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Development of geogebra-based interactive multimedia on triangle and quadrilateral topics to enhance students' understanding of mathematical concepts

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Abstract

Background: Understanding mathematical concepts is essential for students, as it forms the basis for developing other mathematical abilities. Many students struggle with abstract mathematical ideas, particularly in geometry.
Aim: This study aims to examine the validity, practicality, and effectiveness of GeoGebra-based interactive multimedia in enhancing students' understanding of triangles and quadrilaterals.
Method: This study employed a Research and Development (R&D) approach using the ADDIE model, which consists of Analysis, Design, Development, Implementation, and Evaluation phases. The subjects involved were seventh-grade students at a junior high school. Validation of the product was conducted by two material experts and two media experts. Practicality was assessed using student response questionnaires, while effectiveness was measured through a quasi-experimental design involving a pretest-posttest control group. Data were analyzed using descriptive statistics and inferential analysis to determine the improvement in conceptual understanding.
Result: Validation scores reached 88% (material) and 88.2% (media), indicating high validity. Student feedback showed positive responses toward the multimedia's usability and engagement. The experimental group outperformed the control group, with a higher average score, demonstrating the effectiveness of the developed multimedia.

Conclusion: GeoGebra-based interactive multimedia is a valid, practical, and effective tool for improving students' understanding of mathematical concepts, particularly in triangle and quadrilateral topics. Its integration into classroom instruction enhances engagement and supports meaningful learning experiences. Future research is recommended to investigate the long-term effects of such multimedia on students' conceptual retention, its application to other mathematical domains and grade levels, and its integration with collaborative or inquiry-based learning approaches.

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INTRODUCTION

The rapid advancement of science and technology is continuously transforming various sectors, particularly the field of education. The emergence of the Industrial Revolution 4.0 has encouraged a shift toward automation and digitalization, prompting the integration of technology into learning environments (Jaya et al., 2023; Clark & Mayer, 2016). Quality education is essential for producing superior human resources capable of contributing to national development. In schools, the influence of technology enables the swift dissemination of information and knowledge, which is critical in shaping 21st-century learners. Among the essential scientific disciplines that students must master in this digital age is mathematics (Anggraeni et al., 2021). As the world becomes

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increasingly data-driven, mathematical literacy is no longer optional but foundational for navigating complex problems and making informed decisions in everyday life.

Mathematics plays a fundamental role in fostering logical reasoning, critical thinking, and problem-solving skills. Consequently, it is a core subject taught from early education through higher education and serves as the foundation for science and technology. Despite its importance, many students still struggle with comprehending mathematical concepts due to instructional approaches that prioritize rote memorization over meaningful understanding (Rahmawati & Roesdiana, 2022). This gap in understanding is especially prominent in geometry topics such as triangles and quadrilaterals, where spatial reasoning and visualization are essential. When students lack conceptual clarity, it becomes difficult for them to transfer knowledge across different contexts or apply mathematics to real-life situations.

Conceptual understanding is defined as the ability to interpret, represent, and explain mathematical ideas based on personal knowledge construction, rather than simple recall. It is not limited to recognizing procedures or applying formulas; it requires students to internalize the relationships between concepts, identify patterns, and construct logical justifications. This ability is vital in solving problems systematically and deeply (Rahmawati & Roesdiana, 2022). According to Sari et al. (2022), students with a strong conceptual foundation are better able to solve various mathematical problems effectively. A lack of conceptual understanding can lead to misconceptions, fragmented knowledge, and ultimately, reduced confidence in learning mathematics.

Facilitating a deeper understanding of mathematical concepts among students necessitates the use of well-designed and pedagogically sound instructional media. Learning media are tools, methods, or techniques that support the effective delivery of material from teachers to students (Güler et al., 2022). In recent years, interactive multimedia that combines text, audio, animation, and video has emerged as a promising approach to enhance learning engagement and comprehension. Interactive multimedia not only supports diverse learning styles but also promotes learner autonomy, as students can control the pace and sequence of their learning. According to Astri et al. (2022), interactive multimedia allows students to engage actively with learning content, making learning more meaningful and memorable. This is aligned with cognitive learning theory, which emphasizes the importance of learner interaction and contextual learning in constructing durable knowledge (Clark & Mayer, 2016; Iftitah, 2023).

Moreover, interactive multimedia can be accessed through various digital platforms such as websites, software, and mobile applications, making it suitable for both online and offline learning settings (Iswara et al., 2021). Its flexibility and scalability make it an ideal medium in today's learning environments, especially where infrastructure or classroom time is limited. The development of such media is often guided by the ADDIE model, which provides a structured process for analyzing needs, designing instructional content, developing learning materials, implementing interventions, and evaluating outcomes (Branch, 2009; Molenda, 2003). This model ensures that instructional products are both pedagogically sound and learner-centered.

GeoGebra, a dynamic open-source mathematics software, has been widely used to facilitate visualization and exploration of mathematical relationships. Its ability to integrate algebra, geometry, and calculus in a single interactive interface makes it highly valuable in the classroom. Previous studies have shown the effectiveness of GeoGebra in improving students' understanding of mathematical concepts. Yanti et al. (2019) reported a significant improvement in students' conceptual understanding using a scientific approach assisted by GeoGebra. Mukarramah et al. (2022) found that the software positively affected both students' conceptual understanding and problem-solving skills. Similarly, Sonia et al. (2023) showed that students who received instruction using the AIR learning model with GeoGebra outperformed those taught conventionally and responded positively to the experience. Research by Anggraeni et al. (2021) concluded that

GeoGebra-based media for triangle and quadrilateral material achieved a high validity and practicality score, with 89% implementation feasibility.

However, many of these studies have limitations, particularly regarding the lack of interactivity, insufficient multimedia integration, and minimal application of student-centered learning strategies such as problem-based learning (Anggraeni et al., 2021; Lamaka et al., 2023). While GeoGebra offers excellent visual tools, its potential as part of a comprehensive multimedia resource has not been fully explored. Most existing GeoGebra implementations focus solely on geometric constructions and simulations, often neglecting narrative, audio feedback, or gamified elements that could further enhance engagement. In addition, few studies have systematically applied instructional design models like ADDIE to ensure the media developed meet high standards of educational quality and usability.

Therefore, this study aims to develop GeoGebra-based interactive multimedia for triangle and quadrilateral topics, enriched with visual, auditory, and kinesthetic components. The development follows the ADDIE model and seeks to validate the product's validity**,** practicality, and effectiveness in improving seventh-grade students' mathematical concept understanding. Unlike previous efforts, this study offers an integrated and student-centered solution designed to address the limitations of earlier research and support meaningful learning in mathematics (Iftitah, 2023; Jaya et al., 2023). By combining dynamic mathematical tools with multimedia features and solid pedagogical foundations, the resulting product is expected to promote deeper conceptual understanding and a more engaging learning experience for students.

METHOD

This study employed a Research and Development (R&D) approach, which is widely used in educational research to design, develop, and evaluate instructional products through a structured process (Sugiyono, 2010). Specifically, the development followed the ADDIE model, consisting of five systematic stages: Analysis, Design, Development, Implementation, and Evaluation (Branch, 2009; Molenda, 2003). This model is commonly used in instructional design to ensure that educational media are developed in a pedagogically sound and effective manner (Iftitah, 2023; Chang & Abidin, 2024). In this research, the ADDIE framework was applied to develop GeoGebra-based interactive multimedia for teaching quadrilateral and triangle topics in seventh-grade mathematics. Each phase of the ADDIE model was used to validate, refine, and evaluate the product's validity, practicality, and effectiveness (Clark & Mayer, 2016; Jaya et al., 2023).

The product developed in this study was an interactive multimedia learning tool based on GeoGebra, integrated with Canva elements, and implemented using the Problem-Based Learning (PBL) approach to promote meaningful learning experiences (Yanti et al., 2019; Mukarramah et al., 2022). The target users were seventh-grade students at SMP Negeri 2 Sayung during the 2024/2025 academic year. A total of 33 students from class VII-G were selected as the experimental group through purposive sampling, based on input from the mathematics teacher and academic characteristics of the students (Zaharah et al., 2021).

To gather relevant data, the researchers employed several techniques: observation, testing, interviews, and documentation (Anggraeni et al., 2021; Aspriyani & Suzana, 2020). The primary assessment instrument consisted of open-ended essay questions aimed at measuring students' conceptual understanding in mathematics. The test included 10 items that were previously validated for content relevance, reliability, item difficulty, and discrimination index to ensure the quality and fairness of the instrument.

RESULTS AND DISCUSSION

Results

The development of GeoGebra-based interactive multimedia on triangle and quadrilateral topics resulted in a valid, practical, and effective learning tool. Validation by material and media experts yielded high scores (88% and 88.2% respectively), student responses were overwhelmingly positive (average 95%), and the N-Gain score analysis showed a moderate improvement in students' conceptual understanding, with higher gains in the experimental group compared to the control group.

1) Analysis Stage

The analysis stage was carried out through classroom observations in a junior high school setting, focusing on the teaching materials and media used during mathematics instruction. It was found that learning resources were limited to a single textbook provided by the government, indicating the need for additional and more interactive learning materials to enhance students' understanding (Güler et al., 2022; Martatiyana et al., 2023). Therefore, researchers developed an interactive math learning multimedia and were able to motivate students in the learning process. Researchers chose geogebra and canva software with the PBL model, so that students are motivated in the learning process and can improve their ability to understand mathematical concepts. Research by Tamami (2021) has proven that learning using geogebra-based interactive media is valid, interesting, effective. Learning with the AIR model assisted by geogebra is better so that it can improve students' understanding of mathematical concepts (Sonia et al., 2023).

2) Design Stage

After the analysis stage, the next is the design stage. This stage includes preparing the structural framework of the geogebra-based interactive multimedia to be created, what researchers do is analyze the material displayed, analyze the display design, determine evaluation questions, design videos. Furthermore, determining the instrument used is a type of questionnaire given to media experts, material experts and students who are the subject of research. The validation sheet for media experts and material experts is in the instruments used in this study included expert validation sheets, student evaluation tests, and a student response questionnaire. The validation sheets for media and material experts were structured as questionnaires using a five-point Likert scale, with the following criteria: Strongly Agree (5), Agree (4), Neutral (3), Disagree (2), and Strongly Disagree (1). Meanwhile, the instruments used for students consisted of a conceptual understanding test and a response questionnaire to assess the practicality and reception of the multimedia product. At the design stage by research Pratama et al. (2023) prepared materials and designs or rough drawings related to interactive learning multimedia based on articulate stroryline with the help of geogebra which will be developed in the form of storyboards. At the design stage by research Iswara & Cahdriyana (2022) made a design of combining various media combined with geogebra to help student visualization which then produced a product in the form of HTML5.

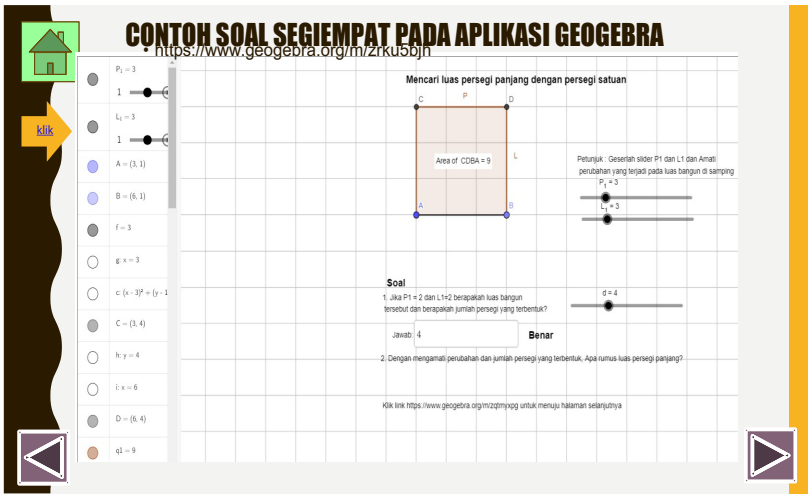

Figure 1. Material of square before revision

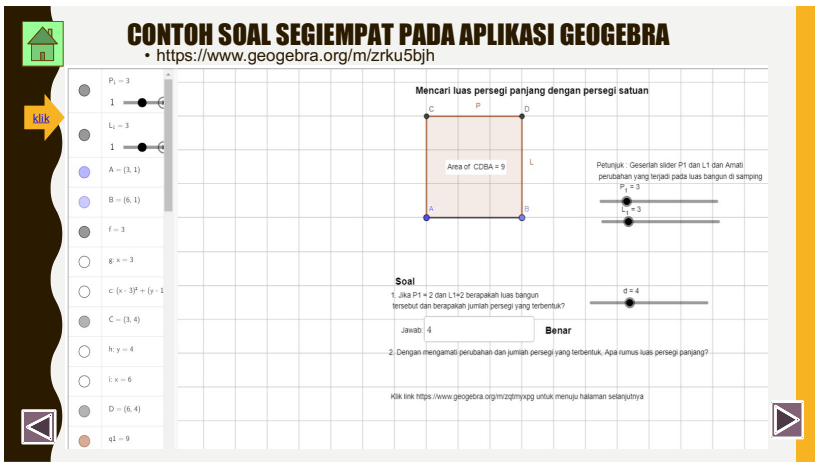

Figure 2. Material of square after revision

3) Development Stage

After the design stage, the development stage was carried out to produce GeoGebra-based interactive multimedia for triangle and quadrilateral materials. This stage involved a pre-research phase, namely product validation by three media experts and three material experts, as commonly applied in educational development research (Aspriyani & Suzana, 2020; Gall et al., 2003). Validation serves to assess feasibility, clarity, and pedagogical soundness before product implementation (Clark & Mayer, 2016; Tamami, 2021).

The validation results from the three media experts indicated an average score of 88.2%, which falls into the "very good" category. Similarly, the three material experts provided an average score of 88%, also categorized as "very good." These results suggest that the GeoGebra-based interactive multimedia is feasible for use in classroom learning, with minor revisions recommended by the experts (Iswara & Cahdriyana, 2022; Pratama et al., 2023). To clarify these findings, the detailed validation results are presented in the tables below. This media validation indicator consists of 4 aspects, namely: general aspects, presentation aspects, language aspects and media graphics aspects

Next is validation by material experts. The results of the validation of the three material experts based on the eligibility criteria obtained an average of 88%. From the results of the material expert validation, it can be interpreted that this geogebra-based interactive multimedia is in the very good category (feasible) to use even though revisions need to be made according to suggestions from

material experts. This material validation indicator consists of 3 aspects, namely: general aspects, material substance aspects, and learning design.

The validation results are used as a draft and then editing and revision are carried out so that the next stage can be carried out, namely the implementation stage. At the development stage by research Pratama et al., (2023) this stage has been compiled, and the storyboard has been designed with the software to be used, and the results will be prototype 1 or multimedia that is not yet feasible. At the development stage by research Iswara & Cahdriyana, (2022) consists of expert validation and development tests.

4) Implementation Stage

At the implementation stage, this phase involves the instrument trial, which is essential for ensuring the quality and appropriateness of the evaluation instruments used in educational research. Evaluation test instruments must be tested to determine their validity, reliability, level of difficulty, and discrimination index, as is standard in educational measurement practices (Widoyoko, 2017). This trial was conducted to determine the feasibility of the evaluation question. After discussing with the mathematics teacher of SMPN in Sayung, the researcher chose class IX-A as the trial class. In the trial question, 10 essay questions will be tested. The results of the trial analysis of 33 students of class IX-A obtained valid questions as many as 10 questions. Furthermore, the calculation of the level of difficulty is known to be 1 difficult category question and 9 easy category questions (Retnawati, 2016). Then from the analysis of the differentiating power of the question it is known that 10 questions have good differentiating power.

After testing the instrument, the researcher conducted a product usage test. At the product use test stage, researchers chose class VII-G with 33 students as the experimental class and class VII-F with 32 students as the control class. The initial analysis of the two classes was taken from the pre-test scores of students' mathematical concept understanding abilities. This implementation stage is in line with the research of Zaharah et al., (2021) the Implementation stage is carried out or applied in actual classroom situations with actual teaching using quantum learning-based mathematics learning multimedia. At the implementation stage by research Aspriyani & Suzana, (2020) at this stage, the e-modules developed are used by teachers in the learning process and observed to record things that need to be improved.

5) Evaluation stage

At the evaluation stage, researchers analyzed the initial and final data. For the normality test in this study, the Lilliefors test was used. The initial data normality test was carried out using spps 2.0 software. Based on the significance value in the test of normality table, the significance value in the control class is 0.797 and in the experimental class is 0.407. Because 0.797 > 0.05 and 0.407 > 0.05 then Ho is accepted. The conclusion is that the samples in the experimental class and control class come from a normally distributed population. To test the homogeneity of the two classes using the bartlett test. Based on the results of calculations that have been carried out using SPSS, in the test of homogeneity of variances table. Based on the two obtained significance values (probability) the value of Sig. = 0.084, then Sig.=0.084 > 0.05 so that the H0 hypothesis is accepted. The conclusion is that H0 is accepted, so the two variances of the population in the Experiment class and Control class are the same (homogeneous data).

The final data normality test was calculated using spss 2.3. Based on the significance value in the test of normality table, the significance value in the control class is 0.288 and in the experimental class is 0.361. Because 0.288 > 0.05 and 0.361 > 0.05 then H0 is accepted. The conclusion means that the samples in the experimental class and control class come from a normally distributed population. The final data Homogeneity test is calculated using spss 2.3. Based on the results of calculations that

have been carried out using SPSS, in the test of homogeneity of variances table. Based on the two obtained significance (probability) values Sig.=0.547, then Sig.=0.547> 0.05 so that the H0 hypothesis is accepted. The conclusion is that H0 is accepted, so the two variances of the population in the Experiment class and Control class are the same (homogeneous data).

The N-gain test using spss 2.3. Based on the results of the output using IBM SPSS 23, the average N-Gain Score for the experimental class was calculated at 0.4883 including in the medium category. In the experimental class, the N-Gain Score ranged from the lowest 0.21 to the highest 0.82. Meanwhile, the average N-Gain Score for the control class is 0.4633, which is included in the moderate category, making it one of the low scores. The N-Gain scores in the control class ranged from a low of 0.25 to a high of 0.80. The N-Gain value provides evidence that the use of interactive multimedia learning models based on geogebra can improve the ability to understand mathematical concepts on quadrilateral and triangle material.

After implementing geogebra-based interactive multimedia learning, then to find out the students' response to the product. Researchers gave a student response questionnaire sheet to 33 experimental class students. The assessment questionnaire contains 30 questions with each question having a maximum value of 5 and a minimum value of 1. The maximum percentage will be achieved by 100%. The results of student responses to learning with interactive multimedia based on geogebra are very good results, many of the students feel very happy in learning and better understand the material. Among the 33 children who became respondents, the highest response value was 95.3% and the lowest response value was 70.7% and the average student response value was 95%, this average was in the very good category

The advantage of the product that has been implemented is that grade 7 math learning students can learn independently from geogebra-based interactive multimedia. This product can be implemented anywhere using the internet. The product is stated to be able to improve the ability to understand mathematical concepts of grade 7 students. It can be concluded that learning by using geogebra-based interactive multimedia with Problem-Based Learning (PBL) model is better than conventional learning grade VII on triangles and quadrilaterals. This shows that learning using geogebra-based interactive multimedia can improve students' mathematical concept understanding abilities on triangle and quadrilateral material.

This is in accordance with research of Anggraeni et al. (2021) which states that the development of geogebra-based learning media on quadrilateral and triangle material for grade 7 SMP Datok Sulaiman Palopo has met the criteria for validity, practicality and effectiveness. This is also supported by research Yanti et al., (2019) which states that there is a significant difference in increasing the understanding of mathematical concepts of students who apply a scientific approach assisted by geogebra and who use ordinary learning. While research by Mukarramah et al., (2022) states the results of research entitled the effect of using geogebra software on students' concept understanding and mathematical problem-solving abilities, illustrating that there is a significant positive effect between the use of geogebra software on students' mathematical concept understanding abilities.

Implication

The results of this study imply that GeoGebra-based interactive multimedia, when designed through a systematic instructional framework like ADDIE, can significantly improve students' conceptual understanding in mathematics, particularly in geometry topics such as triangles and quadrilaterals. The use of dynamic visualizations, interactive features, and digital media elements fosters student engagement and supports the internalization of abstract mathematical concepts. This suggests that technology-enhanced learning tools, when properly validated and pedagogically aligned, can serve as effective alternatives or complements to traditional instruction. The study also

highlights the importance of integrating instructional design principles in developing educational media to ensure both usability and instructional quality.

Limitation of the Study

Despite the positive outcomes, this study has several limitations. First, the sample was limited to a single class in one junior high school, which may affect the generalizability of the results to broader contexts. Second, the study focused specifically on triangle and quadrilateral topics, so its findings may not fully apply to other mathematical domains that require different conceptual demands. Third, while the multimedia integrated various features such as video, visual design, and interactivity, the study did not evaluate which specific elements contributed most to learning gains. Future research is encouraged to explore the impact of such multimedia across different topics, school levels, and learning environments, as well as to analyze the role of individual media components in supporting student outcomes

CONCLUSION

Based on the research findings, it can be concluded that the development of GeoGebra based interactive multimedia on triangle and quadrilateral material for seventh grade students has been proven to be valid, practical, and effective in enhancing their understanding of mathematical concepts. Expert evaluations confirmed the high validity of the product, while student responses indicated that the multimedia was engaging, easy to use, and beneficial for learning. The higher N Gain scores and significant regression results further demonstrated its effectiveness. Beyond its technical success, the integration of GeoGebra in learning addressed challenges in teaching abstract mathematical concepts by providing dynamic, visual, and interactive experiences that foster student engagement and autonomy in accordance with twenty first century learning principles. Therefore, the developed media is not only a high quality instructional tool but also an innovative solution for improving mathematics education. For future research, it is recommended to apply GeoGebra based multimedia to other mathematical topics and educational levels, explore its use in different school contexts, conduct qualitative or long term studies to assess deeper impacts, and integrate it with other digital tools such as augmented reality, virtual reality, or mobile platforms to further enrich interactive and personalized learning experiences.

AUTHOR CONTRIBUTIONS STATEMENT

AB was responsible for designing the research framework, developing the GeoGebra-based interactive multimedia, and drafting the initial manuscript. NDR contributed to data collection, conducted statistical analyses, and interpreted the findings. MB carried out the literature review, revised the manuscript to ensure theoretical consistency, and provided critical feedback throughout the research process. All authors collaborated in reviewing and approving the final version of the manuscript.

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