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Designing a Pop-Up Book–VR Module to Improve Critical Thinking in Solid Geometry Learning

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ABSTRACT

This study aims to develop an innovative instructional module that integrates a Pop-Up Book and Virtual Reality (VR) based on graphic design principles to enhance students' critical thinking skills in learning solid geometry. The research adopts a Research and Development (R&D) approach using the ADDIE model: Analysis, Design, Development, Implementation, and Evaluation. The module was validated by experts, tested for effectiveness, and evaluated through student and teacher responses. Thirty-six Grade IX students and two mathematics teachers from SMP Swasta YWKA Medan were involved as research participants. Data were collected using critical thinking tests (pretest–posttest), observation, questionnaires, and interviews. The results showed that the module was rated "very feasible" by experts with an average score of 90%, particularly strong in content quality, interactivity, and visual design. The N-Gain score of 0.61 indicated a moderate to high improvement in students' critical thinking skills after using the module. Statistical tests confirmed the normality of data distribution, validating the results. In addition, students and teachers gave positive feedback, emphasizing the module's usefulness, engagement, and clarity. This research contributes to educational innovation by presenting a dual-mode instructional media that combines tactile learning and immersive digital experience, addressing the gap between abstract geometry concepts and real-world visualization.

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INTRODUCTION

Mathematics learning at the junior high school level not only aims to equip students with computational skills but also to foster critical thinking and systematic problem-solving abilities. In practice, many students still encounter difficulties in understanding geometry, particularly solid geometry, which requires spatial visualization and three dimensional imagination (Harahap, 2023; Sitepu, Irvan, & Harahap, 2025). The limited use of concrete and interactive learning media leads to weak conceptual understanding and underdeveloped critical thinking among students.

A fundamental cause lies in the use of conventional teaching media, which often fails to support students' visual and cognitive engagement. Two-dimensional representations in textbooks or on whiteboards are typically insufficient to depict geometric forms in full. Consequently, many students develop misconceptions and struggle to connect abstract concepts to concrete representations. Prior research emphasizes that gamified and visually interactive media significantly contribute to enhancing students' critical thinking and collaboration skills in mathematics (Aritonang

& Irvan, 2025). In the context of geometry, integrating physical visual media and immersive digital environments is increasingly essential. Previous studies have highlighted the effectiveness of combining augmented reality and pop-up book formats in increasing student learning autonomy and engagement (Elmunsyah, Rachmadyanti, & Kartikawati, 2019).

To address this issue, educational media innovation becomes a necessary solution. One such innovation is the development of a Pop Up Book based on graphic design, which allows students to physically manipulate geometric shapes. This media is concrete, tactile, and engaging, and aligns with the cognitive development stages of junior high school students. Furthermore, the integration of Virtual Reality (VR) adds an immersive dimension, enabling students to interact with 3D geometric objects within digital environments. This is consistent with Harahap (2023), who identified that students often struggle with the abstraction of solid figures due to a lack of spatial and visual aids in classroom practice.

A significant research gap exists in the lack of studies that explicitly combine Pop Up Books and VR into a unified and structured learning module particularly in efforts to enhance students' critical thinking in geometry. Most existing research has focused on one medium only, either physical manipulatives like Pop Up Books or digital tools like VR in isolation. Other studies have shown that combining spatial visualization with realistic approaches can improve conceptual understanding (Irmayani & Irvan, 2025), but direct integration of physical and virtual media remains rarely addressed systematically. Furthermore, recent development of augmented reality–based geometry modules has proven to improve spatial ability and enhance students' visual understanding in learning three-dimensional materials (Azis, Nasution, & Irvan, 2024).

Moreover, many existing instructional media developments have not been clearly aligned with critical thinking skills as a core competence in 21st-century mathematics learning. In fact, differentiated learning approaches using digital exploration have been proven to support both cognitive and affective development among students (Muhsi, 2025). Other findings also demonstrate that the use of visual aids such as TIMPERSARI significantly improves students' problem-solving skills in algebraic contexts, indicating the importance of physical representation in stimulating critical mathematical thinking (Sitepu, Irvan, & Harahap, 2025).

Additionally, the development of augmented and manipulable media has been shown to enhance students' spatial ability and motivation in learning (Panggabean et al., 2025; Wulandari et al., 2025). These results suggest that combined approaches integrating visual, kinesthetic, and digital elements can serve as effective strategies to bridge the gap between abstract mathematics and concrete learning experiences. Nasution (2023) further emphasizes that VR-based learning media stimulate conceptual comprehension by immersing students in simulated environments that mirror real-world spatial structures.

Based on this context, this study offers an innovative solution through the development of a Pop Up Book–VR learning module based on graphic design. The module is designed not only as a visual aid but also as an exploratory and reflective tool to systematically train students' critical thinking. The development process follows the ADDIE model, and its feasibility and effectiveness will be tested among 9th-grade junior high school students. The integration of technology in mathematics education has been shown to strengthen both conceptual analysis and student engagement when applied effectively (Wahyudi, R., Irvan, I., & Nasution, M. D.,2023). By combining physical and digital media into a cohesive unit, this module is expected to address the limitations of previous instructional tools and contribute meaningfully to the advancement of visual and technology-integrated mathematics education in schools.

RESEARCH METHOD

This research applied a Research and Development (R&D) approach to design, develop, and evaluate a learning module that integrates a Pop-Up Book and Virtual Reality (VR), based on graphic design principles. The main objective was to improve students' critical thinking abilities in learning solid geometry. The development procedure referred to a modified version of the ADDIE model, which includes five sequential phases: Analysis, Design, Development, Implementation, and Evaluation.

In the analysis phase, researchers conducted observations and interviews with teachers and students to identify learning challenges, particularly in understanding three-dimensional objects. This phase emphasized the need for visual, tangible, and immersive instructional media. During the design phase, the structure and content of the module were planned, integrating the tactile interaction of the Pop-Up Book with immersive experiences through VR. In the development phase, the product

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was built using graphic design software and VR tools. The developed module was then validated by two experts one in instructional media and one in mathematics education.

The implementation phase involved a limited trial with students, followed by the evaluation phase, which examined both the feasibility and effectiveness of the module using test instruments and user feedback. The ADDIE model was chosen due to its structured process and its relevance for creating media that blends pedagogical and technological components (Putra & Hidayat, 2022; Sukmadinata et al., 2021; Taufik et al., 2021). Qualitative data from interviews were analyzed using the Miles and Huberman (2020) model, which includes stages of data reduction, display, and conclusion drawing an approach suitable for in-depth exploration in education research.

This study was conducted at SMP Swasta YWKA Medan between May and June 2025, involving 36 ninth-grade students selected purposively based on academic performance and teacher recommendations. In addition, two mathematics teachers participated in classroom observations and provided professional judgments on the developed media.

To obtain comprehensive data, the study used multiple collection techniques as outlined below:

Table 1. Data Collection Techniques

Technique	Instrument	Purpose
Test	Critical Thinking Test (pretest–posttest)	To measure cognitive gains
Observation	Structured observation sheets	To assess student engagement and behavior
Questionnaire	Likert-scale responses (closed & open)	To gather perceptions from students & teachers
Interview	Semi-structured interview guides	To explore in-depth feedback and suggestions

The collected data were analyzed using both quantitative and qualitative techniques. In the expert validation phase, the module was assessed by a media expert and a subject matter expert using a 4-point Likert scale. Scores were converted into percentages and interpreted based on the following criteria:

Table 2. Expert Validation Criteria

Percentage Score	Feasibility Category
81–100%	Very Feasible
61–80%	Feasible
41–60%	Fair
≤40%	Not Feasible

To evaluate the effectiveness of the module, a normality test using the Shapiro–Wilk method was conducted, considering the sample size was fewer than 50 participants. Subsequently, a

Normalized Gain (N-gain) analysis was performed to determine the magnitude of improvement in students' critical thinking scores. The interpretation criteria were as follows:

Table 3. N-Gain Interpretation Criteria

N-Gain Score (g)	Interpretation
$g > 0.7$	High
$0.3 \leq g \leq 0.7$	Moderate
$g < 0.3$	Low

Furthermore, questionnaire results from both students and teachers were processed quantitatively using percentage calculations and categorized descriptively. Meanwhile, interview data were analyzed using Miles and Huberman's (2020) qualitative method involving data reduction, data display, and conclusion drawing. This combination of analytical strategies ensured both the credibility and depth of the findings.

RESULTS AND DISCUSSION

Results

The results of this study present findings from the validation process, effectiveness testing, and user feedback regarding the development of the Pop-Up Book–VR module designed to improve students' critical thinking in learning solid geometry. The results are structured into four sections: expert validation outcomes, pretest and posttest analysis, data normality testing, and qualitative responses from students and teachers. Each result is supported by quantitative data and relevant interpretation to reflect the module's feasibility and educational impact.

Expert Validation Results

Expert validation was conducted to assess the feasibility of the module before classroom implementation. Two evaluators one in instructional design and one in mathematics education—reviewed the module based on several aspects: content relevance, readability, visual quality, and interactivity. Their evaluations were scored on a 4-point Likert scale and converted into percentages.

Table 4. Expert Validation Results

Evaluation Aspect	Maximum Score	Score Obtained	Percentage	Category
Content Appropriateness	20	19	95%	Very Feasible
Readability and Language	20	18	90%	Very Feasible
Design and Visualization	20	17	85%	Very Feasible
Interactivity and VR	20	18	90%	Very Feasible

Average	80	72	90%	Very Feasible

The overall average percentage of 90% indicates that the module was rated as very feasible for implementation. The highest score was in content accuracy (95%), showing strong alignment with the mathematics curriculum. Interactivity and integration with VR also received high validation (90%), affirming that the module's digital features were both appropriate and functional.

Pretest and Posttest Results

To evaluate the module's effectiveness in improving critical thinking, students were given a critical thinking test before and after using the module. The difference in mean scores was analyzed using normalized gain (N-Gain) calculations.

Table 5. Pretest and Posttest Scores and N-Gain

Class	Pretest Mean	Posttest Mean	N-Gain	Interpretation
IX-A	58.33	83.61	0.61	Moderate–High

The N-Gain value of 0.61 falls within the moderate-to-high improvement category. This suggests that after using the Pop-Up Book-VR module, students showed significant development in their ability to think critically especially in analyzing, comparing, and solving problems related to solid geometry.

Normality Test

To ensure the appropriateness of parametric analysis, a normality test using the Shapiro–Wilk method was applied to the pretest and posttest data.

Table 6. Shapiro–Wilk Normality Test Results

Data	W Value	Sig. (p)	Distribution
Pretest	0.957	0.091	Normal
Posttest	0.964	0.115	Normal

Both the pretest and posttest scores have p-values greater than 0.05, confirming that the data follow a normal distribution. This supports the validity of the N-Gain test and indicates that score improvements were not due to data anomalies or outliers.

Student and Teacher Feedback

To assess user satisfaction and usability, student and teacher responses were gathered through questionnaires and semi-structured interviews. Participants rated the module based on its clarity, usefulness, engagement level, and overall impact on learning.

Table 7. Summary of Teacher and Student Responses

Respondent	Average Score (%)	Category
Teacher 1	91%	Very Positive
Teacher 2	88%	Very Positive
Students (avg.)	87%	Positive

Feedback from users was consistently positive. Teachers appreciated the module's ability to increase student participation and simplify complex geometry concepts. Students reported that the Pop-Up Book helped them visualize geometric forms better, while the VR element added enjoyment and immersion to the learning process.

These findings reinforce earlier research indicating that combining physical and digital media can improve learning autonomy, engagement, and higher-order thinking skills in mathematics (Elmunsyah et al., 2021; Irmayani & Irvan, 2025; Aritonang & Irvan, 2025).

Discussion

The results of this study provide strong evidence that the integration of Pop-Up Book and Virtual Reality (VR) into a cohesive learning module significantly enhances students' critical thinking in solid geometry. The module was systematically developed based on the ADDIE model and evaluated through expert validation, cognitive testing, and user feedback.

The expert validation score of 90%, with each aspect rated as "very feasible," confirms that the module is well-designed and pedagogically appropriate. High ratings on content appropriateness (95%) and interactivity (90%) validate the effectiveness of combining visual, physical, and immersive digital media. This supports previous findings that instructional media with dynamic visuals and interactive features can enhance students' focus and cognitive engagement (Panggabean, 2022; Putra & Hidayat, 2022).

The integration of physical media (Pop-Up Book) allows students to manipulate geometric shapes and explore their attributes through tactile learning. This is consistent with Sitepu, Irvan, and Harahap (2025), who demonstrated that manipulative teaching aids like TIMPERSARI improve students' problem-solving skills in algebra. Moreover, the VR component adds immersive experiences that deepen spatial reasoning, a critical skill in understanding three-dimensional objects (Makransky et al., 2020; Irmayani & Irvan, 2025).

The pretest–posttest comparison showed a significant increase in scores, with an N-Gain value of 0.61, categorized as moderate to high. This indicates that the module effectively stimulated critical thinking processes, including comparing, reasoning, analyzing, and making judgments in geometry contexts. Aritonang and Irvan (2025) also found that learning media infused with gamification and mastery models could significantly enhance junior high school students' critical thinking and collaboration.

Additionally, the normality test confirmed that the data distribution was statistically valid, ensuring that the observed improvements were consistent and not due to outliers. This strengthens the argument for the reliability of the intervention and the validity of the test instruments used in the evaluation phase.

The positive response from teachers and students further supports the practical value of the module. Students reported that the module helped them understand abstract geometric forms more clearly and made learning more engaging. Teachers observed increased participation and improved comprehension of spatial relationships. Similar findings were reported by Wulandari et al. (2025), who showed that interactive manipulative tools significantly improve student engagement and conceptual mastery in geometry.

What distinguishes this study from earlier works is the dual-mode media integration: combining tactile and immersive digital learning into one instructional design. Prior studies typically explored either Pop-Up books (Wulandari et al., 2025) or AR/VR technologies (Panggabean et al., 2025) in isolation. The novelty of this study lies in bridging that gap, offering a more comprehensive approach to stimulate both the perceptual and cognitive aspects of mathematical thinking.

Moreover, this approach aligns with current educational priorities to develop 21st-century skills, particularly in mathematics. As noted by Muhsi (2025), combining differentiated instruction with digital exploration has a positive impact on both cognitive and affective domains, particularly in mathematical reasoning and motivation. The results of this study echo that conclusion, showing that hybrid visual-digital media can stimulate deeper thought and sustained engagement among learners.

In summary, the development and use of this Pop-Up Book–VR module addresses a specific instructional need in geometry education helping students visualize, manipulate, and critically analyze solid figures. It bridges the abstraction gap commonly found in geometry learning by

delivering a student-centered, interactive, and reflective learning experience, rooted in sound instructional design and technological integration.

CONCLUSION

This research successfully developed and evaluated a Pop-Up Book–VR learning module based on graphic design, specifically designed to improve students' critical thinking skills in solid geometry. The module was validated as very feasible by experts and proven effective through pretest-posttest gain scores and positive user feedback.

The integration of tactile Pop-Up Book features with immersive VR environments allowed students to both see and interact with geometric forms, providing a more comprehensive and engaging learning experience. This innovative media design significantly contributed to students' ability to think critically, particularly in spatial reasoning, problem-solving, and conceptual understanding.

The study not only confirms the effectiveness of combining physical and digital media in mathematics learning but also provides a practical model for future instructional material development. Teachers, instructional designers, and curriculum developers are encouraged to adopt and adapt similar approaches to address abstract mathematical concepts in more interactive and student-centered ways.

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