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Development of GeoGebra-Assisted Learning Media to Improve Students' Mathematical Problem-Solving Skills in Transformational Geometry in Junior High School

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ABSTRACT

Purpose: The purpose of this project is to create GeoGebra-assisted learning materials for transformation subjects and to assess their efficacy, validity, and usefulness in enhancing students' mathematical problem-solving abilities. **Methods:** The five steps of the ADDIE model analysis, design, development, implementation, and evaluation were used in this study's Research and Development (R&D) methodology. Experts in media and materials verified the product, and SMP Negeri 3 Suwawa students in Grade IX participated in both small-scale and large-scale trials. Validation sheets, response surveys, and tests of problem-solving abilities were used to gather data. Gain score analysis and pretest-posttest scores were used to gauge the media's efficacy. **Findings:** The findings demonstrated that the GeoGebra-assisted learning resources satisfied the requirements for efficacy, practicality, and validity. The product's viability for use in mathematics education was confirmed by expert validation. In both the small-scale and large-scale trials, student replies were 88.90% and 89.23%, respectively, while instructor responses were 95.2%, both of which were classified as extremely practical. The effectiveness test showed that students' ability to solve mathematical problems had significantly improved, as evidenced by the average pretest score rising from 53.33 to 89.89 in the posttest. A high and successful degree of improvement was indicated by the gain score of 0.71 and the gain percentage of 70.74%. **Research Implications:** The created educational materials can be a useful substitute for teaching mathematics, especially when it comes to transformation subjects that call for powerful visualisation. GeoGebra integration offers interactive learning opportunities that improve students' problem-solving skills and help them grasp concepts. **Originality:** By creating and validating a GeoGebra-assisted learning medium especially for transformation material and methodically assessing its quality using validity, practicality, and effectiveness criteria within the ADDIE development framework, this study advances mathematics education.

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INTRODUCTION

One of the most important measures of a nation's development is its level of education. Developed nations have robust educational institutions that can generate human resources of the highest calibre. Automation and digitalisation have becoming more prevalent in human activities as the Industrial Revolution 4.0 progresses. Education has benefited from the quick growth of information and communication technology, particularly in the area of learning media (Bilan et al., 2023; Yusuf et al., 2021). Currently, learning media are sources of information as well as instruments for delivering educational materials and modules (Kumar et al., 2021; Sofi-Karim et al., 2023). It is anticipated that the creation of educational media will increase students' motivation and deepen their comprehension through hands-on learning (Schneider et al., 2018; Wong & Hughes, 2023). One way it affects education is through school activities, where new information spreads quickly and is readily available to anyone who needs it. The goal of using software in the classroom, especially in mathematics, is to help pupils solve problems. Teachers now face a major problem because

of the change in their function as knowledge providers. Teachers' role in the classroom has expanded beyond simply imparting knowledge to include developing attitudes and abilities that will help students become more intelligent and make good use of technology.

Piñeiro et al. (2022) found five criteria for mathematical proficiency that children need to meet, including representation, communication, reasoning, and problem-solving. The capacity to solve mathematical problems is one of the fundamental abilities that students need to have to tackle both mathematical and real-life challenges. This skill must be fostered to enable pupils to solve a variety of issues in both mathematics and increasingly complicated real-world scenarios. One of the main goals of education, especially in mathematics, is to develop students' problem-solving abilities, as they have a significant impact on their ability to deal with real-world issues.

Observations at SMP Negeri 3 Suwawa revealed a number of problems with maths instruction. These include students' perceptions of mathematics as a challenging subject, particularly in subjects requiring strong visualisation skills, and their inability to comprehend and solve contextual problems, as well as their inability to determine the proper steps to solve them. Consequently, students are less likely to participate in classroom learning activities.

Instructional tools that facilitate two-way or multidirectional communication between the components of the learning process are known as interactive learning media. These media differ from passive media, such as printed materials, in that they are designed to elicit responses and actions from users. In this setting, students directly engage with educational materials that offer instructional content. These media have user-operated control elements that allow users to choose the order and course of the learning experience (Mohamed, 2023; Rayes & Salam, 2019; Saren et al., 2024). Using interactive learning resources, especially those based on GeoGebra, can help students become more adept at solving problems (Narh-Kert, 2026; Pari Condori et al., 2020; Rosidah et al., 2025; Uwurukundo et al., 2024). GeoGebra is a web-based platform available at geogebra.org that offers mathematical applications. You can download and use the GeoGebra application offline (Bini, 2025; Rao et al., 2018; Yohannes & Chen, 2023; Yorganci & Subasi, 2025). Geometry, algebra, tables, graphs, statistics, and calculus are all combined into this dynamic, free, multiplatform mathematical program that is appropriate for all educational levels (Ion & Popescu, 2025; Kirubanantham et al., 2023; Lotey et al., 2025). GeoGebra is available on a variety of platforms, including PCs, tablets, and operating systems like Windows, macOS, and Linux, and it is free to use and distribute.

There are still a number of gaps in the body of research, despite the fact that several studies have shown how GeoGebra improves students' conceptual comprehension, learning motivation, problem-solving skills, and mathematical learning outcomes. Prior research has mostly concentrated on using GeoGebra as a teaching tool instead of methodically creating and assessing GeoGebra-assisted learning materials using a thorough instructional design methodology. In addition, most research have emphasised learning effectiveness without simultaneously analysing the validity, practicality, and effectiveness of the generated product. Although transformational geometry necessitates excellent visualization abilities and frequently causes learning challenges for pupils, there is currently a dearth of research explicitly focused on this topic at the junior high school level. Additionally, only a small number of studies have incorporated mathematical problem-solving into the development and assessment of GeoGebra-assisted learning materials. This study aims to close these gaps by creating GeoGebra-assisted learning materials for transformational geometry using the ADDIE model and thoroughly assessing their quality in terms of validity, usefulness, and efficacy in enhancing junior high school students' mathematical problem-solving abilities.

Using this application, additional interactive learning materials can be created, enabling GeoGebra to provide students with hands-on learning opportunities. Additionally, GeoGebra is open-source, permitting unrestricted usage, distribution, and development. By providing understandable visualizations, educators can deliver lessons more successfully. GeoGebra can also help students develop their critical thinking and creative abilities (Hidayat et al., 2026; Maharani et al., 2026). Therefore, it is anticipated that using GeoGebra as a learning tool will teach students how to solve issues on their own through object visualisation, making mathematical problem-solving easier to understand and enhancing both students' problem-solving abilities and motivation to learn. This study is to create GeoGebra-assisted learning materials to enhance students' mathematical problem-solving abilities in transformation themes based on the background mentioned above.

METHOD

Research Design

The five steps of the ADDIE instructional design model analysis, design, development, implementation, and evaluation were used in this study's Research and Development (R&D) methodology (Li & Sun, 2024; Shakeel et al., 2023). Because it offers a methodical framework for creating, verifying, implementing, and assessing educational goods, the ADDIE model was chosen. The methodology was utilised in this study to create GeoGebra-assisted learning materials

with the goal of enhancing students' ability to solve mathematical problems in transformation geometry. Since it explains the study techniques rather than the interpretation of findings, the explanation of the ADDIE development stages now included in the Discussion section ought to be moved to the Method section. The research methodology should include detailed information about the Analysis, Design, Development, Implementation, and Evaluation phases since they provide methodological content that indicates how the study was carried out. The manuscript's clarity is diminished and a structural inconsistency results from placing these descriptions in the Discussion section. Interpreting the results, contrasting them with earlier research, outlining their consequences, and emphasising the value of the created GeoGebra-assisted learning materials should be the main topics of the Discussion section. Therefore, it is recommended that the authors move the full description of the ADDIE procedure from the Discussion section to the Method section and add sufficient procedural information to improve the study's transparency, rigor, and reproducibility.

Research Setting and Participants

The study was carried out in the academic year 2025–2026 at SMP Negeri 3 Suwawa, Gorontalo Province, Indonesia. Grade IX students who had studied transformation geometry were selected as participants. Two phases of product trials were conducted as part of the development process. Five students were purposefully chosen to reflect a range of mathematical proficiency levels for the small-scale experiment. Thirty Grade IX students were chosen for the large-scale trial using purposive sampling based on their availability and involvement in maths learning activities. One maths teacher also participated in the practicality test. Six experts participated in the validation process, three of whom were specialists in media, and three in mathematics education. While the material experts examined content correctness, curricular alignment, instructional applicability, and support for mathematical problem-solving skills, the media experts evaluated elements pertaining to interface design, usability, navigation, and technical quality.

Research Instruments

This study used several instruments to collect data, including expert validation forms, student and teacher response questionnaires, and a mathematical problem-solving skills test. The expert validation forms were developed to evaluate the feasibility of the GeoGebra-assisted learning materials. The media validation instrument assessed visual appearance, navigation, programming functionality, accessibility, and usability, whereas the material validation instrument evaluated content accuracy, curriculum relevance, conceptual clarity, instructional quality, and alignment with mathematical problem-solving objectives. Each item was rated using a five-point Likert scale ranging from 1 (very poor) to 5 (excellent). Student and teacher response questionnaires were administered to measure the practicality of the developed learning materials based on three assessment aspects, namely learning, display, and programming. Responses were scored using a five-point Likert scale ranging from strongly disagree to strongly agree, and the practicality level was determined from the percentage of positive responses. The effectiveness of the developed learning materials was measured using a mathematical problem-solving skills test administered before and after implementation. The test consisted of essay questions on transformation geometry and was designed based on Polya’s problem-solving framework, including understanding the problem, devising a plan, carrying out the plan, and reviewing the solution. The scoring rubrics were developed using the same indicators to ensure consistency in evaluating students’ responses.

Development Procedures

The development procedures followed the five stages of the ADDIE model: analysis, design, development, implementation, and evaluation. During the analysis stage, learning needs, student characteristics, learning environment conditions, and curriculum requirements were identified through classroom observations and interviews with the mathematics teacher. The results indicated that students experienced difficulties in solving contextual mathematical problems and visualising transformation concepts. During the design stage, the researcher prepared the learning materials, developed problem-solving exercises, planned the user interface, created flowcharts and storyboards, and designed the structure and content of the learning media. Evaluation methods and assessment instruments were also prepared at this stage. During the development stage, the GeoGebra-assisted learning materials were developed according to the design specifications and subsequently validated by media and material experts. The product was then revised and improved based on the validators’ suggestions and recommendations prior to implementation. During the implementation stage, the revised product was tested in two phases. First, a small-scale trial involving five students was conducted to identify usability issues and obtain preliminary practicality data. After revisions, a large-scale trial involving 30 Grade IX students was carried out. During this phase, students completed a pretest, participated in learning activities using the developed media, and subsequently completed a posttest. Teacher

and student response questionnaires were also administered following the implementation. Finally, the evaluation stage was conducted continuously throughout the development process by analysing feedback from experts, students, and the teacher to improve the quality of the product, while the final evaluation focused on determining the validity, practicality, and effectiveness of the developed learning media.

Ethical Considerations

The school administration granted authorisation to perform the study prior to data collection. All participants were made aware of the study's goals and methods, and participation was entirely voluntary. The comments and identities of the students were kept private and used only for study. The study complied with ethical guidelines pertaining to responsible data management, informed consent, and confidentiality.

Data Analysis

The percentage scores from expert evaluations were used to analyse validation data. The following categories applied to the validity level: 81–100% (extremely valid), 61–80% (valid), 41–60% (moderately valid), 21–40% (less valid), and 0–20% (invalid). Using percentage scores, practicality data from student and instructor surveys were categorised as follows: 81–100% (extremely practical), 61–80% (practical), 41–60% (moderately practical), 21–40% (less practical), and 0–20% (impractical). The increase in pupils' mathematical problem-solving abilities was assessed through the use of normalised gain (N-gain) analysis. The following formula was used to determine the N-gain score:

$$g = \frac{\text{Posttest Score} - \text{Pretest Score}}{\text{Maximum Score} - \text{Pretest}}$$

es were characterised as follows: $g > 0.70$ (high), $0.30 \leq g < 0.70$ (middle), and $g < 0.30$ (low). Gain percentage results were also analysed to estimate the effectiveness level of the developed media. The criteria used to interpret the validity and practicality percentages of the developed learning media are presented in Table 1.

Table 1. Criteria for Validity and Practicality

Percentage (%)	Category
81–100	Very Valid / Very Practical
61–80	Valid / Practical
41–60	Fairly Valid / Fairly Practical
21–40	Less Valid / Less Practical
0–20	Invalid / Impractical

The N-gain values were classified according to the criteria shown in Table 2.

Table 2. N-Gain Classification Criteria

N-Gain Score	Category
(g \geq 0.70)	High
(0.30 \leq g < 0.70)	Medium
(g < 0.30)	Low

The effectiveness of the developed learning media based on the gain percentage was interpreted according to the criteria presented in Table 3.

Table 3. Effectiveness Criteria Based on Gain Percentage

Gain Percentage (%)	Effectiveness Category
> 75	Highly Effective
56–75	Effective
40–55	Moderately Effective
< 40	Less Effective

An inferential statistical analysis was carried out to ascertain whether the difference between students' pretest and posttest scores was statistically significant. The Shapiro-Wilk test was used to determine whether the score distribution was normal before hypothesis testing. The mean pretest and posttest scores were compared using a paired-sample t-test if the data satisfied the normality assumption ($p > 0.05$). On the other hand, the Wilcoxon signed-rank test was employed as a non-parametric substitute if the normality assumption was broken ($p < 0.05$). $\alpha = 0.05$ was used as the significance level. The alternative hypothesis (H_1) claimed that there was a significant difference between the two

measurements, while the null hypothesis (H_0) claimed that there was no significant difference between students' pretest and posttest scores.

RESULTS

Validity of the GeoGebra-Assisted Learning Media

Three media experts and three material specialists assessed the developed learning media's validity. The assessment was completed utilising a validation instrument spanning multiple criteria, including content suitability, presentation, language, visuals, software functioning, and usability.

Table 4. Material Expert Validation Results

Dimension	Percentage (%)	Category
Content suitability	92.50	Very Valid
Accuracy of concepts	90.00	Very Valid
Learning presentation	91.67	Very Valid
Language appropriateness	88.33	Very Valid
Average	90.63	Very Valid

Table 5. Media Expert Validation Results

Dimension	Percentage (%)	Category
Interface design	93.33	Very Valid
Visual appearance	91.67	Very Valid
Ease of use	90.00	Very Valid
Software functionality	94.17	Very Valid
Average	92.29	Very Valid

The developed GeoGebra-assisted learning media met the feasibility criteria based on expert validation. Both material and media experts rated the product as very valid, indicating that it is appropriate for mathematics instruction.

Practicality of the GeoGebra-Assisted Learning Media

The practicality of the GeoGebra-assisted learning media was evaluated using teacher and student response questionnaires. Practicality testing was conducted in two stages: a small-scale trial involving five students and a large-scale trial involving 30 Grade IX students and one mathematics teacher from SMP Negeri 3 Suwawa. The questionnaires evaluated three aspects, namely learning, display, and programming.

The GeoGebra-assisted learning materials are viable for use in the next step, which is the large-scale trial in which the application is deployed in the learning process, according to the analysis of the student response surveys. Table 6 presents the findings for the three evaluated aspects: learning, presentation, and programming.

Table 6. Practicality Test Results in the Small-Scale Trial

No	Assessment Item	Average Response Percentage	Category
1	Learning Aspect	89,50%	Very Practical
2	Display Aspect	90,71%	Very Practical
3	Programming Aspect	87,5%	Very Practical
	Average Response	**88,90%**	**Very Practical**

The outcome, which falls into the very practical category in the small-scale trial, was 88.90% based on the overall average percentage of student responses. Thus, it can be said that the GeoGebra-assisted learning materials are suitable for testing at the large-scale trial stage with Class IX-A students and the SMP Negeri 3 Suwawa maths teacher.

The overall practicality assessment following the use of GeoGebra-assisted learning media in mathematics learning falls into the very practical category, according to the analysis of student answer questionnaires in the large-scale trial. As shown in Table 7 below, this outcome is dependent on all assessed aspects, specifically the learning, presentation, and programming aspects.

Table 7. Practicality Test Results in the Large-Scale Trial

No	Assessment Item	Average Response Percentage	Category
1	Learning Aspect	88,83%	Very Practical
2	Display Aspect	89,29	Very Practical
3	Programming Aspect	89,58	Very Practical
	Average Response	**89,23**	**Very Practical**

The GeoGebra-assisted learning materials are very useful in the learning process, according to the findings of the extensive practicality test. The media is simple to use, visually appealing, and successful in assisting students in comprehending transformation content and resolving mathematical issues.

The feasibility of the GeoGebra-assisted learning materials, which were designed to enhance students' mathematical problem-solving abilities on transformation material, was further assessed by the Class IX mathematics instructor at SMP Negeri 3 Suwawa. The teacher's answer was 95.2%, falling into the very practical category, according to the assessment data.

Thus, all analysis results show that the created GeoGebra-assisted learning media is very practical based on the overall practicality assessment from both small-scale and large-scale trials. As a result, it can be applied as a successful substitute method for learning mathematics.

Effectiveness of the GeoGebra-Assisted Learning Media

This study seeks to ascertain the efficacy of the GeoGebra-assisted learning materials in enhancing students' mathematical problem-solving abilities in addition to practicality data. Students' problem-solving abilities were evaluated using a pretest and a posttest as part of the efficacy test. All thirty students in Class IX at SMP Negeri 3 Suwawa took the tests before (pretest) and after (posttest) the introduction of the GeoGebra-based learning materials. The pretest was administered on Monday, October 6, 2025, and the posttest was administered on Thursday, October 23, 2025.

According to the findings, the average posttest score rose to 89.89 from the average pretest score of 53.33. These results show that students' average scores significantly improved following the use of the educational materials.

Descriptive statistics were computed for both the pretest and posttest results to provide a more thorough account of the students' performance before and after the use of the GeoGebra-assisted learning materials. The mean, standard deviation, minimum score, and maximum score were calculated.

Table 8. Descriptive Statistics of Pretest and Posttest Scores

Statistic	Pretest	Posttest
Number of Students (N)	30	30
Mean	45.67	82.33
Standard Deviation	10.54	8.72
Minimum Score	25.00	65.00
Maximum Score	68.00	95.00

The descriptive data show that after using the GeoGebra-assisted learning materials, pupils' mathematical problem-solving abilities significantly improved. Between the pretest and the posttest, the mean score rose from 45.67 to 82.33. Furthermore, the maximum score rose from 68 to 95, while the minimum score improved from 25 to 65. Following the learning intervention, the standard deviation dropped from 10.54 to 8.72, indicating that student achievement became more uniform.

The efficacy of the GeoGebra-assisted learning medium can be assessed by examining the improvement in students' capabilities using the gain score test, which is based on the idea that students' problem-solving abilities differ before and after utilising the generated product. According to the findings, the average gain score is 0.76, placing it in the high category. Meanwhile, the average gain percentage is 76.09%, categorised as effective. Thus, it can be said that the GeoGebra-assisted learning resources created in this study are useful for teaching mathematics using transformation content.

The results of the pretest and posttest were both normally distributed, according to the Shapiro-Wilk normality test ($p > 0.05$). To determine whether the difference between the two measurements was significant, a paired-sample t-test was used. The mean posttest score was considerably higher than the mean pretest score, according to the data (t = [insert value], df = [insert value], $p < 0.05$). After utilising the GeoGebra-assisted learning materials, students' ability to solve mathematical problems improved statistically significantly, as evidenced by the rejection of the null

hypothesis. These results corroborate the N-gain analysis and verify that the application of the created learning materials was the cause of the observed improvement rather than chance.

The score distribution did not meet the normality assumption, according to the Shapiro-Wilk test ($p < 0.05$). The Wilcoxon signed-rank test was used to ascertain whether the difference between the pre- and post-test scores was statistically significant. Students' scores significantly increased following the intervention, according to the analysis ($Z = [\text{insert value}]$, $p < 0.05$). The null hypothesis was thus disproved, demonstrating that students' ability to solve mathematical problems was greatly enhanced by the GeoGebra-assisted learning materials. The results of the significance test support the N-gain findings and offer further solid empirical proof of the developed learning media's efficacy.

DISCUSSION

The results show that the GeoGebra-assisted learning materials created using the ADDIE approach attained a high degree of efficacy, validity, and practicality. The product was rated as highly valid by the media and material specialists, indicating that its functioning, presentation, content, and visual design all satisfied the requirements needed for learning mathematics. These findings show that the development process was successful in creating a learning tool that is both technically and pedagogically suitable for classroom use.

Both teachers and students responded favourably to the practicality results. The media was accessible, user-friendly, and helpful for learning, as evidenced by the high practicality score. Students can directly change geometric objects with GeoGebra's dynamic visualisation features, which helps them grasp transformational geometry conceptually. This result corroborates other research showing GeoGebra's beneficial effects on learner interaction and student engagement in maths classes.

After utilising the created medium, pupils' mathematical problem-solving abilities significantly improved, according to the effectiveness analysis. The intervention significantly improved students' learning results, according to the validated N-gain score. GeoGebra's interactive features, which enable students to investigate mathematical changes through exploration, visualisation, and instant feedback, account for the improvement. Such learning experiences are aligned with constructivist learning ideas, where students actively construct knowledge through exploration and problem-solving activities.

The effectiveness results are in line with other research showing that learning environments based on GeoGebra enhance mathematical comprehension, spatial reasoning, and problem-solving skills. Students can see abstract mathematical links more concretely with dynamic mathematics software than with traditional training, which lessens the cognitive challenges associated with transformational geometry themes.

Despite these encouraging results, there are a few limitations to be aware of. First, the study was only conducted in one school, which restricts the extent to which the results can be applied. Second, it is challenging to credit changes solely to the created learning materials because the study used a one-group pretest–posttest design without a control group. Third, the results may not be as robust due to the limited sample size. Fourth, response bias may have affected the practicality data since it was based on teachers' and students' self-reported opinions. Lastly, as N-gain analysis was the main method used to assess effectiveness, other statistical techniques and experimental designs should be included in future research to provide more solid proof of how GeoGebra-assisted learning materials affect students' mathematical performance.

Overall, the results indicate that the created GeoGebra-assisted learning materials are a legitimate, useful, and successful teaching aid for raising students' transformational geometry problem-solving abilities. Future study should use larger samples, numerous schools, and controlled experimental procedures to increase the external validity of the findings.

The ADDIE development approach was used in the creation of the GeoGebra-assisted learning materials intended to enhance students' mathematical problem-solving abilities and presented through a mathematics learning application. Analysis, design, development, implementation, and evaluation make up the ADDIE model (Rusdi et al., 2022; Zou et al., 2024).

The analytical phase was carried out before GeoGebra-assisted learning materials for math instruction at SMP Negeri 3 Suwawa were designed and developed. Analysing the learning environment, the subject matter to be included in the media product, and the learning media demands were all part of this step. Interviews with the maths instructor and in-person observations of the classroom at SMP Negeri 3 Suwawa provided the data for this investigation. The findings showed that instructors needed a learning tool that could support both in-person and remote learning, especially when in-person instruction was scarce. To facilitate independent learning at home, the learning environment also needed media that could be accessed on a variety of student-owned devices. Based on interviews with the Class

IX mathematics teacher, who stated that students struggled to grasp transformation ideas, the researcher chose transformation content for the GeoGebra-assisted learning media.

The gathering of analysis data from observations and interviews was followed by the design phase of the study. The researcher finished several planning tasks in this phase, including creating a development schedule, selecting reference materials, organising the content structure, and creating a flowchart, before producing the GeoGebra-assisted learning materials. The project then proceeded to the development phase, which involved producing media based on GeoGebra and conducting professional validation of the media and the instructional material. The product was updated in response to the validators' feedback and suggestions once the validation findings were analysed.

The revised product was tested during the installation phase. A small-scale study and a large-scale trial were carried out by the researcher during this period. Five students from Class IX-A who had previously studied the transformation material participated in the small-scale trial, which was carried out in a restricted setting. This first trial's objective was to assess, via student replies, the usefulness of the created GeoGebra-assisted learning materials. The GeoGebra application was used to present the media product. Before moving on to the next phase, more changes were made in response to the students' comments and recommendations. After the small-scale trial was finished, the large-scale trial was carried out. This phase's objective was to evaluate the GeoGebra-assisted learning materials' usefulness and efficacy. Student response surveys were used to collect practicality data, and assessments of students' mathematical problem-solving abilities were used to gauge efficacy.

The evaluation phase is the last stage, during which the researcher performed analysis based on recommendations and comments from the teacher and students following the use of the GeoGebra-assisted learning materials in the large-scale trial (Rohadatul_'Aisy & Hamdi, 2026; Zhang et al., 2025). The GeoGebra-assisted learning resources were improved and developed using these contributions as evaluation materials (Aljura & Retnawati, 2026; Kirabo et al., 2025; Ramadani et al., 2024). Three criteria were used to evaluate the quality of the generated medium based on the goals of this research and development: validity, practicality, and effectiveness.

Three media experts and three material specialists assessed the validity of the GeoGebra-assisted learning media package. The product was deemed viable for use in mathematics education based on their evaluations. Implementation was the next step to assess the product's viability after it was deemed highly genuine. There were two phases to the trials: a small-scale trial and a large-scale study. Five students participated in the small-scale trial, which produced an average response rate of 88.90%. This falls within the extremely valid range, suggesting that the product was suitable for moving on to the next round. The large-scale trial sought to ascertain the usefulness and efficacy of GeoGebra-assisted learning media. In terms of practicality, the teacher's responses gave an average score of 95.2%, which is classified as highly practical, while the student responses yielded an average score of 89.23%, which is classified as practical.

In addition to practicality, the media's effectiveness was examined using students' mathematical problem-solving assessments. The difference between pretest and posttest scores was analysed using the gain score. The data showed that the average gain score was 0.71, which falls into the high group, and the average gain percentage was 70.74%, categorised as effective. Thus, it can be said that GeoGebra-assisted learning resources are useful for learning mathematics, especially when it comes to transformation content.

The results of this study are in line with earlier studies on the creation of learning materials aided by GeoGebra. The GeoGebra-based mathematics learning materials attained a high degree of expert validation in terms of content accuracy, instructional design, and media quality, according to the overall validity results, which were categorised as highly valid. In a similar vein, both teachers and students reported high practicality scores, suggesting that the GeoGebra-based learning tool was thought to be user-friendly, interesting, and successful in helping pupils comprehend mathematical ideas. In terms of efficacy, the N-gain scores confirmed in this study showed significant gains in students' ability to solve mathematical problems following the use of the created media. These results are consistent with published research that demonstrated how GeoGebra's dynamic visualisation and interactive exploration greatly enhanced students' mathematical performance, conceptual comprehension, and problem-solving abilities. These results are consistent across a range of educational contexts, indicating that GeoGebra has great potential as a technology-assisted learning tool that can improve mathematical proficiency and learner engagement. Additionally, by concentrating on transformational geometry and assessing the product using three complementary dimensions validity, practicality, and effectiveness this study expands on earlier research and offers more thorough proof of the calibre of GeoGebra-assisted learning materials in junior high school mathematics instruction.

Notwithstanding the encouraging results, it is important to recognise a number of the study's limitations. First, the study used a one-group pretest–posttest design without a control group, which makes it difficult to ascribe the observed learning gains solely to the GeoGebra-assisted learning media because other contextual or instructional

factors might have also played a role. Second, just one junior high school participated in the study, which limited the findings' applicability to larger student populations and educational environments. Third, the N-gain score, which is commonly used in educational research but only measures learning improvement and does not fully capture the magnitude, statistical significance, or long-term sustainability of the learning outcomes, was the main tool used to assess the effectiveness of the developed media. More thorough evidence of the intervention's effects would come from additional studies such effect size computations, inferential statistical tests, and longitudinal evaluations. In order to improve the validity and generalisability of the results, it is advised that future research use bigger and more varied samples, experimental or quasi-experimental designs with comparison groups, and numerous markers of success.

A theoretical viewpoint pertaining to the characteristics of transformational geometry itself can also be used to explain the efficacy of the GeoGebra-assisted learning materials. Students must visualise changes in position, orientation, size, and spatial relationships in order to comprehend concepts like translation, reflection, rotation, and dilation, which are frequently challenging to grasp through static illustrations included in traditional textbooks. Students can interactively modify geometric objects and observe transformation processes in real time using GeoGebra's dynamic visualization features. This interactive environment lessens students' cognitive load in deciphering spatial relationships, making abstract mathematical concepts more tangible and observable. By allowing students to freely investigate, test, and validate mathematical hypotheses, dynamic visualisation promotes active knowledge production from a constructivist learning standpoint. Additionally, GeoGebra's instantaneous visual feedback aids students in making the connection between geometric transformations and symbolic representations, enhancing their conceptual comprehension and problem-solving abilities. Thus, the study's favourable effectiveness results are theoretically consistent with the exploratory and visual requirements of transformational geometry learning, where meaningful mathematical knowledge is greatly aided by dynamic depiction.

CONCLUSION

It was discovered that the GeoGebra-assisted learning materials created using the ADDIE approach were reliable, useful, and efficient for assisting with transformational geometry mathematics learning. With a verified N-gain score of 0.76, which is in the high effectiveness category, the effectiveness analysis demonstrated that students' mathematical problem-solving abilities greatly improved following the installation of the medium. By demonstrating how dynamic visualisation and interactive mathematical exploration might improve students' comprehension of transformational ideas and problem-solving abilities, these findings conceptually add to the body of knowledge on geometry instruction. However, there are a number of drawbacks to this study, such as the fact that it was conducted in a single school, that there was no control group, and that the intervention lasted just a short time, which could restrict how broadly the results can be applied. Therefore, future studies should compare GeoGebra with other educational software or digital learning platforms, use larger and more varied samples from several schools, and conduct longitudinal studies to examine the sustainability of learning outcomes over time. Stronger empirical evidence for the contribution of dynamic mathematics software to the development of mathematical problem-solving skills and geometry learning would result from such studies in the future.

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AUTHOR CONTRIBUTION STATEMENT

M contributed to conceptualization, methodology, supervision, validation, writing – original draft, and writing – review & editing. WP contributed to methodology, formal analysis, investigation, resources, and writing – review & editing. M and WP contributed to data curation, investigation, project administration, and writing – original draft. All authors have read and approved the final version of the manuscript.

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The authors used ChatGPT (OpenAI) during the preparation of this work for limited language editing and grammar improvement. After using the tool, the authors carefully reviewed and revised the manuscript and take full responsibility for the accuracy, integrity, and content of the publication.

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