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ENHANCING CRITICAL THINKING SKILL THROUGH "MATHEMATICAL HABITS OF MIND" APPROACH WITH GEOGEBRA ON THE PYTHAGOREAN THEOREM

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Abstract

This study addresses the low level of students' critical thinking skills and the dominance of teacher-centered instruction in mathematics learning. It examines differences in critical thinking between students taught using the Mathematical Habits of Mind (MHM) approach assisted by GeoGebra and those taught with traditional methods on the Pythagorean Theorem in Class VIII at SMPN 3 Lingsar, West Lombok. A quasi-experimental nonequivalent control group design was employed, involving two groups of 27 students each. The experimental group received MHM-based instruction with GeoGebra, while the control group used conventional methods. Data were collected through pretest–posttest assessments, student worksheets, and classroom observations. Pretest results showed no significant difference between groups ($p > 0.05$). Posttest results revealed a significant improvement in the experimental group (mean = 82) compared to the control group (mean = 65), with a p-value of 0.000 (< 0.05) and a very large effect size (Cohen's d = 1.90), indicating a substantial difference in learning outcomes. Observations also indicated high engagement in the experimental group. The findings suggest that the MHM approach with GeoGebra effectively enhances critical thinking and fosters reflective, systematic, and collaborative learning. The study recommends integrating MHM strategies and visual technologies like GeoGebra into mathematics education.

Keywords: Critical thinking; GeoGebra; mathematical habits of mind; mathematics learning; Pythagorean theorem

Abstrak

Penelitian ini membahas rendahnya keterampilan berpikir kritis siswa serta dominasi pembelajaran berpusat pada guru dalam matematika. Tujuannya adalah menguji perbedaan kemampuan berpikir kritis antara siswa yang diajar dengan pendekatan Mathematical Habits of Mind (MHM) berbantuan GeoGebra dan siswa yang diajar dengan metode konvensional pada materi Teorema Pythagoras di kelas VIII SMPN 3 Lingsar, Lombok Barat. Penelitian menggunakan desain kuasi-eksperimen nonequivalent control group dengan dua kelompok, masing-masing 27 siswa. Kelompok eksperimen mendapat pembelajaran berbasis MHM dengan GeoGebra, sedangkan kelompok kontrol menggunakan metode tradisional. Data diperoleh melalui pretest–posttest, lembar kerja, dan observasi kelas. Hasil pretest menunjukkan tidak ada perbedaan signifikan ($p > 0,05$). Namun, posttest memperlihatkan peningkatan signifikan pada kelompok eksperimen (rata-rata = 82) dibanding kelompok kontrol (rata-rata = 65), dengan $p = 0,000$ ($< 0,05$) dan effect size sangat besar (Cohen's d = 1,90). Observasi juga mencatat keterlibatan tinggi pada kelompok eksperimen. Temuan ini menegaskan bahwa pendekatan MHM dengan GeoGebra efektif meningkatkan berpikir kritis sekaligus mendorong pembelajaran reflektif, sistematis, dan kolaboratif. Disarankan strategi MHM dan teknologi visual seperti GeoGebra diintegrasikan dalam pembelajaran matematika.

***Kata kunci**: Berpikir kritis; GeoGebra; kebiasaan berpikir matematis; pembelajaran matematika; Teorema Pythagoras*

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INTRODUCTION

Critical thinking is an essential 21st-century competency that reflects students' ability to analyze, evaluate, and reason logically (Facione, 1990; Ho & Le, 2026). In mathematics education, it underpins conceptual understanding, problem-solving, and decision-making (Kusumawati et al., 2022). However, mathematics instruction in many schools remains teacher-centered, emphasizing computation over reasoning (Thanheiser & Melhuish, 2023; Woods & Copur-Gencturk, 2024). Consequently, students often struggle to understand concepts and develop reflective thinking, particularly on topics such as the Pythagorean Theorem, which is a foundational prerequisite for geometry (Malikah et al., 2022; Toraman et al., 2020).

Interviews at SMPN 3 Lingsar revealed that most eighth-grade students face difficulties understanding the Pythagorean Theorem, preferring multiple-choice problems and avoiding reasoning-based tasks. This situation suggests limited reflective practice and insufficient mathematical argumentation. Teachers also reported challenges in maintaining student engagement and explaining abstract ideas without visual aids. These findings highlight the need for innovative, student-centered pedagogies that promote both engagement and higher-order thinking.

One promising alternative is the Mathematical Habits of Mind (MHM) approach, which develops mathematical ways of thinking characterized by precision, reflection, and persistence (Handayani, 2015; Rastuti & Setyaningrum, 2024; Star et al., 2009). To enhance its visual component, GeoGebra serves as a dynamic medium integrating geometric and algebraic representations (Alzate et al., 2023; Wahyuni et al., 2023). Visual tools are essential for helping students grasp abstract spatial relationships that are otherwise difficult to explain verbally. Integrating MHM with GeoGebra may thus create learning that is critical, enjoyable, and conceptually rich (Aizikovitsh-Udi & Radakovic, 2012; Romero Albaladejo & García López, 2024).

Empirical evidence shows that Indonesian students' critical thinking remains low, as reflected in TIMSS results that consistently place them at the lower levels on higher-order cognitive tasks (Syafitri et al., 2021). Observations at SMPN 3 Lingsar confirm this pattern: mathematics learning is still dominated by lecturing, with students remaining passive and showing minimal reasoning ability. MHM, derived from Costa and Kallick's framework of intelligent habits, promotes reflective, flexible, and evidence-based thinking (Canogullari & Radmehr, 2025; Handayani, 2015), encouraging students to question, evaluate, and communicate ideas clearly (Habibi et al., 2020; Yandari et al., 2019). Prior studies demonstrate its effectiveness in fostering systematic problem-solving (Aizikovitsh-Udi & Radakovic, 2012; Altakhyneh & Aburiash, 2017; Tashtoush et al., 2022). Meanwhile, GeoGebra enhances comprehension and engagement through dynamic visualization (Gurmu et al., 2024; Nur, 2017; Wahyuni et al., 2023).

Most previous studies have examined MHM and GeoGebra separately (Diva & Purwaningrum, 2023; Romero Albaladejo & García López, 2024). Yet, combining both could synergize metacognitive strategies and visual reasoning to promote higher-order thinking. Limited

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empirical research has explored this integration, particularly in junior high school geometry contexts (Luritawaty et al., 2022; Nenohai et al., 2021; Pamungkas & Nugroho, 2020). Moreover, few studies explicitly link the dimensions of critical thinking interpretation, analysis, evaluation, and inference with MHM components during visual, technology-supported instruction.

Hence, this study offers novelty by integrating MHM strategies with GeoGebra to improve students' critical thinking skills in learning the Pythagorean Theorem. It also provides conceptual contributions by mapping the relationship between critical thinking indicators and MHM components within a technology-enhanced mathematics learning environment. The research question is: Is there a significant difference in students' critical thinking skills between those taught through the MHM approach assisted by GeoGebra and those taught through conventional instruction?

METHODS

This research was conducted within the framework of a quantitative methodology, utilizing a quasi-experimental strategy characterized by applying a Nonequivalent Control Group structure. This design involved two non-randomly selected groups: an experimental group that received instruction using the MHM approach assisted by GeoGebra, and a control group taught using conventional methods. The structure of the design consisted of a pretest (O1 and O3), a treatment phase (X1 and X2), and a posttest (O2 and O4). This design was selected based on practical limitations in conducting fully randomized experiments in school settings, allowing for an objective comparison between groups.

The study was conducted at SMPN 3 Lingsar, West Lombok Regency, with the research subjects being Grade VIII students in the 2024/2025 academic year. The population included all eighth-grade students, divided into four classes, from which two classes were selected as samples using purposive sampling based on initial ability equivalence class VIII. Class VIII-B was designated as the experimental group, and Class VIII-A as the control group, with each class consisting of 27 students. The study was carried out over five sessions in March 2025, including one pretest session, three treatment sessions, and one posttest session.

The primary instrument used in this study was a critical thinking skills test in the form of open-ended questions, administered before and after the intervention (pretest and posttest) to measure changes in students' abilities. In addition, student worksheets (LKS) were used as supporting instruments to observe learning activities during the instructional process. Observation sheets for teachers and students were also employed to assess the implementation of the learning process according to the planned scenarios. Data collection techniques included written tests, documentation of student activities, and direct classroom observation. The construction of all research instruments was grounded in critical thinking dimensions, encompassing interpretation, analytical processing, evaluative judgment, inferential reasoning, and the ability to formulate well-founded conclusions.

Instrument validity was tested through content analysis using expert judgment and the Gregory method to

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ensure that the test items covered all dimensions of critical thinking to be measured. Internal consistency among items was examined using inter-item correlation via SPSS version 25, which showed that most items had moderate to strong positive correlations (ranging from r = 0.41 to r = 0.72). Reliability testing was performed using Cronbach's Alpha to evaluate the internal consistency of the instrument. The result yielded a coefficient of α = 0.84, indicating that the instrument had high reliability and was suitable for collecting primary data. The instrument trial was conducted on a group of students outside the research sample.

The study's data were subjected to descriptive and inferential statistical analyses. The descriptive component aimed to identify central tendency and variability measures, including the mean, standard deviation, and maximum and minimum values derived from the pretest and posttest outcomes. Classical assumption tests were conducted, including normality testing (Shapiro-Wilk) and homogeneity of variance testing (Levene's Test), to determine the appropriateness of parametric tests. Subsequently, an independent samples t-test was performed to identify significant differences between the experimental and control groups.

Additionally, the N-Gain calculation was used to measure the improvement in students' critical thinking skills. The formula employed was:

$$\text{N} - \text{Gain} = \frac{\text{Posttest Score} - \text{Pretest Score}}{\text{Maximum Score} - \text{Pretest Score}} \quad \ldots(1)$$

The interpretation of N-Gain values in this study followed the criteria proposed by Hake (1999). An N-Gain score greater than or equal to 0.70 was categorized as indicating high improvement, a score between 0.30 and 0.69 was categorized as moderate improvement, while a score below 0.30 was categorized as low improvement. All data analysis procedures, including the N-Gain calculation and subsequent statistical tests, were carried out using SPSS version 25.

RESULTS AND DISCUSSION

Presentation of Pretest Data

The pretest was administered to assess students' initial critical thinking skills before implementing different instructional treatments in each group. Class VIII-A was the experimental group, while Class VIII-B, consisting of 27 students, was the control group. The pretest consisted of open-ended questions measuring five critical thinking indicators: interpretation, analysis, evaluation, inference, and conclusion drawing. The results of the descriptive statistical analysis of the pretest scores for both groups are presented in Table 1.

Table 1. Pretest Results of Students' Critical Thinking Skills in the Experimental and Control Groups

Statistical Data	Experimental Group	Control Group
Lowest Score	25	25
Highest Score	78	80
Mean	49.44	49.33
Median	48	48
Standard Deviation	13.00	13.13
Number of Students	27	27

As shown in Table 1, the mean pretest score in the experimental group was 49.44, while the control group scored 49.33. The minimal difference in means (0.11) indicates that both groups' initial critical thinking abilities were relatively equivalent. This is further supported by the similar standard deviation values, which suggest comparable score distributions in both classes.

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It is worth noting that the relatively high pretest scores in both groups (78 and 80) may be attributed to students' partial prior exposure to the Pythagorean Theorem, either through earlier informal learning, prior curriculum content in Grade VII, or extracurricular study. Additionally, the pretest items were designed to assess foundational knowledge relevant to the topic, such as understanding of squared numbers, basic properties of right-angled triangles, and logical reasoning—skills that students may already possess before formal instruction on the theorem itself.

The Shapiro-Wilk test for normality showed that the pretest scores were normally distributed, with significance values of $p = 0.823$ (experimental group) and $p = 0.774$ (control group), greater than 0.05. Levene's Test for homogeneity of variance yielded a significance level of $p = 0.771$ (greater than the threshold of 0.05), indicating that the variances in the two groups were homogeneous. Furthermore, an independent samples t-test was conducted to confirm the equality of initial abilities. The analysis revealed a significance value of Sig. (2-tailed) = 0.824, which is greater than 0.05. This indicates no statistically significant difference between the experimental and control groups before the intervention.

Therefore, it can be concluded that both groups were in an equivalent baseline condition, making them suitable for objective comparison in the subsequent posttest analysis.

Presentation of Posttest Data

The posttest was administered to both groups following the completion of the instructional process to assess students' final critical thinking abilities. The experimental group received instruction through the MHM approach assisted by GeoGebra, while the control group received instruction through traditional teaching methods. The instrument used was identical to the pretests, covering five indicators of critical thinking skills. The results of the descriptive statistical analysis of the posttest scores are presented in Table 2.

Table 2. Posttest Results of Students' Critical Thinking Skills in the Experimental and Control Groups

Statistical Data	Experimental Group	Control Group
Lowest Score	60	52
Highest Score	95	88
Mean	82	65
Median	80	64
Standard Deviation	8.66	9.16
Number of Students	27	27

As presented in Table 2, there is a notable disparity in the average scores obtained by the experimental group, which achieved a mean of 82, in contrast to the control group, which recorded a mean of 65, with a gap of 17 points. This difference suggests a potentially significant effect of the applied intervention, namely the MHM approach supported by GeoGebra.

The normality test using the Shapiro-Wilk method showed that the posttest scores were normally distributed in both groups, with significance values of $p = 0.008$ (experimental group) and $p = 0.049$ (control group), which are still considered acceptable for small sample sizes. The homogeneity of variance test with Levene's Test also indicated that the variances of both groups were consistent ($p = 0.455 > 0.05$).

An independent samples t-test was conducted to examine whether a statistically meaningful difference

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existed in students' critical thinking performance. The results indicated a two-tailed significance level of 0.000, which is well below the conventional alpha criterion of 0.05, thereby confirming the presence of a significant effect. This outcome confirms the existence of a meaningful statistical difference between the experimental and control groups. Consequently, the pedagogical implementation of the MHM approach, supported by GeoGebra, demonstrated superior effectiveness in fostering students' critical thinking compared to traditional instructionnal strategies.

Improvement in Critical Thinking Skills

To gain deeper insights into the effectiveness of the instructional intervention, an analysis of the improvement in students' critical thinking skills was conducted using the *Normalized Gain* (N-Gain) formula. This formula measures the difference between posttest and pretest scores, normalized against the maximum possible score. The average N-Gain scores for each group are presented in Table 3.

Table 3. Average N-Gain Scores for Students' Critical Thinking Skills

Group	Average N-Gain	Improvement Category
Experimental Group	0.72	High
Control Group	0.43	Moderate

Based on Table 3, the experimental group's average N-Gain score was 0.72, which falls into the high category. In contrast, the control group achieved an average N-Gain score of 0.43, which is categorized as *moderate*. This difference indicates that the MHM approach assisted by GeoGebra improved students' critical thinking skills more than the conventional teaching method.

To determine whether this improvement was statistically significant, an independent samples t-test was conducted on students' final test scores as a proxy for normalized gain (N-Gain), given the equivalence of pretest means across groups. The results showed a significant difference in favor of the experimental group ($M = 81.67$, $SD = 8.09$) compared to the control group ($M = 65.07$, $SD = 9.30$), with $t(52) = 6.995$, $p = 0.000$.

Additionally, the effect size was calculated using Cohen's $d = 1.90$, which indicates a very large effect. This result demonstrates not only statistical significance but also practical importance, suggesting that the instructional strategy involving MHM and GeoGebra had a substantial impact on students' development of critical thinking skills.

These findings affirm that implementing the MHM-based instructional strategy impacted the final achievement scores and enhanced students' critical thinking processes. Students in the experimental group attained higher scores and demonstrated greater development from their initial performance. This reflects the effectiveness of an approach that encourages students to engage in reflective, systematic, and collaborative thinking, supported by the dynamic visualizations offered through GeoGebra.

Supporting Data

This study also involved classroom observations conducted in the experimental group to complement and strengthen the quantitative findings. The observations aimed to assess the instructional process's implementation level based on the steps outlined in the

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MHM approach assisted by GeoGebra. The instruments used included teacher and student observation sheets, which documented the instructional activities from the beginning to the end of each session and the extent of student engagement in participating actively and reflectively.

The observed activities covered three main instructional components: the preliminary activity, the core activity, and the closing activity. During the initial phase, the focus was on how the teacher motivated and prepared the students. The core activity included problem orientation, individual and group exploration, and problem-solving development through the MHM approach integrated with GeoGebra. Student activities observed included asking questions, responding to questions, engaging in discussions, experimenting with solution strategies, and participating in visual manipulations using GeoGebra. In the closing phase, observations focused on evaluation, reflection, and the students' construction of conclusions regarding the lesson content.

Table 4. Percentage of Achievement in Teacher Activities in the Experimental Class

Instructional Activity	Session 1	Session 2	Session 3
Preliminary: Opening, Motivation	100%	100%	100%
Core Activity: Problem Orientation, Exploration, Discussion	100%	100%	100%
Closing: Evaluation, Reflection	100%	100%	100%
Overall Average	**100%**	**100%**	**100%**

Based on the observation results in Table 4, all teacher activities in the experimental class were implemented successfully, with a 100% achievement rate in every session. This indicates that the learning scenario based on the MHM approach integrated with Geo-Gebra was implemented consistently and systematically. The teacher effec-tively guided students in exploring the Pythagorean Theorem through structured group activities and dynamic visual manipulations. Further-more, the reflection and conclusion-building phases demonstrated that the teacher acted not merely as a transmitter of knowledge but also as a facilitator of critical thinking. These activities reflect the successful implementation of a learning model that supports the development of higher-order thinking skills.

In addition to teacher observations, student activities were also observed to assess their engagement during the instructional process. The findings showed that students in the experimental class responded actively and enthusiastically throughout all phases of instruction. They engaged in group discussions, actively posed and answered questions, and independently explored the concept of the Pythagorean Theorem using GeoGebra's visual features. These activities aligned with several MHM indicators such as "thinking inter-dependently," "questioning and posing problems," and "thinking flexibly." With the support of GeoGebra, students could concretely visualize the relationships between the sides of a triangle and perform manipulations that stimulated reflective and systematic thinking. These activities indicated that students were not merely following instructions, but were actively constructing conceptual understanding.

Based on the observation of both teacher and student activities, it can be concluded that the instructional process

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using the MHM approach assisted by GeoGebra was successfully implemented in the experimental class. All phases of instruction proceeded as planned, with high levels of engagement from both the teacher and students. These findings further support the quantitative results that significantly improved students' critical thinking skills. Thus, implementing this approach was statistically effective and pedagogically sound in classroom practice.

Interpretation of Posttest and N-Gain Results

The posttest results showed a notable difference in critical thinking skills between the students in the experimental group and those in the control group. Students who received instruction through the MHM approach, supported by GeoGebra, achieved an average score of 82. At the same time, those in the control group, who were taught using conventional methods, attained an average score of only 65. This difference was confirmed by the independent samples t-test results, which yielded a significance value of 0.000 < 0.05, indicating that the instructional treatment had a statistically significant effect on improving students' critical thinking skills.

Moreover, the analysis of learning gains using the Normalized Gain (N-Gain) formula showed that the experimental group experienced a high level of improvement (N-Gain = 0.72). In contrast, the control group demonstrated only a moderate increase (N-Gain = 0.43). These findings suggest that the MHM approach supported by GeoGebra had a statistically significant impact and a meaningful pedagogical effect on developing students' critical thinking abilities. This result aligns with the findings of Yandari *et al.* (2019), who stated that the MHM strategy fosters reflective thinking patterns and deep intellectual habits, particularly in problem-based mathematics instruction.

The MHM approach offers a structured framework for exploration by cultivating reflective thinking habits, encouraging questioning, evaluating arguments, and drawing conclusions based on evidence—activities closely aligned with established indicators of critical thinking (Facione, 1990; Romero Albaladejo & García López, 2024). Integrating GeoGebra gives students an interactive platform to visualize and test mathematical hypotheses, enhancing their engagement and deepening their conceptual understanding of the Pythagorean Theorem (Alzate et al., 2023; Nur, 2017). This combination of approach and technological tool enables a learning process that is not merely outcome-oriented but also promotes critical and constructive thinking throughout the instructional experience.

Relationship Between Results and Critical Thinking Indicators

The notable increase in posttest scores among students in the experimental group can be better understood by looking at how these scores relate to the five key critical thinking skills: interpretation, analysis, evaluation, inference, and concluding (Syaiful et al., 2022). The MHM approach systematically trains students to develop these aspects through reflective, argument-based, and exploratory mathematical thinking practices.

For instance, the interpretation indicator is fostered through activities involving the visual collection of data using GeoGebra, aligning with the

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MHM principle of *gathering data through all senses* (Habibi et al., 2020). Students can observe the relationships among the sides of a triangle and derive meaning from interactive visualizations. The analysis indicator is also enhanced through *questioning and posing problems*, encouraging students to deconstruct problem structures, identify patterns, and compare solution strategies (Luritawaty et al., 2022). These activities stimulate cognitive flexibility, essential for understanding multiple representations of the Pythagorean Theorem.

In terms of evaluation and inference, the MHM approach prompts students to examine the logic of their solutions and make conjectures based on jointly constructed mathematical evidence, achieved through discussion and manipulating visual objects in GeoGebra. This process corresponds to the MHM characteristics of *thinking interdependently* and *striving for accuracy* (Canogullari & Radmehr, 2025). Regarding the conclusion drawing indicator, MHM-based instruction allows students to formulate generalizations from their exploratory processes, supporting the thinking habits, *communicating with clarity and precision,* and *persisting* in the face of complex problems (Handayani, 2015).

These conceptual connections were also evident in the students' responses. For example, one of the posttest items (Item 3) asked: *"A right triangle has legs of 7 cm and 24 cm. Student A claims the hypotenuse is 25 cm, while Student B says it is 23 cm. Who is correct, and why?"*.

A typical response from the control group was: *"Student A is correct because $7^2 + 24^2 = 25^2$"*. Meanwhile, a student from the experimental group responded: *"Student A is correct because $7^2 = 49$ and $24^2 = 576$. Their sum is 625, and since $25^2 = 625$, the triangle satisfies the Pythagorean Theorem. So it must be a right triangle"*.

The latter response shows clearer logical justification and deeper processing, demonstrating the student's ability to interpret data, analyze components of the problem, and draw a conclusion with clarity—key dimensions of critical thinking. The use of GeoGebra in this context enabled students to visualize the relationship and verify the claim interactively, strengthening their reasoning process.

Thus, implementing the MHM approach assisted by GeoGebra increased students' numerical scores and cultivated thinking processes aligned with critical thinking skill standards. Each instructional activity was consistently designed to activate these indicators through meaningful, collaborative, and technology-enhanced learning experiences.

The Role of GeoGebra in Instruction

GeoGebra is pivotal in supporting interactive, visual, and exploratory mathematics instruction. In this study, GeoGebra was utilized to help students concretely understand the Pythagorean Theorem through visual simulations. By manipulating the vertices of a right triangle, students could directly observe changes in side lengths and their relationships by the formula $a^2 + b^2 = c^2$. This process reinforced conceptual understanding and enabled students to construct mathematical arguments based on visual evidence.

As a dynamic instructional medium, GeoGebra allows students to explore geometric, algebraic, and numerical representations that facilitate

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reflective and flexible thinking. This aligns with the findings of Wahyuni et al. (2023) and Alzate *et al.* (2023), who argue that GeoGebra enhances students' comprehension of abstract mathematical concepts through easily manipulable visualizations. Interactive features such as dragging, tracing, and animation provide multisensory learning experiences that enrich students' engagement and understanding.

GeoGebra also supports the development of several categories within the MHM, such as *gathering data through all senses*, *creating, imagining, innovating*, and *applying past knowledge to new situations* (Habibi et al., 2020; Romero Albaladejo & García López, 2024). In instructional activities, students are encouraged to focus on the final result and formulate and verify hypotheses through visual experimentation. This approach fosters active student engagement and enables them to build understanding through *learning by doing*.

Thus, GeoGebra serves not merely as a visual supplement but as a cognitive tool that enhances students' thinking processes in learning mathematical concepts. When combined with instructional strategies such as MHM, GeoGebra reinforces conceptual foundations and critical thinking processes that are essential for meaningful 21st-century mathematics learning.

Support from Theory and Previous Research

The findings of this study align with a growing body of previous research demonstrating that both the MHM approach and the use of GeoGebra—independently or in combination—can enhance students' critical thinking skills. For instance, Bülbül & Güler (2021) concluded that MHM-based instructional strategies supported by multimedia significantly improved students' mathematical critical thinking, particularly in problem-solving contexts. This approach trains students to habitually ask questions, think systematically, and express arguments with sound logic.

Similar findings were reported by Yandari *et al.* (2019), who observed that implementing MHM as part of Higher Order Thinking Skills (HOTS)-oriented instruction fostered students' active responses to mathematical problems and encouraged the development of reflective thinking dispositions. Meanwhile, Diva and Purwaningrum (2023) demonstrated that integrating MHM with technologies such as Wolfram Alpha significantly enhanced students' analytical and evaluative abilities in solving problems related to two-dimensional geometry. The present study builds on this evidence by showing that GeoGebra, with its strong visualization and interactivity features, yields similar if not more profound effects, particularly in teaching geometric concepts such as the Pythagorean Theorem.

Furthermore, this study complements the findings of Nurhayati et al. (2021) and Alzate *et al.* (2023), highlighting GeoGebra's potential to improve students' understanding and engagement through dynamic features that facilitate visual and experiential learning. The present research contributes additional insight by integrating GeoGebra directly into the MHM instructional approach—a combination that has been relatively underexplored at the junior secondary school level. This integrated model has been proven to significantly promote all

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five aspects of critical thinking, from interpretation to conclusion drawing.

Therefore, this study's results support prior research's theoretical and empirical foundations and broaden the understanding of the effectiveness of integrating MHM and GeoGebra in 21st-century mathematics instruction, emphasizing HOTS and reflective thinking.

Contributing Factors to Success

The successful implementation of the MHM approach supported by GeoGebra in enhancing students' critical thinking skills can be attributed to several contributing factors identified during the research process. One of the key factors was the teacher's systematic instructional planning and consistent execution of the lesson scenarios, as evidenced by the 100% implementation rate observed across all sessions. The teacher effectively managed the classroom, facilitated gradual conceptual exploration, and provided feedback encouraging students to reflect on their thinking processes.

In addition, students' readiness to actively engage in learning activities played a critical role. The MHM approach created opportunities for students to engage in discussion, exploration, and argumentation—experiences they rarely encountered in conventional classrooms. With the support of GeoGebra, students had access to visual tools that enhanced their understanding and stimulated curiosity about mathematical patterns and concepts. GeoGebra also accommodated students with visual or kinesthetic learning preferences, enabling them to absorb information more effectively by directly manipulating geometric objects.

A conducive learning environment further supported the success of the instructional process. This study was conducted in a classroom familiar with digital tools and structured student worksheets (LKS), which helped maintain students' focus on activities designed according to MHM principles. Moreover, students experienced meaningful learning, as they sought correct answers and engaged in reflective and systematic thinking processes.

Through the combination of professional teacher facilitation, active student participation, interactive media support, and a supportive learning environment, MHM-based instruction assisted by GeoGebra was effectively implemented. It significantly impacted the development of students' critical thinking skills.

CONCLUSIONS AND SUGGESTIONS

This study concludes that the Mathematical Habits of Mind (MHM) approach assisted by GeoGebra effectively improves the critical thinking skills of Grade VIII students at SMPN 3 Lingsar in learning the Pythagorean Theorem. The posttest results showed a significant difference between the experimental and control groups, with the experimental group achieving higher average scores and a large effect size. Students taught with MHM and GeoGebra also demonstrated greater engagement and reflective learning habits compared to those taught conventionally. These findings confirm that integrating strategic mathematical thinking with visual digital tools can enhance learning outcomes and foster 21st-century competencies.

Based on these results, it is suggested that mathematics teachers

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apply the MHM approach with GeoGebra, especially for geometry and other abstract topics requiring visualization. Schools and policymakers should support this effort by facilitating training and resources for technology-based learning. For future research, the integration of MHM with GeoGebra can be investigated in other mathematical domains, across different grade levels, or in combination with alternative pedagogical models such as project-based or inquiry-based learning to broaden its applicability and effectiveness.

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