International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 09 Issue 04 April 2026
DOI: 10.47191/ijcsrr/V9-i4-48, Impact Factor: 8.048
IJCSRR @ 2026
www.ijcsrr.org

Development of *Geogebra-Assisted* Learning Materials for Circle Topics Based on the van Hiele Model

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ABSTRACT: This study aims to develop GeoGebra-assisted instructional materials on circle topics based on the van Hiele model that meet the criteria of validity, practicality, and effectiveness. The study employed a Research and Development (R&D) approach using the 4D model, consisting of the Define, Design, Develop, and Disseminate stages. The participants were high school students divided into an experimental group and a control group. Data were collected through validation sheets, observation sheets, student response questionnaires, readability tests, and learning outcome assessments. The results indicate that the developed materials are valid, with average validity scores ranging from 3.58 to 3.85. Practicality was demonstrated by a high level of instructional implementation (3.75), very high student activity (93.2%), and highly positive student responses (92.68%). Effectiveness was confirmed by a classical mastery rate of 89%, a high N-Gain score (0.77), and a statistically significant difference between the experimental and control groups ($p < 0.05$). These findings suggest that GeoGebra-assisted instructional materials based on the van Hiele model are effective in improving students' mathematics learning outcomes, particularly in geometry.

KEYWORDS: circle geometry, dynamic geometry software, GeoGebra, instructional material development, van Hiele model

INTRODUCTION

Learning that is aligned with students' characteristics and needs is a fundamental prerequisite for effective instruction. When instructional approaches correspond to students' cognitive abilities, they are more likely to support meaningful and sustained understanding of mathematical concepts (Lusyana & Lestari, 2022). In mathematics education, particularly in geometry, learning remains challenging because many concepts are inherently abstract and require well-developed visualization skills (Firmansyah et al., 2020). Therefore, instructional approaches are needed that can assist students in understanding geometric concepts in a gradual and systematic manner.

One approach that addresses this need is the van Hiele learning model, which is grounded in van Hiele's theory of geometric thinking. This theory posits that students progress through hierarchical levels of understanding: visualization, analysis, informal deduction, formal deduction, and rigor. Instruction based on this model is structured into five phases: information, guided orientation, explanation, free orientation, and integration. These phases facilitate students' active engagement in constructing geometric understanding in accordance with their cognitive development (Giovanni et al., 2022). Empirical studies have also demonstrated the effectiveness of this approach. For example, Yudianto et al. (2022) reported that the implementation of van Hiele learning phases significantly improves students' levels of geometric thinking. Thus, the van Hiele model emphasizes not only learning outcomes but also the process of students' knowledge construction.

However, in practice, mathematics instruction in many classrooms remains dominated by teacher-centered approaches, particularly lecture-based methods. Such approaches tend to limit students' active participation and engagement in the learning process (Nwabuaku & Iroriteraye-Adjekpovu, 2021). As a result, students often exhibit low conceptual understanding and may develop negative attitudes and anxiety toward mathematics (Budiman, 2014). These conditions indicate the need for instructional approaches that actively engage students while supporting their thinking processes in a structured and progressive manner.

In addition to pedagogical approaches, the integration of technology has become an important component of effective geometry instruction. One widely used tool is GeoGebra, a dynamic mathematics software that enables the visualization of abstract concepts. GeoGebra allows students to construct, explore, and manipulate geometric objects interactively, thereby enhancing their representational abilities, creativity, and problem-solving skills (Hohenwarter & Lavicza, 2024; Puspita et al., 2023; Septian et al., 2023). The integration of GeoGebra into instruction can therefore strengthen the implementation of the van Hiele model, particularly in supporting students during the visualization and analysis stages.

The development of instructional materials represents a strategic step in optimizing the implementation of the van Hiele model. Well-designed instructional materials enable teachers to organize learning activities systematically in accordance with the instructional phases of the model (Fakhri, 2023). Previous studies have demonstrated that GeoGebra-assisted instructional tools can improve learning outcomes; however, several limitations remain. For instance, Sari et al. (2022) developed GeoGebra-assisted materials but did not explicitly integrate the van Hiele learning phases into the design. Similarly, Amaliah et al. (2022) developed GeoGebra-based learning media but did not construct a comprehensive instructional package aligned with a specific pedagogical framework.

More broadly, existing studies have shown that technology integration in geometry learning enhances visualization and conceptual understanding. Nevertheless, its alignment with structured frameworks of geometric thinking development has not been systematically addressed. This indicates a critical research gap, namely the lack of instructional materials that explicitly integrate dynamic geometry technology with the hierarchical stages of students' geometric thinking as described in the van Hiele model.

Therefore, this study seeks to address this gap by developing GeoGebra-assisted instructional materials that are systematically aligned with the van Hiele learning model. The topic of circles was selected because it involves complex and abstract concepts that require strong visualization skills, making it particularly suitable for this integrated approach. The general objective of this study is to develop instructional materials that meet the criteria of validity, practicality, and effectiveness. Specifically, this study aims to: (1) describe the development process of GeoGebra-assisted instructional materials based on the van Hiele model, and (2) produce instructional materials that meet the criteria of validity, practicality, and effectiveness.

MATERIALS AND METHODS

This study employed a Research and Development (R&D) design using the 4D model proposed by Thiagarajan, which consists of four stages: Define, Design, Develop, and Disseminate. The study aimed to develop a set of GeoGebra-assisted instructional materials for circle topics based on the van Hiele learning model. The developed materials included instructional modules, student worksheets, a user manual, and learning outcome tests designed to support the implementation of the model in classroom settings.

The participants of this study were 12th-grade students enrolled in an advanced mathematics course. The sample consisted of two intact classes: an experimental class comprising 28 students and a control class comprising 27 students. A purposive sampling technique was employed to ensure the comparability of students' initial abilities, as determined through pre-test results. During the implementation phase, the experimental class was taught using the GeoGebra-assisted instructional materials based on the van Hiele model, while the control class received conventional instruction using lecture-based methods supported by textbooks and whiteboard explanations.

The validity of the instruments was established through expert judgment to ensure the appropriateness of content, clarity, and alignment with the research objectives. This approach is widely recognized in educational research as a method for ensuring content validity through systematic evaluation by experts (Loureiro et al., 2023; Salfate et al., 2023). In addition, the reliability of the instruments was analyzed using Cronbach's Alpha to measure internal consistency among the instrument items. A higher Cronbach's Alpha value indicates greater consistency in measuring the same construct, although its interpretation requires consideration of the assumption of unidimensionality (Balladares-Pico et al., 2023; Zakariya, 2022).

Data were collected using multiple instruments, including validation sheets to assess the validity of the instructional materials, observation sheets to evaluate the implementation of instruction and student activities, student response questionnaires to capture students' perceptions of the learning process, learning outcome tests consisting of pre-tests and post-tests to measure effectiveness, and readability test instruments to assess the clarity of the developed materials.

The research procedure followed the stages of the 4D model in a systematic manner. In the Define stage, needs analysis, student analysis, concept analysis, and the formulation of learning objectives were conducted to identify the requirements of the instructional design. In the Design stage, the instructional materials were developed, GeoGebra was selected as the primary learning medium, and the research instruments were designed to align with the study objectives. In the Develop stage, expert validation and field testing were conducted to refine the materials and ensure that they met the criteria of validity, practicality, and effectiveness. Finally,

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www.ijcsrr.org

in the Disseminate stage, the developed instructional materials were distributed on a limited scale through both offline and online platforms to facilitate their use in broader educational contexts.

Data analysis in this study was conducted to evaluate the quality of the developed instructional materials in terms of validity, practicality, and effectiveness.

Validity Analysis

The validity of the instructional materials was determined through expert judgment using a 4-point Likert scale. The materials were considered valid if the average score (Va) fell within the range of 3 ≤ Va ≤ 4. The criteria used to interpret the validity scores are presented in Table 1.

Table 1. Validity Categories

Score V_a	Validity Category
$1 < V_a < 2$	Invalid
$2 \leq V_a < 3$	Moderately Valid
$3 \leq V_a < 4$	Valid
$V_a = 4$	Highly Valid

Practicality Analysis

The practicality of the instructional materials was assessed using three indicators: instructional implementation, student activities, and student responses. These indicators were selected because they collectively represent the feasibility of implementation, the level of student engagement, and students' perceptions of the developed materials.

Instructional implementation reflects the extent to which the materials can be applied in accordance with the designed learning procedures. Student activities indicate the level of student participation during the learning process, while student responses capture students' acceptance and evaluation of the instructional materials. A set of instructional materials is considered practical if all three indicators achieve at least a high category for implementation and student activities, and a positive category for student responses. The criteria for evaluating instructional implementation are presented in Table 2.

Table 2. Learning Implementation Categories

Score I_O	Criteria
$1 \leq I_O < 2$	Low
$2 \leq I_O < 3$	Medium
$3 \leq I_O < 4$	High
$I_O = 4$	Very High

Student activity was further analyzed as a key indicator of engagement in using the instructional materials. The categories of student activity are presented in Table 3.

Table 3. Categories of Student Activities

Score	Criteria
$90\% \leq P_s \leq 100\%$	Very Good
$80\% \leq P_s < 90\%$	Good
$65\% \leq P_s < 80\%$	Fair
$P_s < 65\%$	Not Good

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In addition, student responses were analyzed to evaluate the level of acceptance and perception of the developed materials. The criteria for student responses are presented in Table 4.

Table 4. Categories of Student Responses

Percentage	Criteria
$85\% \leq R_S$	Very Positive
$70\% \leq R_S < 85\%$	Positive
$50\% \leq R_S < 70\%$	Less Positive
$R_S < 50\%$	Not Positive

These three indicators were analyzed in an integrated manner to determine the overall practicality of the instructional materials in real classroom settings.

Effectiveness Analysis

The effectiveness of the instructional materials was evaluated using three indicators: student learning achievement, improvement in learning outcomes, and statistical test results.

Student learning achievement was considered complete if individual scores reached at least 79, while classical completeness was achieved if at least 70% of students met this criterion. Improvement in learning outcomes was analyzed using the N-Gain test, with categories presented in Table 5.

Table 5. N-Gain Categories

Criteria	N-Gain
$g > 0{,}7$	High
$0{,}3 < g \leq 0{,}7$	Moderate
$g \leq 0{,}3$	Low

Statistical analysis was conducted to compare the learning outcomes of the experimental and control classes. Prior to hypothesis testing, assumption tests—including normality and homogeneity tests—were performed to ensure that the data met the requirements for parametric analysis. Once these assumptions were satisfied, an independent samples t-test was conducted using IBM SPSS 25 to determine whether there was a significant difference between the two groups.

The decision criteria for hypothesis testing were as follows: if the significance value (two-tailed) was greater than 0.05, the null hypothesis (H_0) was accepted, indicating no significant effect of the GeoGebra-assisted instructional materials on learning outcomes. Conversely, if the significance value (two-tailed) was less than 0.05, the null hypothesis (H_0) was rejected and the alternative hypothesis (H_1) was accepted, indicating a significant effect of the instructional materials on students' mathematics learning outcomes.

RESULTS

This study presents the results of the instructional material development process as well as the evaluation of the developed materials in terms of validity, practicality, and effectiveness.

The development process followed the 4D model, beginning with the Define stage, which involved an analysis of learning needs, student characteristics, and instructional content. The findings revealed that instruction at the research site was predominantly lecture-based, with minimal use of instructional media. This condition indicated the need for a more interactive and constructivist learning approach. Based on this analysis, circle material was selected as the focus of the study due to its abstract nature and its reliance on strong visualization skills.

In the Design stage, instructional materials were systematically developed based on the identified needs. An initial prototype (Draft 1) was produced, consisting of instructional modules, worksheets, and assessment instruments. GeoGebra was selected as the primary learning medium to support dynamic visualization, and all components were designed to align with the phases of the van

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IJCSRR @ 2026

Hiele learning model. The instruments were also developed to ensure alignment with the research objectives prior to expert validation.

The Develop stage involved expert validation and revision of the initial prototype. Based on feedback from validators, revisions were carried out to produce Draft 2, which was subsequently implemented in the experimental class. The Disseminate stage was conducted on a limited scale, where the developed instructional materials were distributed both offline and online to facilitate broader accessibility.

Validity

The validity of the developed instructional materials was evaluated through expert judgment. The results of the validation are presented in Table 6.

Table 6. Validity Coefficient Achievements of Learning Tools

No.	Device	Va	Category
1	Teaching Module	3.58	Valid
2	User Manual	3.72	Valid
3	Worksheets	3.85	Valid
4	Learning Outcome Test	3.70	Valid

The validation results show that the validity coefficients range from 3.58 to 3.85, all of which fall within the "valid" category ($3 \leq V_a \leq 4$). This indicates that the developed instructional materials meet the criteria of content validity, construction, and language appropriateness, and are therefore suitable for use in geometry instruction.

The validity of the research instruments was also assessed, and the results are presented in Table 7.

Table 7. Validity Coefficients of the Research Instrument

No.	Instrument	Va	Category
1	Readability Test Sheet	3.65	Valid
2	Observation Sheet for Instruction Implementation	3.83	
3	Student Activity Observation Sheet	3.76	Valid
4	Student Response Questionnaire	3.91	Valid

All instruments achieved validity scores within the valid category, confirming that they are appropriate for data collection. Overall, these findings indicate that both the instructional materials and the research instruments meet the established validity criteria.

Practicality

The practicality of the instructional materials was evaluated based on three indicators: instructional implementation, student activities, and student responses. The results show that the implementation of instruction achieved a score of 3.75 on a scale of 4, which is categorized as high. Student activity reached 93.2%, categorized as very good, while student responses reached 92.68%, categorized as very positive.

These results indicate that the developed instructional materials are practical and can be effectively implemented in classroom settings. The high level of student activity and positive responses further suggest that the materials are capable of promoting active engagement and meaningful participation during the learning process.

Effectiveness

The effectiveness of the instructional materials was evaluated based on learning achievement, improvement in learning outcomes, and statistical test results. The results of student learning outcomes are presented in Table 8.

Table 8. Learning Outcomes

Indicator	Value
Highest Score	100
Lowest Score	68
Average Score	87.36
Students ≥ 79 (Achieved Mastery)	25
Students < 79 (Not Achieved)	3
Classical Mastery Percentage	89%

Table 8 shows that the average score of students in the experimental class was 87.36, with a highest score of 100 and a lowest score of 68. A total of 25 students achieved a score of at least 79, resulting in a classical mastery rate of 89%, which exceeds the minimum criterion of 70%. This indicates that the learning outcomes meet the effectiveness criteria.
Further analysis using the N-Gain test is presented in Table 9.

Table 9. N-Gain Categories for the Experimental and Control Classes

Class	Average N-Gain	Category	Description
Experimental	0.77	High	High Increase
Control	0.49	Moderate	Moderate Increase

The results show that the experimental class achieved an average N-Gain score of 0.77, which falls into the high category, while the control class achieved an average score of 0.49, categorized as moderate. This indicates that the improvement in learning outcomes in the experimental class was higher than in the control class.
Before conducting hypothesis testing, assumption tests were performed. The results of the normality test are presented in Table 10.

Table 10. Results of Normality Test (Pre-test and Post-test)

Data Set	Sig. Value	Interpretation
Experimental (Pre-test)	0.969	Normal
Control (Pre-test)	0.608	Normal
Experimental (Post-test)	0.365	Normal
Control (Post-test)	0.132	Normal

All significance values are greater than 0.05, indicating that the data are normally distributed. The results of the homogeneity test are presented in Table 11.

Table 11. Results of Homogeneity Test

Data Set	Sig. Value	Interpretation
Pre-test	0.964	Homogeneous
Post-test	0.971	Homogeneous

The results indicate that the data are homogeneous, as all significance values exceed 0.05. Therefore, the assumptions for parametric testing are satisfied. The results of the independent samples t-test are presented in Table 12.

Table 12. Independent Samples t-Test Results

Test	Sig. (2-tailed)	Decision
Post-test Result	0.000	Significant Difference

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The significance value ($p < 0.05$) indicates a statistically significant difference between the experimental and control classes. Based on this result, the null hypothesis (H_0) is rejected and the alternative hypothesis (H_1) is accepted. This finding confirms that the implementation of GeoGebra-assisted instructional materials based on the van Hiele model has a significant effect on improving students' mathematics learning outcomes.

DISCUSSION

This study aimed to develop GeoGebra-assisted instructional materials based on the van Hiele model and to examine their quality in terms of validity, practicality, and effectiveness. The findings indicate that the developed materials meet all three criteria, suggesting that the integration of structured cognitive stages and dynamic visualization can enhance geometry learning.

In terms of validity, the instructional materials were evaluated by three experts and achieved an average score of 3.71, which falls within the "valid" category. This result indicates that the materials are appropriate in terms of content, presentation, language, and internal consistency. The validity of the materials suggests that the design successfully aligns the instructional components with the theoretical framework of the van Hiele model. This finding is consistent with Sari et al. (2020), who reported that instructional materials based on van Hiele learning phases can achieve a high level of validity when systematically designed.

The practicality results further demonstrate that the developed materials can be effectively implemented in classroom settings. The high implementation score (3.75), combined with very high student activity (93.2%) and highly positive student responses (92.68%), indicates that the materials not only function as intended but also actively engage students in the learning process. These findings suggest that the integration of GeoGebra within the van Hiele framework creates a learning environment that supports interaction, exploration, and participation. This result is in line with previous studies on van Hiele-based instructional tools, which also reported high levels of implementation feasibility (Sari et al., 2020).

More importantly, the effectiveness findings provide strong evidence of the impact of the developed materials on students' learning outcomes. The classical mastery rate reached 89%, exceeding the required threshold, while the N-Gain analysis indicated a high level of improvement in the experimental class compared to the control class. The statistical test results further confirmed a significant difference between the two groups ($p < 0.05$). These findings indicate that the integration of the van Hiele model with GeoGebra is not only theoretically sound but also empirically effective in improving students' understanding of geometry.

The effectiveness of this integration can be explained from a cognitive perspective. GeoGebra, as a dynamic geometry software, enables students to manipulate geometric objects interactively, allowing them to observe patterns and relationships directly. This process reduces the level of abstraction typically associated with geometry learning and supports conceptual understanding through visual and exploratory experiences. In addition, the visualizations generated by GeoGebra function as a bridge between abstract and concrete representations, thereby facilitating deeper conceptual understanding of circle-related concepts.

Furthermore, this process is closely related to the development of spatial reasoning skills. By interacting with dynamic representations, students are able to perform mental transformations and better understand relationships between geometric objects (Pattanapiboon & Nishizawa, 2024; Fiangga et al., 2025; Kurt et al., 2023). These findings reinforce the view that visualization plays a crucial role in geometry learning, particularly in supporting students' transition across levels of geometric thinking.

The effectiveness of the developed materials is also closely linked to the structure of the van Hiele model. During the visualization and analysis stages, GeoGebra supports the construction of concrete representations that help students understand abstract concepts (Firmansyah et al., 2019). At the informal deduction stage, students are able to explore relationships between geometric properties through direct manipulation, which promotes active knowledge construction. This aligns with previous studies showing that the use of GeoGebra can improve student engagement and learning outcomes in geometry (Budiman & Rosmiati, 2020; Mayadi, 2021).

Beyond confirming previous findings, this study contributes to the literature by demonstrating that the effectiveness of technology in mathematics learning is not determined solely by its use, but by how it is integrated within an appropriate pedagogical framework. In this case, the systematic integration of GeoGebra into each phase of the van Hiele model provides a coherent structure that supports both cognitive development and conceptual understanding. This finding highlights the importance of aligning technology, pedagogy, and content in instructional design.

In addition to cognitive outcomes, the findings also reveal changes in students' learning behavior. Initially, students tended to be passive and unfamiliar with the use of GeoGebra. However, over time, they became more confident and actively engaged in exploration and discussion. Group activities further supported collaborative problem-solving (Firmansyah et al., 2022; Annizar et al. 2025; Kurniati et al. 2026). These observations suggest that technology-supported learning environments can foster not only cognitive development but also affective engagement and learner autonomy. In contrast, students in the control class, who experienced conventional instruction, tended to be more passive and less engaged.

Despite these positive findings, this study has several limitations. The sample size was limited to two classes within a single school, which may affect the generalizability of the results. In addition, the intervention was conducted over a relatively short period, and the instruments were not tested on a larger population. Future research is therefore recommended to involve a larger sample size, explore different mathematical topics, and examine the long-term impact of integrating GeoGebra with the van Hiele model.

CONCLUSION

This study demonstrates that GeoGebra-assisted instructional materials based on the van Hiele model meet the criteria of validity, practicality, and effectiveness. The validity results indicate that all components of the developed materials are appropriate in terms of content, construction, and language. In terms of practicality, the high level of instructional implementation, student activity, and positive student responses confirms that the materials can be effectively applied in classroom settings. The effectiveness findings further show that the materials significantly improve students' mathematics learning outcomes, as evidenced by the high classical mastery rate, substantial N-Gain scores, and statistically significant differences between the experimental and control groups.

Beyond these empirical findings, this study contributes to the field of mathematics education by demonstrating that the effectiveness of technology integration depends on its alignment with a coherent pedagogical framework. The systematic integration of GeoGebra within the phases of the van Hiele model provides a structured learning environment that supports students' conceptual understanding and cognitive development in geometry.

Practically, the developed instructional materials offer an alternative approach for teachers to implement more interactive and student-centered learning. The integration of dynamic visualization and structured learning stages enables students to engage more actively in exploring geometric concepts.

However, this study has several limitations, including the relatively small sample size and the focus on a single mathematical topic. Future research is therefore recommended to involve larger and more diverse samples, explore different mathematical topics, and examine the long-term impact of this instructional approach on students' learning outcomes and higher-order thinking skills.

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DOI: 10.47191/ijcsrr/V9-i4-48, Impact Factor: 8.048
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