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Dunia Geometri 3D: Developing an AR-Integrated Website to Enhance Students' Conceptual Understanding of Spatial Geometry

Mazia Azizah[1], Lisnani[2*], Hilma Alia[3], Muhammed Rizwan[4], Ana Renanda[5]

[1,2*,3,5]Mathematics Education, Surabaya State University
Maospati Street, Magetan, East Java, Indonesia
[1]*24111754039@mhs.unesa.ac.id*; [2*]*lisnanilisnani@unesa.ac.id*;
[3]*24111754038@mhs.unesa.ac.id*; [5]*24111754025@mhs.unesa.ac.id*

[4]Engineering Program, Asia Pacific Institute of Information Technology Union Pl
Colombo 00200, Sri Lanka
[4]*cb016215@students.apiit.lk*

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Abstrak

Penelitian ini mengembangkan media pembelajaran berbasis website terintegrasi multimedia interaktif untuk materi bangun ruang menggunakan model ADDIE (Analysis, Design, Development, Implementation, Evaluation) dengan subjek penelitian siswa SMP kelas VII yang berjumlah 34 orang. Instrumen penelitian mencakup angket dan tes. Teknik analisa data berdasarkan analisis kevalidan, kepraktisan, dan keefektifan media yang dikembangkan. Website "Dunia Geometri 3D" mengintegrasikan visualisasi 3D, video pembelajaran, pameran virtual AR Step, quiz interaktif Google Form, dan game edukatif Wordwall. Hasil penelitian ini yaitu media pembelajaran berbasis website terintegrasi multimedia interaktif untuk materi bangun ruang yang valid, praktis, dan efektif. Analisis peningkatan pemahaman konsep menggunakan uji N-Gain menunjukkan skor 0,45 dengan kategori sedang, mengindikasikan bahwa media pembelajaran ini efektif meningkatkan pemahaman konsep geometri ruang siswa secara signifikan. Media pembelajaran ini berkontribusi terhadap transformasi pembelajaran geometri di era digital dengan memfasilitasi literasi digital dan pembelajaran mandiri abad 21.
***Kata Kunci**: Bangun Ruang; Multimedia Interaktif; Pembelajaran Geometri; Teknologi Pendidikan; Website Pembelajaran.*

Abstract

This study developed a website-based learning media integrated with interactive multimedia for spatial geometry material using the ADDIE (Analysis, Design, Development, Implementation, Evaluation) model with 34 seventh-grade junior high school students as research subjects. The research instruments included questionnaires and tests. Data analysis techniques were based on the analysis of the validity, practicality, and effectiveness of the developed media. The "Dunia Geometry 3D" website integrates 3D visualization, learning videos, AR Step virtual exhibitions, interactive Google Form quizzes, and Wordwall educational games. The results of this study are website-based learning media integrated with interactive multimedia for spatial geometry material that is valid, practical, and effective. Analysis of the increase in conceptual understanding using the N-Gain test showed a score of 0.45 in the moderate category, indicating that this learning media is effective in significantly improving students' understanding of spatial geometry concepts. This learning media contributes to the transformation of geometry learning in the digital era by facilitating digital literacy and independent learning in the 21st century.
Keywords: Spatial Geometry; Interactive Multimedia; Geometry Learning; Educational Technology; Learning Website.

I. INTRODUCTION

Geometry learning, especially the material on spatial structures, is a fundamental component in the mathematics curriculum which requires visualization skills and an understanding of complex abstract concepts (Žakelj & Klančar, 2022). However, the reality of learning in Indonesia shows that the majority of students, especially junior high school students, experience significant difficulties in understanding spatial geometry concepts that are (Lisnani et al., 2025).

Difficulties faced by students include the inability to imagine and manipulate three-dimensional shapes in their minds, difficulty visualizing spatial relationships between elements of geometric shapes such as sides, edges, and vertices, and obstacles in transforming two-dimensional representations in textbooks into a complete three-dimensional understanding. These limited spatial visualization abilities impact low understanding of the concepts of volume, surface area, and nets of geometric shapes, which ultimately affects students' overall geometry learning outcomes (Oktavia et al., 2024).

These limitations are often due to conventional learning approaches that still rely on lecture methods and static learning media such as textbooks, which are unable to accommodate students' needs for more interactive and engaging learning experiences. The development of digital technology in the last decade has opened up transformative opportunities in the world of education, where bibliometric research over the past 30 years shows a significant upward trend in the implementation of digital learning with the important role of interactive learning in improving student learning outcomes.

The transformation of the learning paradigm from traditional to learner-centered interactive teaching is a solution in the digital era, given that active engagement and interactivity have been shown to substantially improve educational quality and outcomes. The integration of social media and digital tools in interactive learning has been shown to positively impact student engagement, creativity, motivation, and commitment to academic exploration (Shabur & Siddiki, 2024).

A comprehensive meta-analysis study revealed that the use of interactive learning environments such as augmented reality, virtual reality, mixed reality, and interactive digital games has a significant effect on cognitive and affective learning outcomes, with augmented reality ranking highest in learning effectiveness (Koç & Kanadlı, 2025).

One of the efforts to overcome the difficulties of visualizing spatial geometry, Augmented Reality (AR) technology offers a very crucial innovative solution (Saputro et al., 2024). The advantage of AR in learning spatial geometry lies in its ability to facilitate the manipulation of virtual objects in real-time, where students can rotate, enlarge, reduce, and explore spatial shapes from various perspectives that are not possible with conventional learning media, and facilitate students to actively build understanding through exploration and experimentation with virtual objects, supporting the development of spatial visualization skills and geometric thinking

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that are essential for mastering the concept of spatial shapes (Prasetyowati et al., 2025).

The context of web-based mathematics learning in Indonesia shows promising results, where web-based learning media is proven to be able to improve students' abilities and facilitate independent learning effectively (Asmawati et al., 2023). Future projections show that artificial intelligence and interactive learning technologies will create adaptive, personalized, and immersive learning systems, while supporting the development of a more inclusive and multidisciplinary educational ecosystem.

Various studies that develop learning media tend to focus on one or two aspects of learning technology, such as augmented reality (AR) or virtual reality (VR) separately, but have not explored the holistic integration of various interactive multimedia components in one accessible and user-friendly website platform for the context of learning spatial geometry (Huang et al., 2023).

The novelty of this research lies in the development of website-based learning media that comprehensively integrates various interactive multimedia elements including 3D visualization, AR, artsteps, animation, interactive simulation, audio narration, gamification and adaptive practice questions in one integrated platform specifically designed for learning geometric shapes. The formulation of the research problem is: How to develop website-based learning media integrated with interactive multimedia on geometric shapes that are valid, practical, and effective to improve students' understanding of geometric concepts? The purpose of this research is to produce website-based learning media products integrated with interactive multimedia on geometric shapes that meet the criteria of validity, practicality, and effectiveness based on expert assessments, teacher and student responses, and student learning outcomes. The benefits of this research theoretically contribute to the development of mathematics education technology, especially in the design of web-based interactive learning media, while practically it provides innovative solutions for mathematics teachers in teaching geometric shapes more effectively and interestingly, as well as facilitating students to learn independently and interactively according to the needs of 21st-century learning.

II. METHOD

This study uses the Research and Development method with the ADDIE model, which consists of five systematic stages: Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model was chosen based on its flexibility and effectiveness in developing technology-based interactive learning media, as proven in various interactive multimedia development studies that produce high-quality products (Pratiwi et al., 2025). The implementation of this research consists of expert review and involves three different groups of research subjects to ensure the validity and reliability of the development results

through comprehensive formative evaluation stages. (Lisnani et al., 2023).

The Analysis stage was carried out through a needs analysis using a questionnaire distributed to 34 students to identify learning characteristics, students' difficulties in understanding spatial geometry material, and the need for website-based learning media features including text materials, learning videos, 3D visualizations, interactive practice questions, online quizzes, educational games, and Augmented Reality features.

The Design stage includes website architecture design, interface and navigation design, preparation of interactive multimedia storyboards that integrate 3D spatial visualization elements, geometric concept animations, learning videos, integrated Google Form quizzes, educational games from Wordwall, and the AR Step feature for exploring three-dimensional shapes, as well as designing research instruments in the form of expert validation sheets and user satisfaction questionnaires.

The Development phase includes the development of interactive multimedia content using responsive web technology with the integration of various external platforms such as Google Forms for assessment, Wordwall for learning gamification, and AR Step for 3D spatial visualization exhibitions. The developed products are then validated by mathematics subject matter experts, learning media experts, and educational technology experts to ensure the validity of the content and design of the learning media in accordance with multimedia learning principles and pedagogical standards.

The implementation phase was conducted in stages using a systematic formative evaluation approach, involving a total of 34 students divided into three different trial stages. The first stage was a one-to-one trial involving 3 students from different classes, where each student used the website individually with intensive observation from the researcher to identify technical issues, navigation errors, bugs in the AR feature, and initial usability constraints. The second stage was a small group trial involving 9 students from another class, where students worked in groups to explore all the website features while the researcher observed their interactions, gathered feedback through group discussions, and evaluated the practicality and responsiveness of the media in a collaborative learning setting.

The third stage is a field test involving 22 7th grade students as the main research group, where implementation is carried out in regular learning to measure the effectiveness of the media on improving learning outcomes, understanding of spatial concepts, and user satisfaction in a real learning context (Lisnani et al., 2023). The selection of diverse research subjects from various classes is intended to obtain more comprehensive data regarding the practicality and effectiveness of media on heterogeneous student characteristics.

The evaluation stage is carried out continuously at each stage of development (formative evaluation) and at the end of implementation (summative evaluation) to measure the level of validity, practicality

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and effectiveness of the learning media. (Agustin et al., 2025).

Data collection instruments included questionnaires and tests. A needs questionnaire with 17 statement items for the analysis stage, a satisfaction questionnaire with 15 statement items using a Likert scale to measure the practicality and user response to the website features, an evaluation quiz via Google Form entitled "3D Geometry World Quiz" and an expert review questionnaire for the website validity test with 17 statement items and a validity test for the evaluation questions with 16 question items to assess validity. The test provided 20 multiple-choice questions to measure students' understanding of the concept of spatial shapes. The data analysis technique used quantitative descriptive analysis with criteria for validity, practicality, and effectiveness as shown in the following table. (Oktavia et al., 2024).

Table 1.
Interpretation Criteria for Percentage Validity, Practicality, and Effectiveness

Achievement Percentage	Category
80% < N ≤ 100%	Very Valid/Very Practical/Very Effective
60% < N ≤ 80%	Valid/Practical/Effective
40% < N ≤ 60%	Quite Valid/Quite Practical/Quite Effective
20% < N ≤ 40%	Less Valid/Less Practical/Less Effective
0% < N ≤ 20%	Invalid/Impractical/Ineffective

III. RESULT AND DISCUSSION

A. Result

1. Analysis Stage

The results of a questionnaire analysis of needs for website-based learning media indicate that the majority of students (73.68%) strongly require learning media that present comprehensive material on geometric shapes with 3D visualizations that help them visualize geometric shapes. 78.95% of students expressed a strong need for instructional videos explaining the properties and formulas of geometric shapes, while 84.21% of students needed online practice questions and quizzes to test their understanding. Another significant finding was that 75.79% of students strongly needed educational games to make learning more enjoyable, and 71.05% of students needed augmented reality features to understand the shapes and nets of geometric shapes. The need for flexible access and integration with external platforms achieved the highest score (81.5%), indicating students' preference for learning that is easily accessible anywhere and integrated with a familiar digital ecosystem.

This data indicates the urgency of developing learning media that integrates various interactive learning modalities, in line with the finding that interactive learning environments significantly enhance students' academic engagement and cognitive development.

2. Design Stage

The main menu structure is designed to include eight sections: Material (text content of geometric shapes), Video (tutorial for learning six types of geometric shapes), 3D Gallery (virtual exhibition of 3D geometry using AR Step), Questions (interactive question bank), Games (educational games from Wordwall and 3D

Shape Builder), Profile, Development Team, and Contact.

Figure 1. Home Page of the "3D Geometry World" Website.

The visual design adopts multimedia learning principles by balancing text, images, 3D animation, and video elements to optimize students' cognitive load. The interactive multimedia storyboard is designed with a constructivist learning approach, allowing students to independently explore spatial concepts through the manipulation of virtual objects, as shown in Figure 2.

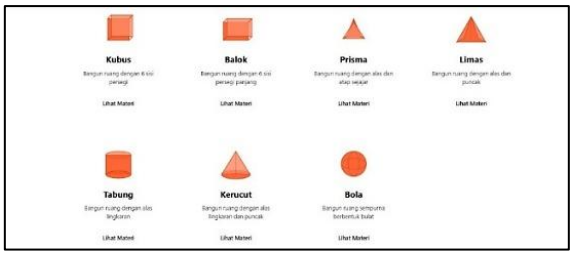

Figure 2. Display of the Material Page with 3D Visualization of Spatial Structures.

The material page is designed with 3D visualizations for each type of geometric shape (cube, cuboid, prism, pyramid, cylinder, cone, and sphere) with explanations of characteristics, formulas, and examples of applications in everyday life. The learning video section is designed modularly with six video tutorials that explain the concepts and calculation procedures for each geometric shape. The 3D Gallery feature is designed as an interactive virtual exhibition using AR Step technology that allows students to explore 3D geometric models with 360-degree rotation, in line with the finding that interactive visual representations are very effective in learning geometry. (Žakelj & Klančar, 2022).

Figure 3. Educational Game Features and Interactive Question Bank.

The educational games section is designed by integrating Wordwall for word games and quizzes, as well as 3D Shape Builder for spatial building challenges, and Volume Challenge for volume calculation exercises.

3. Development Stage

The development stage was carried out by implementing the design into a functional website using responsive web technology based on HTML5, CSS3, and JavaScript. The development of interactive multimedia content was carried out systematically, including the creation of text materials with 3D visualization of geometric shapes using the Three.js library, the production of six learning videos with a duration of 5-8 minutes per video explaining the concept and calculation of geometric shapes, the development of a 3D virtual exhibition using artstep for interactive geometric exploration integrated with AR as in Figure 4.

Figure 4. AR Feature Display with Interactive Three-Dimensional Space Visualization.

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The "3D Geometry World" website product that has been developed then went through a validation process by three experts: a mathematics material expert, a learning media expert, and an educational technology expert. The validation results show that the learning media obtained an average score of 3.45 (86.25%) With a "very valid" category from the three validators with minor recommendations regarding navigation improvements and the addition of feedback on interactive quizzes, these results are comparable to similar research on cube and block materials that obtained 80-90% validity (Jufri et al., 2024). The validation results for the evaluation questions obtained an average score of 3.31 (82.25%) with the category "very valid".

4. Implementation Stage

Implementation was carried out over four learning sessions with scenarios: the first session for website introduction and feature exploration, the second and third sessions for independent learning using the website with teacher guidance, and the fourth session for understanding evaluation through the "3D Geometry World" quiz. Observations during implementation showed a significant increase in student active engagement, learning motivation, and collaborative interactions among students in exploring multimedia content, in line with evidence that interactive technology-enhanced learning improves the quality and outcomes of learning as shown in Figure 5.

Figure 5. Students Explore the 3D Gallery and Arstep Features.

The Arsteps feature allows students to visualize three-dimensional geometric shapes that can be manipulated directly through their devices. When AR is activated, the screen displays a virtual geometric model that can be rotated 360 degrees, zoomed in to view details of elements like sides and edges, and repositioned to suit the student's exploration needs.

The data shows that the average quiz completion time was 25 minutes with a 100% completion rate, indicating that the duration and difficulty level of the questions were appropriate to the students' abilities.

5. Evaluation Stage

a. Evaluation of the Practicality of Learning Media

The evaluation of the learning media's practicality was conducted through a satisfaction questionnaire distributed to 34 junior high school students with 15 statement items using a Likert scale of 1-4. The analysis results showed a practicality level of 72%, categorized as good.

The analysis results show that the AR Step/3D visualization feature received the highest rating (3.09), indicating that interactive three-dimensional visualization

is very effective in helping students imagine and understand the shape of geometric shapes, in line with the finding that students' positive perceptions of AR technology in geometry learning are very high. The overall average score of 2.88 with the "Good" category confirms that the interactive multimedia integrated website-based learning media has met the practicality criteria for implementing geometric shape learning.

b. Evaluation of Understanding of Spatial Concepts

The N-Gain test analysis showed a score of 0.45 in the moderate category, the distribution of scores showed that 60% of students (20 out of 34 students) achieved learning completion with a score of ≥65, while 40% of students still needed remediation. Four students (26.7%) obtained very good scores (75-100), indicating a comprehensive understanding of the concept of geometric shapes. This variation in results indicates that although learning media is effective for the majority of students, learning differentiation and intensive mentoring are still needed for students with greater mathematics learning difficulties, in line with the finding that interactive multimedia significantly improves comprehension scores although with individual variations.

B. Discussion

This research implements a systematic ADDIE model, where each stage of development is carried out based on empirical data and continuous formative evaluation, in line with the finding that the ADDIE model is effective in producing high-quality learning products (Pratiwi et al., 2025).

The integration of various learning modalities—text, 3D visualization, video, interactive quizzes, educational games, and AR—creates a holistic learning experience and accommodates diverse student learning styles. This multimodal approach aligns with the principles of multimedia learning, which emphasize the importance of optimizing multiple cognitive channels to enhance retention and comprehension. The finding that the AR Step feature received the highest rating (3.09/4.00) underscores the crucial role of interactive 3D visualization in geometry learning, consistent with research demonstrating the effectiveness of AR in enhancing geometry learning gain.

The learning completion rate of 60% with an average quiz score of 48.3 indicates moderate results and requires special attention. Although this figure is lower than similar research that achieved an effectiveness of 77.35% (Lisnani et al., 2023), Several contextual factors need to be considered. First, the complexity of the geometric geometry material, which includes seven types of geometric shapes with various calculation concepts, requires high cognitive processing. Second, significant variations in students' prior abilities influence learning outcomes, with students with strong prior knowledge of geometry performing significantly better (75-100%) than students with weak mathematical foundations.

Analysis of error patterns revealed that questions related to the volume of curved solid shapes (cones, cylinders, spheres) and calculating surface areas with complex

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dimensions had the highest error rates. This indicates that these concepts require reinforcement through more varied practice exercises and more structured scaffolding. In contrast, questions on identifying the basic characteristics of solid shapes showed a high success rate, demonstrating the effectiveness of 3D visualizations and learning videos in building fundamental conceptual understanding. These findings align with research showing that interactive learning environments like OSapp produce significant and sustained improvement in the understanding of complex concepts (Llano et al., 2025).

The improvement of understanding of spatial geometry concepts through interactive multimedia-integrated website-based learning media can be explained through the framework of Mayer's Multimedia Learning Theory and Paivio's Dual Coding Theory. According to Mayer's Multimedia Learning Theory, optimal learning occurs when information is presented through visual and verbal channels simultaneously, where the human brain processes information through two separate but complementary channels. In the context of this study, the combination of textual explanations of the characteristics of spatial figures, audio narration in learning videos, and interactive three-dimensional visualizations creates a multimodal learning experience that optimizes students' cognitive capacity. This process facilitates the formation of stronger mental representations because students not only read about abstract concepts, but also see, hear, and interact directly with virtual models of spatial figures.

Paivio's Dual Coding Theory supports this explanation by stating that information encoded simultaneously visually and verbally produces a stronger memory trace than information encoded alone. When students explore geometric shapes through the Arstep feature, they build verbal representations of the shapes' names and properties as well as visual representations of the three-dimensional shapes. The integration of these two representations through the manipulation of virtual objects creates a complex network of cognitive associations, facilitating the retrieval of information when needed. Research data shows that students who actively manipulate three-dimensional models score higher on problems requiring mental visualization, confirming that interactive experiences with multimedia strengthen the formation of cognitive schemas about geometric concepts.

The specific mechanisms of understanding enhancement can be traced through three main cognitive pathways. First, interactive three-dimensional visualizations reduce extrinsic cognitive load by presenting complex information in a more easily processed format, freeing up cognitive capacity for deeper conceptual understanding. Second, interactive features such as object rotation and virtual manipulation encourage active learning, where students do not passively receive information but actively construct understanding through exploration. Third, immediate feedback from interactive quizzes and educational games reinforces

learning through reinforcement mechanisms, where correct answers are confirmed and errors are corrected in real time.

The 3D virtual exhibition (3D Gallery) is considered interesting and informative, providing an immersive learning experience that goes beyond the limitations of conventional learning media, in line with the potential of immersive technology in creating engaging learning experiences (Huang et al., 2023; Mehta et al., 2024; Zhao et al., 2025)

The development of this interactive, multimedia-integrated website-based learning media significantly contributes to the transformation of geometry learning in the digital age. This learning media not only provides educational content but also facilitates the development of 21st-century competencies such as digital literacy, independent learning, problem-solving, and collaboration (Lisnani et al., 2025). Students' ability to access materials anytime and anywhere through a variety of devices supports ubiquitous learning that is responsive to the lifestyles of today's digital native generation. Research shows that active engagement in technology-based learning enhances creativity, motivation, and commitment to academic exploration. (Fathimah et al., 2024; Shabur & Siddiki, 2024).

Integration with external platforms such as Google Forms, Wordwall, and AR Step demonstrates an open and adaptive learning ecosystem approach, allowing for continuous content updates and feature expansion without the need for fundamental reconstruction. (Jayasiriwardene & Meedeniya, 2023). This is in line with future trends in education where AI and interactive learning technologies will create increasingly adaptive, personal, and immersive systems. (Alam & Windiarti, 2023). Personalization of content and variety in interactive multimedia has proven important to accommodate heterogeneous learning needs (Gerbaudo-González et al., 2024; Ho et al., 2023).

Research limitations need to be acknowledged for the contextualization of the findings and research subjects which are still limited to 1 school (Llano et al., 2025). Recommendations for further research include: (1) implementation of a quasi-experimental design with a control group to measure comparative effectiveness; (2) expansion of the research sample to various schools with diverse demographic characteristics; (3) development of adaptive learning features that adjust the level of content difficulty based on individual student abilities; (4) integration of a learning analytics system to track learning patterns and provide personalized feedback; (5) development of a teacher training module to optimize the use of media in learning practices; and (6) long-term retention evaluation to measure the impact of ongoing learning.

IV. CONCLUSION

Research on the development of interactive multimedia-integrated website-based learning media on spatial geometry material using the ADDIE model has produced valid, practical, and effective learning products to improve junior high school students' understanding of geometric concepts. Needs analysis shows

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a high urgency (73-81%) for interactive learning features including 3D visualization, video tutorials, online quizzes, educational games, and Augmented Reality. The "Dunia Geometry 3D" website developed received very good validation from experts with an average score of 86.25% in the very valid category, a practicality level of 72% in the good category based on evaluations by 34 students, with the Arsteps/3D visualization feature achieving the highest rating (77.3%). The effectiveness evaluation showed a learning completion rate of 60% with an N-Gain score of 0.45 in the moderate category, indicating a significant increase in conceptual understanding although learning differentiation is still needed for students with learning difficulties.

The results of this study make a significant contribution to the field of mathematics education, particularly in the development of digital technology-based geometry learning media. Furthermore, this study demonstrates the importance of a universal design approach that considers accessibility for students with limited technological resources, encouraging the development of alternative offline modes or lightweight versions that retain the essence of interactive learning.

This study has limitations, namely that the use of AR is not yet optimal in this learning medium. Based on the findings and limitations of the study, several recommendations are proposed for educational practitioners and future researchers. For mathematics teachers, it is recommended to implement this learning medium within a blended learning framework, where students conduct independent exploration through websites at home as preparation (flipped classroom) and use face-to-face time for in-depth discussions, collaborative problem-solving, and clarification of misconceptions (Jufri et al., 2024).

Further research is recommended to implement an experimental design with a control group to measure the comparative effectiveness of this learning media against conventional methods more rigorously. Expanding the research sample to various schools with diverse geographic and socio-economic conditions will increase the external validity of the findings and provide a more comprehensive understanding of the contextual factors that influence the media's effectiveness. Finally, research on developing teacher competency in designing and implementing technology-based learning will complement the research ecosystem on the digital transformation of mathematics education.

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AUTHOR'S BIOGRAPHY

Mazia Aulia Azizah

A bachelor's student majoring in Mathematics Education at Surabaya State University he received the award as a presenter at the 2025 National Mobility Seminar.

Dr. Lisnani, M.Pd.

She earned her Doctoral in Mathematics Education from the University of Sriwijaya, Indonesia. Her research interest includes ethnomathematics, Realistic Mathematics Education (RME), learning media, and the integration of technology in mathematics education. She published many articles in journals indexed by Scopus and accredited by SINTA.

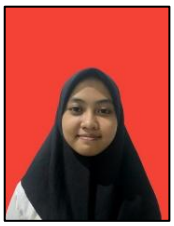
Hilma Alia

Born in Magetan Regency, August 16, 2005. A bachelor's student majoring in Mathematics Education at Surabaya State University. She has published books with ISBNs, national and international seminar proceedings, and Sinta 4 journals.

Muhammed Mehran Rizwan

A Computing Student at APIIT Sri Lanka. He has strong interest in software engineering and cybersecurity.

Ana Kharisma Renanda



Born in Magetan Regency, March 1, 2007. A bachelor's student majoring in Mathematics Education at Surabaya State University.