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The Effectiveness Of Realistic Mathematics Education (RME) Assisted By GeoGebra On Students' Mathematical Literacy

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Abstract

This research investigates the efficacy of implementing a Realistic Mathematics Education (RME) methodology enhanced by the integration of GeoGebra technology to strengthen learners' mathematical literacy competencies. This research employed quantitative methodological principles, utilising a pre-experimental one-group pre- and post-assessment design. The study venue was a junior secondary educational facility in Yogyakarta, where 32 Year 8 students participated, selected through cluster-based random sampling protocols. Data were collected using pretest and posttest instruments, which were validated through content validity and reliability testing. The results showed a significant improvement in students' mathematical literacy, with an average pretest score of 36.93 and a posttest score of 82.38, and an N-Gain score of 0.72, categorised as high. Paired sample t-test analysis indicated a significant effect of the RME approach with GeoGebra ($p < .001$). The learning process involved contextual problem-solving, mathematical modelling with GeoGebra, and the application of the Pythagorean Theorem. The findings demonstrate that integrating RME and GeoGebra effectively enhances mathematical literacy by supporting visualisation, conceptual understanding, and contextual reasoning. This study recommends the broader implementation of RME with technological support and suggests further research using stronger experimental designs to explore additional learning outcomes.

Keywords: *GeoGebra; Mathematical Literacy; Realistic Mathematics Education*

Introduction

Mathematics serves as a fundamental catalyst in developing diverse competencies essential for the 21st century. Such competencies encompass analytical reasoning, innovative thinking, investigative and exploratory abilities, autonomous learning, proactive engagement and perseverance, information processing, holistic reasoning, interpersonal communication, and metacognitive awareness (OECD, 2023). One mathematical competency that underpins these 21st-century skills is mathematical literacy (Rizki & Priatna 2019). Mathematical literacy describes the capacity for quantitative thinking that allows individuals to generate, execute, and interpret mathematical approaches when confronting challenges in diverse practical circumstances (OECD, 2023). Such proficiency supports people in understanding the mathematical underpinnings of world systems and in making informed assessments and choices that define responsible, engaged, and analytical societal participants (OECD, 2013, 2019). Research conducted by Kusuma et al. (2022) indicates that critical thinking has a significant influence on the achievement of mathematical literacy indicators. Similarly, Sitopu et al. (2024) emphasize the importance of mathematical literacy across various dimensions, including logical reasoning, its relevance to 21st-century skills, and its contribution to enhancing global competitiveness.

The global emphasis on mathematical literacy as a core skill essential for individual development has prompted the Indonesian government to implement the Minimum Competency Assessment (Asesmen Kompetensi Minimum, AKM). AKM is an assessment program designed to measure students' fundamental competencies, particularly in reading literacy and mathematical literacy (also known as numeracy). This program focuses on reasoning skills, logical and systematic thinking, as well as the critical use of information and knowledge in solving real-life problems. Through AKM, students are encouraged to enhance their literacy by solving problems across a variety of real-world contexts (Wijaya & Dewayani, 2021). A study conducted by Aljabar, Gimin, and Primahardani (2024) highlighted the importance of integrating literacy and numeracy tools into the curriculum and daily instruction. The integration of AKM is anticipated to boost pupils' mathematical literacy performance (Aljabar, Gimin, & Primahardani, 2024).

Despite its recognised importance, students' mathematical literacy remains low. Multiple research endeavours have confirmed that pupils' quantitative reasoning skills exhibit continued developmental deficiencies (Masfufah & Afriansyah, 2021; Vebrian et al., 2021; Fitriani & Salsinha, 2021). Kusuma et al. (2022) found that students had not yet achieved all the established indicators of mathematical literacy. Similarly, Ridho (2023) revealed that students struggle to translate mathematical ideas embedded in problems into visual representations, which in turn hinders their ability to solve the given problems.

The implementation of fitting educational approaches functions as a key element in developing pupils' mathematical literacy proficiency. Realistic Mathematics Education (RME) is a learning theory that emphasises the use of practical contexts throughout teaching methodologies. According to Freudenthal (1973), mathematics should be seen as a process rather than a finished product to be delivered to students. Hans Freudenthal (2002) further explained that in RME, students begin learning through non-mathematical real-life situations and gradually develop mathematical thinking through a process known as horizontal mathematising (from real-world contexts to mathematical models) and vertical mathematising (from informal models to formal models and eventually to general mathematical symbols). Research suggests that mathematics teachers should adopt instructional materials based on the RME approach (Ulandari, Amry, & Saragih, 2019). This recommendation is supported by findings from Palinussa and Tamalene (2021), which indicate an improvement in students' mathematics learning outcomes through RME. Similarly, and Turmudi (2024) found that RME has a substantial and productive influence on pupils' quantitative reasoning skills.

Beyond choosing suitable pedagogical methodologies, the incorporation of technological resources substantially impacts educational processes. GeoGebra functions as an effective instrument for supporting learners in developing mathematical understanding. GeoGebra represents open-source, multi-platform dynamic mathematical software created to enhance mathematics education through interactive mathematical object representation, thus promoting the visualization of theoretical concepts (Hall & Lingefjard, 2017). According to Bu and Schoen (2015), GeoGebra serves as a conceptual tool that helps students connect real-world situations to mathematical ideas. Thus, GeoGebra can be regarded not only as a platform for interactive visualization and construction of mathematical concepts but also as a conceptual bridge between real-life contexts and mathematical reasoning. Research by Tamam and Dasari (2021) emphasised the benefits of using GeoGebra in mathematics education, including enhancing the quality of instruction, particularly in exploring, visualising, and constructing mathematical concepts. Moreover, it helps improve students' mathematical skills such as proof, reasoning, and problem-solving abilities. This is supported by findings from Suwito (2022), which showed that GeoGebra is effective in enhancing students' mathematical literacy.

Previous studies have integrated the RME approach with GeoGebra. Research conducted by Antasari et al. (2023) Demonstrated that the RME approach supported by GeoGebra can enhance students' learning activities and academic performance. This finding is supported by N. Fitriani, Hidayah, dan Nurfauziah (2021), who reported that RME assisted by GeoGebra had a significant effect on both learning outcomes and students' abstraction abilities. Similarly, a study by Putri Solihat, Roesdiana, dan Haerudin (2022) indicated that students experiencing RME instruction augmented by GeoGebra displayed superior achievements compared to those receiving conventional educational delivery without GeoGebra implementation in mathematical problem-solving competence.

Based on the discussion as mentioned above, both the RME approach and the use of GeoGebra show promising potential for enhancing students' mathematical abilities. To address the existing gap, this study implements the RME approach supported by GeoGebra to improve students' mathematical literacy. The findings of this research are expected to serve as a valuable reference for educational practitioners and policymakers in designing curricula and instructional strategies that align with advancements in science and technology.

Methods

This research applied quantitative investigative principles through pre-experimental design implementation, notably employing a single-group pre- and post-assessment arrangement within one class unit. The study was conducted at a middle school facility in Yogyakarta during October 2024. All eighth-grade students constituted the research population, categorized into four separate classroom divisions. Cluster-based random selection methods were employed, yielding 32 student participants for the study. The research methodology is demonstrated in Table 1 below.

Table 1. Research Design

Pretest	Treatment	Posttets
O_1	X	O_2

The data collection technique used in this study was testing. The test instruments consisted of a pretest and a posttest. The pretest was administered to assess students' initial abilities, followed by the implementation of the RME approach supported by GeoGebra as the treatment. The posttest was then conducted to evaluate students' abilities after the treatment. The test item specification (blueprint) is presented in Table 2 below.

Table 2. Test Blueprint of Mathematical Literacy Skills Instrument

No.	Componen	Indicator	tem Type	Item Number
1.	*Formulate*	Identifying relevant information	Essay	1a, 2a, 3a
		Constructing a mathematical model		1b, 2b, 3b
2.	*Employ*	Manipulating mathematical information, applying concepts, facts, procedures, and reasoning to solve problems		1c, 2c, 3c
3.	*Interpret*	Providing arguments based on interpretations		1d, 2d, 3d

Adapted from the PISA mathematical literacy framework; all items use occupational contexts.
Source: (OECD, 2023b)

Before implementation, the research tools were assessed for validity and reliability properties. The validity approach adopted within this investigation comprised content validity. The instrument was validated by three experts using a validity index based on Aiken's formula (Aiken, 1980; 1985; Kumaidi, 2014 in Retnawati, 2016). According to Aiken's V table, with three raters and a maximum rating score of 5, the item is considered valid if the V index is greater than or equal to 0.92. The validity results of each pretest and posttest item in this study showed a V index greater than 0.92, indicating that the test items were appropriate for measuring students' mathematical literacy.

Subsequently, the reliability characteristics of the instrument were analyzed through Cronbach's Alpha estimation procedures. The reliability criterion was set at 0.65, meaning that if the reliability coefficient (r) is at least 0.65, the instrument is considered to meet the minimum acceptable level. The reliability results of the test instruments used in this study are presented in Table 3 below.

Table 3. Reliability of Pretest and Posttest of Mathematical Literacy Skills

Test	**Statistic**	**Criteria**	**Decision**
Pretest	0,65	0,65	Reliable
Posttest	0,65	0,65	Reliable

Adapted from DeVellis (2017)

Once instrument validity and reliability were established, data collection was conducted through the administration of pretests and posttests. The statistical analysis methods employed in this study included both descriptive and inferential analytical procedures. Descriptive evaluation focused on data related to the educational process delivery and pupils' mathematical literacy proficiency. Inferential evaluation was employed for hypothesis testing through the JASP program. Before hypothesis examination, a foundational test particularly, distribution normality verification was conducted. The decision standard was based on the probability value and the significance parameter (α), with a normal distribution confirmed when the probability value exceeded α (0.05). Once the assumption was met, hypothesis testing was performed.

In this study, the hypothesis was tested using a paired sample t-test. With a significance level of α = 0.05, the decision rule is that if p-value < α (0.05), then the mean pretest score is significantly lower than the mean posttest score. Then, to assess the effectiveness of the learning, the n-Gain <g> was used with the following criteria.

Table 4. n-Gain Score Classification

n-Gain Category	**<g> Value Range**	**Description**
High	<g> > 0.7	Very high improvement
Medium	0.3 <g> ≤ 0.7	Moderate improvement
Low	<g> ≤ 0.3	Low improvement

Source: Hake (1998)

The n-Gain score was calculated using the following equation:

$$n - Gain = \frac{Posttest\ score - Pretest\ Score}{Maximum\ Score - Pretest\ Score}$$

Results and Discussion

Results

The results of the study indicate that students' mathematical literacy skills improved after participating in instruction using the RME approach supported by GeoGebra. A descriptive summary of students' mathematical literacy performance is presented in Table 5 below.

Table 5. Descriptive Statistics of Students' Mathematical Literacy Skills

Description	**Experimental Group Scores**	
	Pretest	**Posttest**
Mean Score	8,86	19,77
Mean Percentage Score	36,93	82,38
Standard Deviation	3,48	3,72
Minimum Score	0,00	45,83
Maximum Score	58,33	100

The data were obtained using JASP software.

As shown in Table 5, the average percentage of students' initial mathematical literacy ability was 36.93%. After the intervention, the average score increased to 82.38%. The percentage improvement in scores between the pretest and posttest for each indicator of mathematical literacy is presented in Table 6 below.

Table 6. Percentage Improvement of Mathematical Literacy Ability by Indicator

Process	**Indicator**	**Mean Score Percentage**		**Improvement**
		Pretest	**Posttest**	
Formulate	Identifying relevant information	48,48	88,63	40,14
	Constructing a mathematical model		78,02	46,97
Employ	Manipulating mathematical information, applying concepts, facts, procedures, and reasoning to solve problems	36,36	82,31	45,95
Interpret	Providing arguments based on interpretations	27,27	78,78	51,51

The data were obtained using Microsoft Excel software.

Based on Table 6, improvements were observed across all indicators of mathematical literacy from the pretest to the posttest. The highest increase was found in the fourth indicator, with a gain of 51.51%, followed by the second indicator at 46.97%, the third at 45.95%, and the first at 40.14%. To evaluate the scope of intervention effects on students' quantitative literacy capabilities, hypothesis testing was undertaken. Before hypothesis assessment, a preliminary assumption test was implemented. Normality checking was conducted using the Shapiro-Wilk procedure with a significance criterion of 0.05. The normality analysis results are depicted in Table 7.

Table 7. Normality Test Result

Category	Statistic	Sig. Level	Decision
Pretest	0.204	0.05	Normal
Posttest	0.080	0.05	Normal

The data were obtained using JASP software.

Table 7 reveals that the significance value for the pretest normality evaluation was 0.24 (exceeding the 0.05 threshold), and the posttest produced a significance value of 0.80 (beyond 0.05). Therefore, it can be inferred that both pretest and posttest scores for pupils' mathematical literacy abilities demonstrate normal distribution properties. As the normality condition was met, hypothesis validation could be executed. The hypothesis was investigated through paired sample t-test procedures. The hypothesis testing findings are illustrated in Table 8 below.

Table 8. Paired Sample t-Test Result

Category	Mean	Calculated *t*	df	−*t* table	*p-value*	Decision
Pretest Posttest	36.932 82.386	-12.260	21	- 1.72	<0.001	H_0 rejected

The data were obtained using JASP software

According to Table 8, the computed t-statistic reached -12.260, falling below the critical t-threshold of -1.72, while the probability value was < .001, remaining under the alpha level (α) of 0.05. Consequently, the null hypothesis (H_0) is rejected. This demonstrates that teaching through RME methodology enhanced by GeoGebra produces a substantial impact on learners' mathematical literacy competencies. Following this, an N-Gain assessment was conducted to evaluate the effectiveness of the learning intervention. The N-Gain evaluation outcomes are displayed in Table 9 below.

Table 9. n-Gain Calculation Results

Mean Pretest Score	Mean Posttest Score	n-Gain	Interpretation
37	82	0.72	High

The gain interpretation was made based on the criteria presented in Table 4

Based on Table 9, this study revealed that the RME approach supported by GeoGebra has a significant influence on students’ mathematical literacy. Moreover, the use of RME with GeoGebra was found to be effective in improving students’ mathematical literacy skills.

Discussion

The research findings establish that adopting Realistic Mathematics Education (RME) supplemented by GeoGebra successfully facilitates the development of learners' mathematical literacy, reaching high proficiency categories. The initial assessment mean was 36.932, and the final assessment mean reached 82.386, resulting in an N-Gain index of 0.72. The fusion of RME instructional strategy and interactive technological resources, notably GeoGebra, has demonstrated considerable enhancement of pupils' mathematical literacy capabilities.

The employment of Realistic Mathematics Education (RME) supported by GeoGebra commenced through contextual situation analysis. The investigator introduced practical problems concerning fundamental Pythagorean Theorem principles, serving as the initiation point for RME-focused learning strategies. The second stage involved explaining the contextual problem. The researcher elaborated on the issue and developed a mathematical model, which was then represented using GeoGebra. The researcher also explained the solution process, formulated conclusions regarding the problem, and reconnected the solution to its original real-world context.

The next stage was solving the contextual problem. The researcher guided and facilitated students to collaboratively solve the problem. Students used the GeoGebra software to visualise mathematical concepts. With GeoGebra, students were able to construct triangles to determine the hypotenuse or one of the sides of a right-angled triangle. The fourth stage involved discussing the solution to the contextual problem. In this phase, the researcher asked a representative from one of the groups to present the results of their discussion. The final stage was concluding. The researcher provided feedback on students' work and, together with the students, formulated a conclusion related to the contextual problem and the Pythagorean Theorem. After completing all the instructional stages, the researcher conducted a reflection on the learning process.

During the learning process, the implementation did not reach 100% effectiveness. Some students remained passive, were reluctant to ask questions, and encountered difficulties operating GeoGebra, which hindered their ability to rediscover the Pythagorean Theorem. To address this, the researcher provided support (scaffolding) through supplementary materials and peer assistance, allowing students to receive guidance in rediscovering mathematical concepts rather than constructing them entirely independently. This approach aligns with the principle of *guided reinvention* in RME, in which students are given opportunities to experience a process that enables them to rediscover mathematical concepts (Gravemeijer, 1994).

According to Gravemeijer (1994), there are four levels in Realistic Mathematics Education (RME): the situational level (presenting real-life or contextual problems that are familiar to students), the referential level or *model of* (where students begin to describe and represent the given context), the general level or *model for* (where students move toward solving the problem), and the formal level (where students work with formal mathematical rules, procedures, notations, and symbols). These levels in RME align with various indicators of mathematical literacy. Below is an example of a student's pretest response related to mathematical literacy skills.

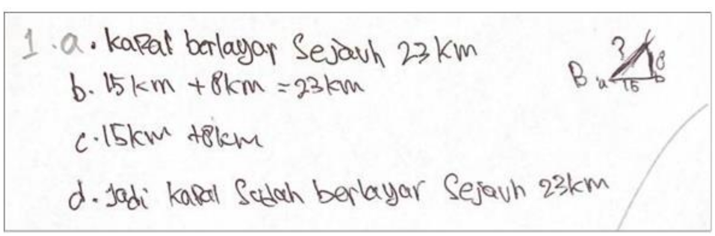

Figure 1. Student's Pretest Result

In question 1a, the student provided only partial information and failed to identify all the relevant data from the problem. This indicates that the student did not meet the first indicator of mathematical literacy (formulate), which involves identifying and extracting necessary information. The student also did not demonstrate a clear understanding of the real-world context, thus failing to reach the situational level of experience. In question 1b, the student's response was also incorrect. They did not construct a representative model of the problem, meaning they did not meet the second indicator of mathematical literacy (formulate), which involves creating a mathematical model based on the given situation. This also indicates the student did not achieve the referential level. In question 1c, the student did not use any formulas or mathematical procedures, nor did they demonstrate reasoning. Instead, the student merely restated information from the problem without performing any calculations. As a result, the student did not meet the third indicator of mathematical literacy (employ), which involves applying mathematical concepts and procedures, and failed to reach the general level. In question 1d, the student misinterpreted the result based on an incorrect model and was unable to draw an accurate conclusion connected to the real-world context. This indicates that the student did not meet the fourth indicator of mathematical literacy (interpret).

After receiving the treatment through RME instruction supported by GeoGebra, students were given a posttest. Below is an example of a student's posttest response demonstrating their mathematical literacy skills.

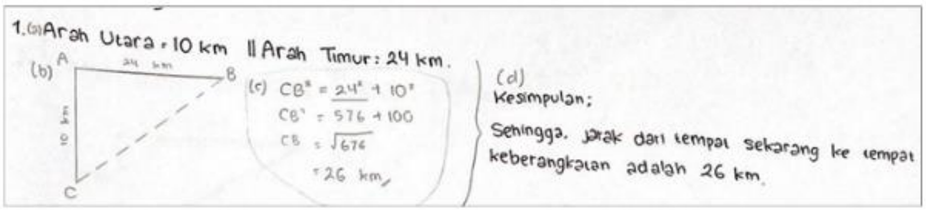

Figure 2. Student's Posttest Result

In question 1a, the student identified key information from the problem, namely that the ship travelled 10 km north and then 24 km east. This demonstrates the student's understanding of the context and ability to extract the essential data needed to solve the problem. Therefore, the student met the first indicator of mathematical literacy (formulate), which involves identifying the required information, and achieved the situational level. In question 1b, the student drew a right triangle, where the vertical side (10 km) represented the northward journey and the horizontal side (24 km) represented the eastward journey. This illustrates the student's ability to translate real-world information into a mathematical form. Consequently, the student met the second indicator of mathematical literacy (formulate), which involves constructing a mathematical model based on a real-world situation. The student also achieved the referential level by representing the contextual situation using an informal mathematical model.

In question 1c, the student applied the Pythagorean Theorem to calculate the ship's distance from the starting point and wrote out the steps of the computation. This indicates that the student fulfilled the third indicator of mathematical literacy (employ), which involves applying mathematical concepts and procedures. The response also reflects that the student had progressed to the general or formal level in the RME framework. In question 1d, after obtaining the result of 26 km, the student stated that this was the distance from the ship to its starting point. This demonstrates the student's ability to interpret the mathematical result in the context of the problem. The student successfully met the fourth indicator of mathematical literacy (interpret). This response also reinforces the student's comprehension across the referential and situational levels, showing awareness of the meaning of the mathematical result obtained.

Previous research conducted by Istiqomah, Kamid, dan Hasibuan (2021) Demonstrated that RME-based instruction effectively influences students' mathematical literacy. Similarly, a study by Mudumi, Palinussa, dan Rumalean (2025) Indicated substantial impact of Realistic Mathematics Education (RME) on pupils' mathematical literacy performance. Nurhayati, Supratman, dan Rahayu (2023) Correspondingly, it was determined that employing teaching tools integrated with RME showed success in strengthening pupils' mathematical literacy proficiency. Ariati et al., (2022), provided evidence that the application of the RME approach significantly enhanced students' mathematical literacy.

Besides choosing a suitable instructional method, incorporating technology is equally vital in facilitating student learning. Instructional media can function as a practical aid for teachers in presenting learning content more efficiently (Maulani et al., 2022). This is supported by Suwito (2022), who reported that technology was proven effective in improving mathematical literacy. GeoGebra enhanced students' ability to solve mathematical problems. This finding aligns with the study by Amri, Armanto, dan Surya (2025), which confirmed that interactive media utilising the GeoGebra application is a valid and effective method for improving students' numeracy literacy. In a similar vein, the findings of Shafa dan Yunianta (2022) revealed that this type of media is effective in supporting the learning process and has a positive impact on improving students' mathematical literacy.

This research suggests that educators adopt the RME approach integrated with GeoGebra as an effective means to foster students' mathematical literacy. The study's key contribution is its evidence of improved mathematical literacy outcomes through the application of the RME framework, along with an in-depth analysis of students' problem-solving strategies in literacy tasks involving the Pythagorean Theorem. Additionally, this research integrates technological tools specifically the GeoGebra software to solve problems involving mathematical literacy. The implementation of RME, enhanced by the use of GeoGebra, has demonstrated effectiveness in advancing students' mathematical literacy, thereby supporting the cultivation of critical 21st-century competencies.

Students' mathematical literacy skills showed improvement after the treatment. In the formulation process, the students' average maximum score increased by 35%; in the employ process, it increased by 46%; and the largest improvement was observed in the interpret and evaluate process, with an increase of 53%. The highest gain in the third process likely occurred because the students' average score in that area was very low during the pretest. Below are excerpts from students' posttest answers for each process.

Conclusion

Data analysis confirms that integrating GeoGebra within the Realistic Mathematics Education (RME) framework yields a statistically significant improvement in students' mathematical literacy. This is substantiated by the rise in average performance from pretest to posttest, alongside the results of the paired sample t-test. GeoGebra effectively supports students in conceptualising and constructing mathematical representations of authentic real-life problems. Furthermore, the N-Gain score falls within the high category, indicating that the RME approach assisted by GeoGebra is effective in enhancing mathematical literacy. This study contributes to the advancement of technology-based and contextual learning in mathematics education, supporting previous findings that integrating RME and GeoGebra can strengthen students' higher-order mathematical thinking skills.

Based on these findings, it is recommended that mathematics teachers apply the RME approach supported by GeoGebra more broadly in the classroom, particularly for topics that require modelling and visual understanding, such as the Pythagorean Theorem. Moreover, schools and educational policymakers are encouraged to provide training on integrating mathematical software, such as GeoGebra, to enhance teachers' capacity for technology-based instruction. This study was limited to a single class using a pre-experimental design; therefore, future research is recommended to employ stronger experimental designs, such as quasi-experimental methods with control groups, to allow for more objective comparisons of the treatment effects. Subsequent researchers are also encouraged to explore the impact of this approach on other aspects such as learning motivation, self-efficacy, and implementation across different grade levels and mathematical topics to broaden the generalizability of the findings.

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