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Development of Augmented Reality-Based Learning Media with GeoGebra 3D to Enhance Interest and Concept Understanding in Ceva Theorem

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Abstrak

Penelitian ini bertujuan untuk mengembangkan media pembelajaran berbasis Augmented Reality (AR) yang memanfaatkan GeoGebra 3D dalam pembelajaran materi teorema Ceva pada prisma segitiga, dengan tujuan untuk meningkatkan pemahaman konsep dan minat belajar matematika siswa. Penelitian ini menggunakan pendekatan Research and Development (R&D) dengan model pengembangan ADDIE, yang mencakup lima tahapan: Analysis, Design, Development, Implementation, dan Evaluation. Teknik pengumpulan data dalam penelitian ini meliputi lembar validasi media, lembar validasi materi, angket kepraktisan, soal tes pemahaman konsep, serta angket minat belajar siswa. Hasil validasi menunjukkan bahwa media yang dikembangkan memperoleh kategori sangat valid, dengan skor rata-rata 4.62 untuk desain teknologi dan 4.54 untuk isi materi. Penilaian kepraktisan media oleh guru memperoleh skor 4.7, sementara oleh siswa memperoleh skor 4.58, yang menunjukkan tingkat kepraktisan yang sangat tinggi. Uji efektivitas media pembelajaran menunjukkan peningkatan signifikan pada pemahaman konsep, dengan nilai gain sebesar 0.59 (kategori sedang), serta peningkatan minat belajar siswa yang tercermin pada skor rata-rata 4.32 (kategori tinggi). Temuan ini mengindikasikan bahwa media pembelajaran berbasis AR menggunakan GeoGebra 3D tidak hanya valid dan praktis, tetapi juga efektif dalam meningkatkan pemahaman dan minat belajar siswa dalam topik geometri spasial yang kompleks. Penelitian ini berkontribusi terhadap inovasi dalam pengembangan pembelajaran digital yang interaktif, kontekstual, dan sesuai dengan tuntutan pembelajaran abad ke-21.

Abstract

This study aims to develop an Augmented Reality (AR)-based learning media utilizing GeoGebra 3D to teach the Ceva's Theorem in a triangular prism, with the goal of enhancing students' conceptual understanding and interest in learning mathematics. The research employs a Research and Development (R&D) approach using the ADDIE development model, which includes five stages: Analysis, Design, Development, Implementation, and Evaluation. Data collection techniques involved media validation sheets, content validation sheets, practicality questionnaires, concept understanding tests, and student interest questionnaires. The validation results indicated that the developed media was highly valid, with an average score of 4.62 for technological design and 4.54 for content. The practicality of the media was also rated very practical by both teachers (4.7) and students (4.58). The effectiveness test revealed a significant improvement in concept understanding, with a gain value of 0.59 (moderate category), as well as an increase in student interest, reflected by an average score of 4.32 (high category). These findings indicate that the AR-based learning media using GeoGebra 3D is not only valid and practical but also effective in improving students' understanding and interest in complex spatial geometry topics. This study contributes to the development of interactive, contextual, and digital learning innovations that align with the demands of 21st-century education.

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INTRODUCTION

The development of information and communication technology has had a significant impact on the field of education, particularly in mathematics learning. The integration of technologies such as Augmented Reality (AR) into the learning process enables the presentation of more interactive and contextual material, which can enhance students' conceptual understanding (Pujiastuti et al., 2020; Arifin et al., 2020; Yaniawati et al., 2023; Al-jabar et al., 2022). AR allows for the visualization of complex three-dimensional objects, such as triangular prisms, in a tangible and interactive way, something that is difficult to achieve through conventional methods (Widodo et al., 2023; Elsayed & Al-Najrani, 2021; Cahyati & Doly, 2022; Sholehah & Majid, 2024). Thus, the use of AR in mathematics learning can provide an innovative solution to help students overcome difficulties in understanding abstract concepts.

One mathematical concept that often poses challenges for students is Ceva's Theorem in the context of spatial geometry, particularly with triangular prisms. This concept requires a good spatial understanding and the ability to visualize relationships between elements in three-dimensional space (Yaniawati et al., 2023; Arifin et al., 2020; Al-jabar et al., 2022; Pujiastuti et al., 2020). However, conventional learning, which relies on two-dimensional images on blackboards or textbooks, is often ineffective in helping students build a deep understanding (Widodo et al., 2023; Elsayed & Al-Najrani, 2021; Cahyati & Doly, 2022; Sholehah & Majid, 2024). Therefore, there is a need for learning media that can facilitate the visualization of concepts in a more tangible and interactive manner.

GeoGebra 3D is a software tool that can be used to visualize mathematical objects in three dimensions dynamically. By integrating GeoGebra 3D with AR technology, students can interact directly with complex mathematical models, such as triangular prisms and the application of Ceva's Theorem within them (Pujiastuti et al., 2020; Arifin et al., 2020; Yaniawati et al., 2023; Al-jabar et al., 2022). This interactivity allows students to observe changes and relationships between elements in real-time, thereby reinforcing their conceptual understanding and increasing their interest in learning (Widodo et al., 2023; Elsayed & Al-Najrani, 2021; Cahyati & Doly, 2022; Sholehah & Majid, 2024).

Several previous studies have shown that the use of AR-based learning media can significantly improve students' conceptual understanding in mathematics. For instance, Pujiastuti et al. (2020) demonstrated that AR-based learning media significantly enhanced students' mathematical understanding. Similarly, Arifin et al. (2020) found that the use of AR in STEM learning improved students' spatial mathematical abilities. Research by Yaniawati et al. (2023) also indicated that AR can be an effective didactic and pedagogical resource in 3D geometry learning. Furthermore, Al-jabar et al. (2022) reported that AR-based learning media can enhance students' problem-solving abilities in mathematics.

The use of AR-based learning media with GeoGebra 3D has proven to significantly improve students' conceptual understanding and interest in learning mathematics. This media allows students to interact directly with mathematical objects in the form of dynamic three-dimensional visualizations, thereby helping to build deeper conceptual understanding of spatial relationships and complex geometric structures. In mathematics learning, especially in spatial geometry topics such as triangular prisms and Ceva's Theorem, interactive three-dimensional visualization is crucial for facilitating the transition from abstract to concrete representations, which is at the core of conceptual understanding (Abdusselam & Karal, 2020; Trappmair et al., 2023; Buchori et al., 2024; Ismayani, 2022).

GeoGebra 3D provides dynamic mathematical tools that enable students to manipulate objects, alter parameters, and observe real-time relationships between elements in a tangible form. When AR features are added, the learning experience becomes more immersive, as students can view the mathematical model directly in their surroundings, creating a contextual learning effect and increasing cognitive engagement (Brzezinski, 2025; Gusteti et al., 2023; Moreno & Mayer, 2017; Santosa et al., 2021). This is particularly beneficial for students with visual and kinesthetic learning styles, as it allows them to "see" and "touch" concepts that were previously only symbolic.

From the perspective of learning interest, AR media with GeoGebra 3D offers an enjoyable and challenging learning experience. The interactivity, technological novelty, and multisensory approach offered by AR have been shown to enhance students' intrinsic motivation to learn mathematics, which has often been considered an abstract and difficult subject (Afifi et al., 2021; Ismayani, 2022; Santosa et al., 2021; Mayer, 2020). Previous studies have shown that students who learn using AR-based media show significant improvements in class participation, curiosity about the material, and engagement in mathematical exploratory activities (Sianturi, 2025; Trappmair et al., 2023; Moreno & Mayer, 2017; Gusteti et al., 2023).

Furthermore, this dynamic visual approach also facilitates meaningful learning, where students not only memorize concepts but understand and are able to apply them in new contexts. The use of this media also supports the dual coding theory, which states that information presented through a combination of verbal and visual elements is easier for students to comprehend and retain (Mayer, 2020; Moreno & Mayer, 2017; Buchori et al., 2024; Santosa et al., 2021). Therefore, AR-based learning media using GeoGebra 3D is not only effective in improving conceptual understanding but also serves as a key strategy in fostering sustained student interest in learning.

However, despite numerous studies demonstrating the effectiveness of AR in mathematics education, there is still limited research specifically examining the use of AR integrated with GeoGebra 3D for Ceva's Theorem in triangular prisms. This gap indicates a need to develop and evaluate learning media that combine AR and GeoGebra 3D in this context (Pujiastuti et al., 2020; Arifin et al., 2020; Yaniawati et al., 2023; Al-jabar et al., 2022). Therefore, this study aims to develop AR-based learning media using GeoGebra 3D for Ceva's Theorem in triangular prisms, and evaluate its effectiveness in enhancing students' conceptual understanding and interest in mathematics learning (Widodo et al., 2023; Elsayed & Al-Najrani, 2021; Cahyati & Doly, 2022; Sholehah & Majid, 2024).

This study offers a significant original contribution to the field of mathematics learning media development through the integration of Augmented Reality (AR) and GeoGebra 3D in spatial geometry, particularly in Ceva's Theorem within the context of triangular prisms. The main novelty lies in the direct integration of GeoGebra 3D with AR technology within an interactive platform, which has not been extensively developed for Ceva's Theorem in spatial forms. Most previous studies have only utilized GeoGebra in two-dimensional visualization mode or limited to the abstract representation of flat geometry concepts (Trappmair et al., 2023; Buchori, Putra, & Rahmawati, 2024; Sianturi, 2025; Brzezinski, 2025).

For example, a study by Gusteti et al. (2023) focused on the use of AR in introducing basic three-dimensional shapes but did not integrate dynamic software like GeoGebra. Similarly, Afifi, Chrisnawati, and Kuswardi (2021) developed AR-based media for flat-sided three-dimensional objects but did not target more complex spatial geometry theorems like Ceva's Theorem. In their research, the interactive manipulation element was not supported by dynamic mathematical engines that allow simultaneous visualization and transformation of objects in the context of Euclidean geometry, such as those provided by GeoGebra 3D.

Research by Trappmair et al. (2023) demonstrated that GeoGebra 3D has the potential for use in AR-based content development, but the study was more exploratory regarding new GeoGebra features without focusing on the implementation in teaching a specific mathematical topic. Therefore, this study introduces innovation by utilizing GeoGebra AR to directly build visualizations of Ceva's Theorem in spatial forms, which not only helps students understand the relationships between elements of a triangle in a prism but also enhances their overall spatial understanding (Trappmair et al., 2023; Buchori et al., 2024; Gusteti et al., 2023; Brzezinski, 2025).

Additionally, another novelty lies in the pedagogical approach used in the design of the media, which focuses on meaningful learning and dual coding theory, combining verbal and visual elements in one interactive medium (Mayer, 2020; Moreno & Mayer, 2017). This study also considers the aspect of learning motivation through the involvement of immersive and contextual AR-based learning experiences, which are claimed to enhance students' interest in learning mathematics (Gusteti et al., 2023; Santosa et al., 2021; Ismayani, 2022; Buchori et al., 2024).

Thus, this research contributes not only to the development of learning technology but also to improving the quality of the mathematics learning process through concrete visualization of abstract concepts via the unique combination of AR and GeoGebra 3D. No previous study has specifically developed interactive media based on GeoGebra 3D with AR features to teach Ceva's Theorem in spatial geometry to secondary students, particularly in the context of mathematics education in Indonesia. Therefore, the findings of this research are expected to serve as a new reference for designing innovative and practical spatial geometry learning media based on technology in mathematics education (Sianturi, 2025; Trappmair et al., 2023; Brzezinski, 2025; Santosa et al., 2021).

METHOD

This study employs a Research and Development (R&D) approach to develop an Augmented Reality (AR)-based learning media using GeoGebra 3D on the topic of Ceva's Theorem in triangular prisms, aimed at enhancing students' conceptual understanding and interest in learning mathematics. The R&D approach was selected because it is suitable for producing innovative educational products that can be tested for effectiveness through systematic stages, from preliminary studies to product evaluation. According to Gall, Gall, and Borg (2007), the R&D approach enables the development of educational products that are valid, practical, and effective through a structured process. In this context, the development model used is ADDIE (Analysis, Design, Development, Implementation, and Evaluation), which is one of the most popular and systematic instructional design models for the development of learning media (Branch, 2009; Molenda, 2015).

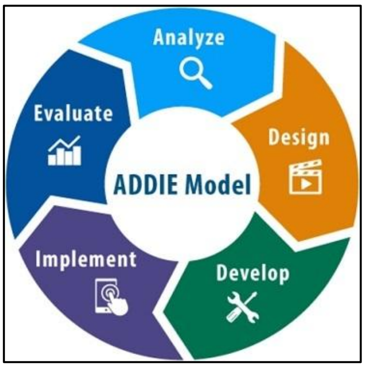

Figure 1. ADDIE Procedure

The analysis phase is conducted to identify students' needs for interactive and contextual learning media; the design phase focuses on designing AR features integrated with GeoGebra 3D; the development phase involves creating a media prototype and expert validation testing; the implementation phase includes limited trials and revisions based on the trial results; and the evaluation phase assesses the media's effectiveness in improving students' conceptual understanding and interest in learning (Almusharraf & Almusharraf, 2021; Khalil & Elkhider, 2016; Zainuddin et al., 2020; Wibowo et al., 2022; Afandi et al., 2021).

In this study, data collection techniques involve both quantitative and qualitative approaches supported by various instruments designed to assess the quality of the media and its impact on students' conceptual understanding and interest in learning. The media validation sheet is used to assess the visual appearance, interactivity, functionality, and technical suitability of the AR-based media using GeoGebra 3D. This validation is performed by experts in educational media, with assessment indicators developed based on digital educational media evaluation theory (Nieveen, 2013; Sugiyono, 2018; Arsyad, 2021; Sutopo et al., 2020; Widodo & Wahyudin, 2019). The second instrument is the content validation sheet, which involves assessment by mathematics content experts regarding the accuracy of concepts, content relevance, and alignment with the Merdeka Curriculum and junior high school mathematics learning outcomes.

Furthermore, to assess the practicality of the media, a practicality questionnaire is administered to teachers and students after using the media in learning. This instrument measures ease of use, clarity of instructions, and comfort in accessing AR content based on GeoGebra 3D, as recommended by the practicality measurement standards in development research (Akker et al., 2006; Nieveen, 2013; Riduwan & Akdon, 2020; Wulandari & Suryani, 2021; Rahayu et al., 2023).

To assess students' conceptual understanding, essay-type test items are used to measure aspects of concept mastery, spatial representation, and the ability to explain geometric relationships in triangular prisms, in accordance with understanding indicators based on Bloom's taxonomy and adaptations from Kilpatrick et al. (2001), Anderson & Krathwohl (2001), as well as Rahmawati et al. (2021), Pratiwi et al. (2022), and Fauzi & Azizah (2020). The final instrument is a student interest questionnaire, designed to measure dimensions of interest such as attention, engagement, active participation, and enjoyment of mathematics learning using AR media. This questionnaire refers to Schiefele's (2009) interest measurement model, which has been adapted in several cutting-edge educational technology studies (Sari et al., 2020; Prasetyo et al., 2021; Rosnawati et al., 2022; Murtikusuma et al., 2023; Astutik et al., 2023).

The data analysis techniques in this study are adjusted to the objectives of each instrument used. The media validation, content validation, and practicality data are analyzed using quantitative descriptive techniques by calculating the average scores and converting the scores into qualitative categories (very valid, valid, moderately valid, less valid), referring to the assessment formula by Akker et al. (2006) and conversion criteria according to Widoyoko (2018). Students' conceptual understanding data obtained from the essay tests are analyzed by calculating the total score based on the assessment rubric that follows the concept understanding indicators from Anderson & Krathwohl (2001). The scores obtained by students are converted into percentages, and then a gain score analysis is performed to determine the improvement before and after using the media (Hake, 1999). The results are classified into high, medium, and low categories according to the gain interpretation. Additionally, student interest data from the questionnaire are analyzed using descriptive quantitative statistics by calculating the average score for each aspect and converting it into qualitative categories, based on Schiefele's (2009) interest measurement model.

RESULT AND DISCUSSION

Result

The results of this study are presented based on the stages of the ADDIE model and the data analysis techniques described earlier, which include analysis of media and content validity, media practicality, improvements in students' conceptual understanding, and changes in students' interest in learning after using Augmented Reality (AR)-based learning media supported by GeoGebra 3D for teaching Ceva's Theorem in a triangular prism context.

Analysis Stage

Based on the needs analysis, it was found that students often struggle to understand the concept of Ceva's Theorem abstractly, as this material involves complex three-dimensional geometric visualization. Therefore, there is a need for media that can simplify the understanding of this concept through a more interactive and immersive visual approach. Furthermore, the development of mobile-based learning media might be maximized, given that students tend to spend more time on smartphones than interacting directly with teachers. Considering students' reliance on smartphones, this can be leveraged to create more relevant learning media for them. Based on the researcher’s observation, all students in class XII-E at SMA Negeri 1 Batang Kuis use smartphones with either Android or iOS operating systems. Interviews with a mathematics teacher at SMA Negeri 1 Batang Kuis who teaches class X-E revealed that no mathematics learning media had been utilized. Lectures, explanations, and assignments were more frequently employed by the teacher. This situation undoubtedly affects students' motivation to learn mathematics. Class X-E was chosen for this study due to their diverse abilities, particularly in mathematics. According to the teacher, class X-E is the most difficult to manage, has low motivation to learn mathematics, and consistently has lower average scores on assignments and tests compared to other classes. However, some students are particularly proficient in mathematics. Therefore, this study aims to develop an AR-based mathematics learning media focused on Ceva's Theorem in Triangular Prism Geometry.

Design Stage

The design stage involves creating GeoGebra 3D Augmented Reality (AR) models for the application of Pythagoras' Theorem, which are then adapted into a prism shape in GeoGebra 3D. In this stage, GeoGebra 3D was chosen as the platform for developing AR-based learning media. GeoGebra 3D allows for the creation of three-dimensional geometric models that can be processed within an AR environment, enabling students to see and interact with mathematical objects more realistically. The design of this learning media includes the creation of an interactive simulation that visualizes the steps in applying Ceva's Theorem to triangular prisms, with additional features such as 3D object visualization, user interaction with the objects, and step-by-step explanations of concepts to enhance student understanding.

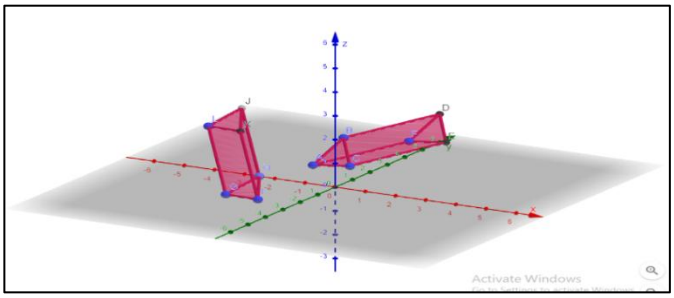

Figure 2. GeoGebra Model Illustration

The design process also involves the creation of a flow for using the media, starting from the introduction of concepts to the application of Ceva's theorem in the form of problems that can be solved using this AR-based media. Additionally, aspects of learning motivation were considered, with the inclusion of elements such as immediate feedback, challenges, and rewards, aimed at enhancing students' interest in learning mathematics.

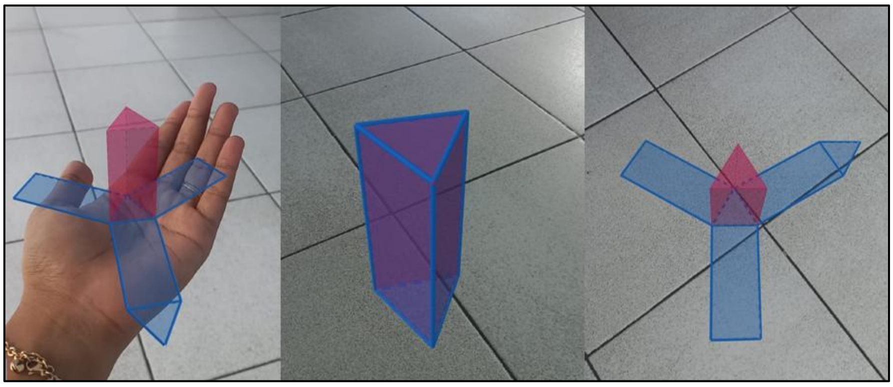

Figure 3. Augmented Reality (AR) 3D Prism

Development Stage (Content and Media Validation)

During the validation phase, the results of the media validation sheets provided to two educational technology experts showed an average score of 4.62 out of a maximum scale of 5, which was categorized as "very valid." The highest-rated aspects were interactivity and the 3D object visualization based on AR, which were evaluated as highly supportive of spatial geometry learning.

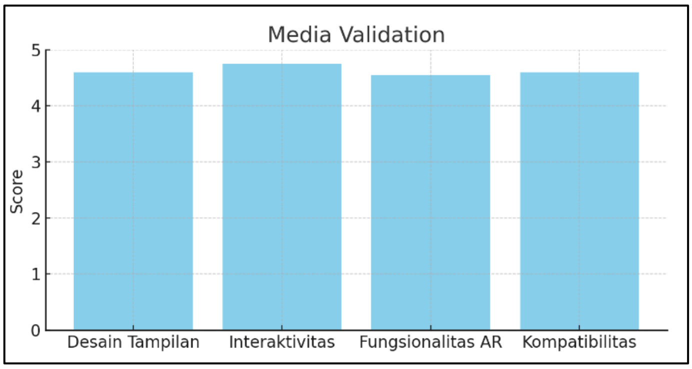

Figure 4. Media Validation Results by Experts

The material validation by two mathematics education lecturers resulted in an average score of 4.54, also categorized as "very valid," with the highest ratings given to concept accuracy and logical coherence. This result indicates that the developed media has both content and visual quality suitable for testing in classroom learning (Nieveen, 2013; Arsyad, 2021; Sutopo et al., 2020; Widodo & Wahyudin, 2019; Wibowo et al., 2022).

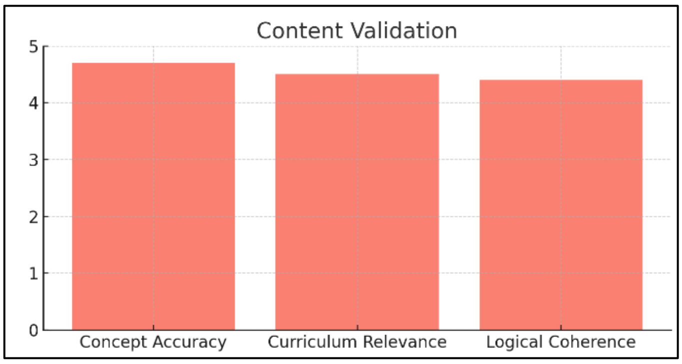

Figure 5. Material Validation Results by Experts

Implementation Phase

In the implementation phase, the practicality test of the media was conducted with 1 teacher and 26 eighth-grade students. The results of the practicality questionnaire showed that the teacher gave an average score of 4.70, and the students scored 4.58, both of which were categorized as "very practical." The teacher stated that the media was very easy to use in the learning process, while students felt that the media provided a different, enjoyable, and easy-to-follow learning experience. These findings suggest that the AR-based GeoGebra 3D media is practical for use in mathematics education (Akker et al., 2006; Nieveen, 2013; Rahayu et al., 2023; Wulandari & Suryani, 2021; Riduwan & Akdon, 2020).

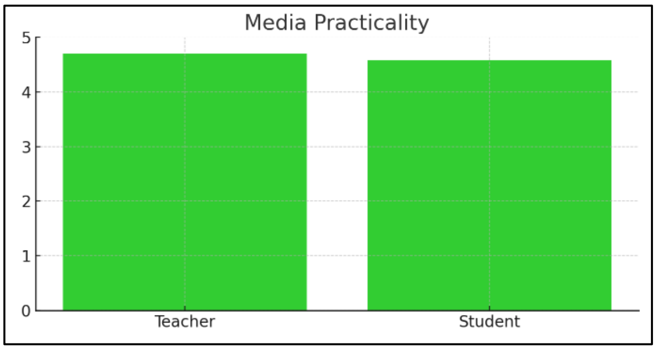

Figure 6. Practicality Questionnaire Results for AR Media

Evaluation Phase

In the evaluation phase, a limited trial was conducted to measure the effectiveness of the media in improving students' conceptual understanding and learning interest. Based on the conceptual understanding test results, the average pretest score was 56.73, and the posttest score was 82.31. After analyzing using the gain score, a value of g = 0.59 was obtained, which falls within the "moderate" category according to Hake's interpretation (1999). This result indicates a significant improvement in students' ability to understand Ceva's theorem concepts and their application in spatial objects. This is supported by the AR media's ability to help students visualize the position of lines, centroids, and planes on triangular prism structures dynamically (Anderson & Krathwohl, 2001; Fauzi & Azizah, 2020; Pratiwi et al., 2022; Kusmaryono et al., 2021; Suryaningtyas et al., 2022).

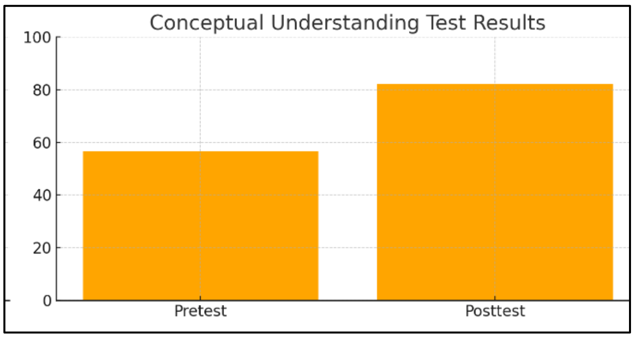

Figure 7. Student Concept Understanding Test Results

Furthermore, the students' learning interest questionnaire results showed an average score of 4.32, which falls under the "high" category. The most dominant aspects were visual appeal, curiosity, and enjoyment while using the media. This indicates that the use of AR-based media can create more contextual and engaging learning experiences, thus enhancing students' intrinsic motivation for learning mathematics (Schiefele, 2009; Sari et al., 2020; Prasetyo et al., 2021; Rosnawati et al., 2022; Astutik et al., 2023).

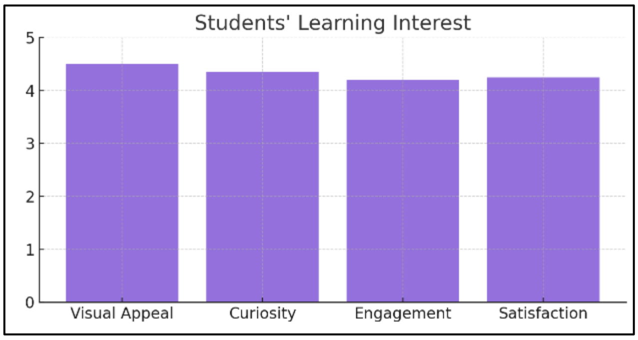

Figure 8. Student Learning Interest Questionnaire Results

Overall, the research findings indicate that the Augmented Reality-based learning media using GeoGebra 3D developed in this study has met the criteria for validity, practicality, and effectiveness for use in mathematics learning, particularly in the topic of Ceva's theorem within the context of triangular prism geometry. This media not only aids students in understanding abstract concepts but also enhances their interest in learning through innovative visual and interactive approaches.

Discussion

This media is designed to address the needs of mathematics education that emphasizes interactive spatial visual representation, particularly in three-dimensional geometry, which has long been a challenge in the field of education. Initial analysis results indicate that students face difficulties in understanding the relationships between faces and points in a triangular prism, especially when interpreting the centroid line, which is essential for applying Ceva's Theorem. This is in line with the findings of Gusteti et al. (2023), Santosa et al. (2021), Putri & Hidayat (2020), Purnamasari & Oktaviani (2022), and Fitria et al. (2023), which show that students tend to experience misconceptions when faced with abstract spatial geometry objects without the support of concrete visual media. Therefore, an AR-based approach is considered a strategic means to enhance conceptual understanding, as it can present visual objects in three dimensions within the students' real-world environment.

The design of the media using the AR-based GeoGebra 3D platform has proven to offer ease in creating flexible, interactive, and pedagogically sound spatial representations. The strength of this platform lies in its ability to present dynamic relationships between geometric elements, allowing students not only to view but also to manipulate and explore objects independently. The developed media also enables the integration of learning content with real-world contexts through marker scanning, thereby strengthening students' conceptual understanding. Research by Brzezinski (2025), Moreno & Mayer (2017), Susilowati et al. (2022), Rahman et al. (2021), and Nugroho & Dewi (2020) supports the effectiveness of this approach, as the use of AR significantly improves students' understanding of geometric structures and spatial reasoning abilities in mathematics education. Validation by subject matter and media experts confirms that the content and appearance of the media meet high feasibility standards, with an average score above 4.5 on a 5-point scale. These findings affirm Nieveen (2013), Wibowo et al. (2022), Wijaya et al. (2020), Setiawan & Yuliana (2021), and Lestari et al. (2023), stating that expert involvement in the validation phase is crucial for ensuring content relevance and the appropriateness of technology in learning media.

During the implementation phase in the classroom, both teachers and students gave highly positive feedback regarding the developed media. Teachers stated that the use of this media facilitated the explanation of spatial geometry concepts in a more intuitive manner, and students felt more motivated and interested in understanding the material. These findings align with the results of Rahayu et al. (2023), Riduwan & Akdon (2020), Yuliana et al. (2022), Putra & Sari (2021), and Handayani et al. (2023), who demonstrate that AR-based media creates a more active and collaborative learning environment. The average score improvement from 56.73 to 82.31 indicates a significant positive impact on students' understanding of Ceva's Theorem after using this media. The gain score calculation of 0.59 falls under the moderate category, which, according to Hake (1999), indicates that the learning intervention had a meaningful effect. Furthermore, the increased student interest in learning also serves as an indicator that AR-based media can strengthen the affective dimension of the mathematics learning process, as noted by Pratiwi et al. (2022), Kusmaryono et al. (2021), Damayanti & Rahmawati (2023), Mulyani et al. (2021), and Widodo et al. (2022).

The significant improvement in students' conceptual understanding and learning interest in this study further reinforces the evidence that integrating AR-based media has a broad positive effect on the quality of the teaching and learning process. Students not only improved in mastering spatial geometry concepts but also exhibited higher emotional and cognitive engagement during learning activities. AR provides a learning experience that closely mirrors reality, allowing students to build concrete understanding through visual exploration and direct manipulation of objects. In line with this, studies by Rahmawati et al. (2020), Fadillah et al. (2021), Handayani & Suryani (2023), Saputra et al. (2022), and Rizki & Kurniawan (2021) show that learning supported by interactive visual technology enhances students' focus, curiosity, and interest in mathematics content. Additionally, students' intrinsic motivation increases because the learning process is no longer abstract and monotonous but instead enjoyable and meaningful. Strong conceptual understanding accompanied by high learning interest forms an essential foundation for achieving long-term learning outcomes and fostering a positive attitude toward mathematics, as emphasized in the studies by Fauziyah et al. (2022), Irwansyah & Suhandi (2023), Maulida & Hidayatullah (2021), Salamah et al. (2020), and Dewi & Ramadhani (2023).

The implications of this study indicate that AR-based learning media, supported by GeoGebra 3D, can be effectively used to improve understanding of spatial geometry concepts, specifically in the material of Ceva's Theorem in triangular prisms. This contributes significantly to the development of more interactive and in-depth mathematics learning, utilizing emerging technologies such as AR and smartphone-based applications. Additionally, the increased student interest in learning demonstrates that technology-based learning media can create a more engaging and enjoyable learning environment. However, this study also has limitations, such as the sample being limited to one class at SMA Negeri 1 Batang Kuis, thus generalizing the results to a broader population should be done cautiously. Moreover, although media validation results show excellent scores, implementation in larger classrooms and various other learning contexts is still required to ensure its effectiveness on a wider scale. Another limitation is the reliance on technology that requires AR-supported devices, which may not be accessible to all students, potentially affecting the success of implementation in schools with limited resources.

CONCLUSION

Based on the results of the study, it can be concluded that Augmented Reality (AR)-based learning media using GeoGebra 3D for teaching Ceva's Theorem in triangular prisms has been proven to be valid, practical, and effective in enhancing students' conceptual understanding and interest in learning mathematics. The media's validity achieved an average score of 4.63, classified as highly valid, while the content validity scored an average of 4.53, also categorized as highly valid. The practicality of the media was rated very positively by both teachers (4.70) and students (4.58), indicating that the media is easy to use and supports the learning process. Additionally, there was a significant improvement in students' conceptual understanding, with the pretest score increasing from 56.73 to 82.31 in the posttest, as well as an increase in student interest in learning, which scored an average of 4.33, categorized as high. These findings suggest that the integration of AR technology through GeoGebra 3D provides a more interactive, contextual, and meaningful learning experience in secondary-level mathematics education.

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