technical criteria required for effective educational media. The combination of quantitative validation and qualitative feedback provided a comprehensive understanding of the application’s strengths and areas for enhancement. These findings form a crucial basis for the next phase of research, which will involve field trials to examine the application’s effectiveness in improving students’ conceptual understanding of geometric solids in real classroom settings.

Discussion

The findings of this study show that the digital learning application developed through the Multimedia Development Life Cycle (MDLC) model has reached an acceptable level of feasibility in terms of both its instructional content and its media performance. The expert reviewers rated the product in the “feasible” to “highly feasible” categories, suggesting that the application meets the standards expected of professional educational media. These results reaffirm that the MDLC model offers a well-structured and dependable pathway for creating digital learning tools that can be reviewed at each stage of development [11].

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Viewed from a theoretical angle, MDLC provides a framework that weaves together pedagogical considerations and technological design in a coherent way [12]. Each stage, ranging from concept development to final distribution, serves a particular purpose in ensuring that the application is not only functional but also instructionally meaningful. In the early phases, developers can fine-tune the alignment between learning objectives, learner needs, and the look and feel of the interface. Attention to principles like cognitive load is especially important here, as it helps ensure that information is presented clearly without overwhelming users [13].

During the assembly phase, all multimedia elements designed earlier, such as images, text, animations, narration, and sound, are brought together. This integration reflects Mayer's Cognitive Theory of Multimedia Learning, which states that students learn better when verbal and visual information complement each other [13]. The application developed in this study puts this idea into practice by combining structured explanations with visuals, animations, and voice narration, creating a learning atmosphere that keeps students' attention while helping them build stronger understanding [14].

From the instructional content perspective, experts confirmed that the material aligns with the curriculum's main competencies and learning indicators. The content is organized logically, uses language suitable for the intended learners, and incorporates real-world examples that make abstract mathematical ideas easier to relate to. This approach echoes the principles of constructivism, which emphasize that learning becomes more powerful when students can link new concepts to prior knowledge and familiar contexts.

The product's accuracy and alignment with curriculum standards strengthen its potential to serve as both a classroom aid and an independent learning resource. Teachers can use the application to enrich instruction, while students can revisit the material at their own pace. This flexibility resonates with current directions in open and distance education, which highlight the importance of accessibility, learner autonomy, and interactive learning experiences.

From a media standpoint, expert evaluations drew attention to several notable strengths. The interface was considered straightforward and easy to navigate, with a clean visual design that felt cohesive across different sections. Interactive elements—including navigation controls, animations, and brief quizzes—help sustain learners' motivation. A large body of research supports the idea that such interactivity is crucial for effective digital learning, as it influences emotional engagement, focus, and overall satisfaction [15], [16], [17], [18].

The design characteristics of this application align with principles of human computer interaction (HCI), which emphasize usability, accessibility, and user experience. A user-friendly interface not only facilitates ease of navigation but also reduces cognitive barriers that may distract learners from content comprehension. Furthermore, consistency in visual layout and typography helps maintain a professional aesthetic and supports cognitive continuity across modules. This balance between usability and aesthetics enhances perceived usefulness and acceptance of the application, particularly in educational settings where technological literacy among students can vary significantly.

Despite these strengths, this research acknowledges several limitations. The validation process was limited to expert evaluations and did not include empirical testing with end users, namely, students. Consequently, user experience factors such as actual learning effectiveness, motivation, engagement, and usability from the learners' perspective have not been measured. As a result, the study's findings represent preliminary evidence rather than conclusive outcomes about the product's pedagogical impact. Future research should incorporate a field-testing phase involving student participants to gather empirical data on learning gains, user satisfaction, and behavioral engagement. A quasi-experimental or mixed-methods design could be employed to measure pre- and post-learning performance, qualitative feedback, and motivation indicators.

Another limitation lies in the scope of technological assessment. Although the current validation covered functionality and design, further research could explore aspects such as system performance across various devices, accessibility for users with special needs, and adaptability for different learning contexts. Incorporating universal design for learning (UDL) principles could further enhance inclusivity by ensuring that the application accommodates diverse learning styles and abilities.

Nonetheless, the outcomes of this study offer meaningful contributions to the field of educational technology. The application developed through the MDLC framework demonstrates that combining systematic multimedia design with pedagogical insight can yield high-quality instructional products. The MDLC model provides developers with a clear and flexible structure for iterative design, ensuring that each stage is revisited and refined based on feedback. This iterative nature fosters continuous improvement, which is essential in maintaining relevance and quality in the rapidly evolving digital learning landscape.

In conclusion, the discussion affirms that the MDLC-based approach produces a learning application that is both pedagogically sound and technically viable. Expert validation offers initial evidence of its quality and potential effectiveness as a digital learning innovation. Although broader empirical evaluation is needed, the findings suggest that the MDLC model can serve as a practical framework for educators, instructional designers, and technologists aiming to develop media that support interactive and meaningful learning experiences. This research contributes to the growing discourse on integrating multimedia development methodologies within education, demonstrating how systematic, user-centered, and theory-informed design processes can enhance learning outcomes in the digital era.

CONCLUSION

This study concludes that the Augmented Reality (AR), based learning application developed through the Multimedia Development Life Cycle (MDLC) model has successfully met both pedagogical and technical feasibility standards. Validation results from subject-matter and media experts confirm that the application is suitable for use as a digital learning tool, with content accuracy aligned to the national

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mathematics curriculum and a design that supports interactivity and user engagement.

Theoretically, the application demonstrates how AR technology can bridge the gap between abstract mathematical concepts and concrete visual experiences, allowing learners to manipulate three-dimensional geometric objects and better understand their volume and surface area. This finding supports the Cognitive Theory of Multimedia Learning by Mayer (2009), emphasizing that the combination of visual and verbal information enhances conceptual understanding and memory retention.

Practically, the AR application provides an innovative medium for both classroom and self-directed learning, helping students visualize geometric concepts dynamically while motivating them to explore mathematical relationships more deeply. The user interface was rated as intuitive and visually consistent, while the interactive components, such as object manipulation, animations, and quizzes, enhanced user engagement and learning motivation.

However, the study also acknowledges certain limitations. The validation process involved only experts and did not include empirical testing with students. Consequently, aspects such as learning effectiveness, usability from the user's perspective, and the application's impact on motivation and achievement remain unexplored. Future research should therefore include field trials and experimental studies to evaluate the educational effectiveness of AR-based learning tools more comprehensively.

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