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The Effectiveness of GeoGebra-Assisted Realistic Mathematics Education in Enhancing Students' Conceptual Understanding

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Abstract

This research studied the application of Realistic Mathematics Education and GeoGebra which could enhance students' conceptual understanding in mathematics, especially for geometry themes on flat-sided shapes. The study included 26 eighth-grade students of a junior public high school in Yogyakarta, Indonesia. The research, which adopted a pre-experimental design with one-group pretest–posttest arrangement, intended to explore the extent of students' understanding improvement as GeoGebra was implemented in RME-based learning. Two conceptual understanding tests were applied, before and after intervention, alongside observation sheets aimed at monitoring activities in the class. The analysis showed that the average score increased from 47.76% to 80.29%. The test of the paired sample t-test showed a significant difference between the pre- and post-test means. Meanwhile, the N-gain score obtained 0.63, falls within a moderate category regarding effectiveness, while the learning implementation reached 98.33%, categorized as very good. These indicate that integrating RME with GeoGebra enhances accessibility in mathematics concepts to the learners and involves active participation. Limitations, however, include poor pre-knowledge of the students, irregular attendance, and distractions from using mobile phones, probably affecting their engagement and performance.

Keywords: conceptual understanding ability; geogebra; realistic mathematics education.

INTRODUCTION

Mathematics is a science that is organized in a deductive form, being based on elements and axioms previously proved. Mathematics is very much relevant to everyday life and is considered an important subject for developing critical, logical, and rational thinking. For this reason, it is included as one of the compulsory subjects at schools (Sutherland, 2007; Haigh, 2019). Furthermore, mathematics enhances students' hard skills, including understanding, reasoning, problem-solving, communication, connections, and mathematical representation (NCTM, 2014). Conceptual understanding plays a vital role in mathematics. Several problems in real life and workplaces require knowledge of mathematics to analyze the problem and solve it effectively (OECD, 2023b).

In this context, conceptual understanding is defined as students' abilities to interpret, integrate, and relate mathematical concepts, operations, and relationships in a way that is accurate, effective, flexible, and comprehensive. It also provides the critical foundation for developing procedural fluency-the ability to apply procedures meaningfully and adaptively when solving problems (Kilpatrick et al., 2001). In 2014, NCTM explained that the goal of mathematics instruction is to enable students to make sense of concepts, to understand how concepts are interrelated, and to solve different types of problems using that knowledge. Students demonstrate solid conceptual understanding when they can describe problems and concepts in their own words, explain them to others, and use the ideas they have learned in solving mathematical problems effectively (Departemen Pendidikan Nasional, 2022).

According to the OECD (2023a), Indonesian students scored an average of 366 points in mathematics, far below the average of OECD countries at 472 points, placing Indonesia in a rank of about 70th out of 81 countries in the results of PISA 2022. The OECD also mentioned that only about 18% of Indonesian students reached at least Level 2 proficiency, indicating big weaknesses in conceptual understanding and the ability to apply mathematics to real contexts core competency assessed in PISA (OECD, 2023a). According to the OECD (2023b), PISA tasks in mathematics solving involve a strong conceptual basis: in that sense, students' mental substrate gets involved. The results reveal substantial weak spots in Indonesian students' mathematical knowledge, and the urgent requirement to employ instructional strategies that support the intentions and values of the Merdeka Curriculum.

Active and engaging learning strategies need to be used for learners to fully grasp and remember what they learn. Students should be able to connect what they learn with the real world and transfer their knowledge. However, As Johnson (2002) and Burman (2021) emphasize, meaningful mathematics learning should be accessible to learners. Furthermore, conceptual learning can only take place if students are engaged in the learning process. A teacher's role in learning should not be seen as an information deliverer but rather a person who guides and facilitates the process of knowledge construction. One successful method, which supports this is RME based on the use of real-life contexts to enable students to understand mathematical ideas in depth and with meaning. This is consistent with the observation reported by Yelvalinda et al. (2019), Gunur et al. (2019), and Wahyuni et al. (2023), who found that cooperative, student-centred teaching strategies such as the use of games can significantly improve students' conceptual learning.

The RME approach recognizes the significance of students' empirical experience for the development of conceptual mathematical knowledge. RME takes advantage of concrete learning stages by design, along the way allowing for abstract concepts to be given a clear meaning and relevance in context (Gravemeijer, 1994; Van den Heuvel-Panhuizen & Drijvers, 2020; Gravemeijer et al., 2017). In mathematics learning, the situation in everyday life provides a way for students to interpret abstract mathematical concepts to something that can be understood and related (Yuniati et al., 2020; Nusantara et al., 2025). In that way, RME facilitates putting mathematics in a context and students' mathematical problem-solving experiences (Van Zanten & Van den Heuvel-Panhuizen, 2021). Similar researches were also conducted by Putranto and Marsigit (2018), Fredriksen (2021), Sukmaningthias et al. (2022), and Herawaty et al. (2019) have demonstrated that the use of RME can telegraphically advance students' conceptual understanding as opposed to traditional approaches. RME can enhance up to date educational needs with technology use in the classroom. For instance, GeoGebra works in harmony with

RME to use dynamic mathematical visualization and provide student-centred learning to make learning more interactive (Purbaningrum & Mahmudi, 2024; Yerizon et al., 2022).

GeoGebra is dynamic mathematics software which adds enhancing the learning process for students by allowing students to interactively visualize and manipulate abstract mathematical concepts mainly geometry (Ziatdinov & Valles, 2022; Bedada & Machaba, 2022). Studies have shown that the combination of GeoGebra and active learning strategies is effective when applied to intercultural mathematical problems making them visual, interactive and dynamic. Integrating such integration can make it easier for students to understand abstract concepts, view them from many angles and encourage a more active learning process (Gurmu et al., 2024; Putri, Munzil & Setiyaningrum, 2019). While possessing these merits, research that focuses on the use of GeoGebra from an RME perspective is still scarce. This is a promising combination, especially in geometry, where spatial reasoning (and the visualisation of 3-D objects) are significant problems for many students. The students are able to experiment and explore geometric object easily in dynamic GeoGebra as well as underlying relation of the theory that is less easy if only using static of representation (Nadhifa et al., 2019; Azizah et al., 2021; Birgin & UzunYazıcı, 2021). This research investigates the efficiency of GeoGebra-based RME in developing students' conceptual knowledge of mathematics at junior high school level. Research Question: Does GeoGebra-based RME significantly influence students' understanding of mathematical concept?

METHOD

Research Type

This research employed a quantitative design with a pre-experimental approach through the one-group pretest–posttest design. The choice of this design is considered appropriate because the research was meant to test whether the GeoGebra-assisted RME approach improves the performance of students in understanding key concepts in mathematics. This one-group pretest–posttest model is an effective way to measure the level of change by comparing student performance between before and after the intervention. While this type of research design does not involve a control group, it is applicable within classroom research, where the key issue usually is to establish if the treatment results in significant improvement. The assessment was done in terms of administering a pretest before the treatment and then a posttest to establish changes due to the intervention.

Research Subject

This study was conducted during the first semester of the 2024/2025 academic year at a public junior high school located in the central area of Yogyakarta City. The school was chosen because of its supportive learning environment, adequate educational facilities, and curriculum that matched the instructional approach adopted in this research. The population consisted of all eighth-grade students, amounting to 180 students across six classes. From this population, a cluster random sampling technique was used to select 26 students from class VIII B. Even though the class originally had 32 students, six were absent during both the pretest and posttest, so only 26 students remained as the final sample for analysis. As Creswell & Creswell (2018) explain, this technique involves the division of the population into clusters, usually based on geographical location, after which one cluster is randomly chosen and all its members included as participants. This method is justified because students are often already organized into intact classes, and thus cluster sampling is a more practical, cost-effective, and representative form of sampling than would otherwise be possible, at the same time preserving the natural classroom context.

Research Procedure

1. Preparation Phase

To measure students' conceptions of some important ideas in geometry, there is a need to develop learning tools such as teaching modules, Student Activity Sheets (SAS), lesson implementation plans, and pre-test and post-test instruments.

2. Implementation Phase

The students were first given a pre-test on the subject matter to assess the current level of their mastery. The instructional approach adopted here was the GeoGebra-assisted RME approach, focusing on specific topics of geometry regarding cubes and cuboids. This learning process was carried out in three sessions for comprehensive conceptual understanding.

3. Evaluation Phase

A post test was conducted after the instruction to measure students' gain in conceptual understanding. Also, the data were analyzed to obtain the level at which students' understanding of mathematical concepts improved due to the treatment.

These instruments were therefore validated by two experts in mathematics education using the Aiken, (1985) validity index. All items achieved the highly valid categorization with a mean Aiken's V score of 0.98625. Reliability testing was done via the Cronbach's alpha formula as suggested by George & Mallery, 2020. The reliability coefficient obtained was 0.711, an acceptable score. Table 1 below shows indicators adopted for measuring students' conceptual understanding of mathematics in this study, adapted from the framework of mathematical proficiency highlighted by Kilpatrick et al. (2001, p. 119).

Table 1. Indicators of Students' Ability to Understand Mathematical Concepts

No	**Indicator**	**Criteria**
1	Refraining from a concept.	Rephrasing the definition of a concept.
2	Grouping objects based on certain characteristics.	Explore the properties of a concept to better understand its application.
3	Ability to provide examples and non-examples of a concept.	Provide examples and non-examples of a concept.
4	The ability to express a concept through various forms of mathematical representation.	Presenting mathematical concepts in various representations.
5	The ability to apply concepts or algorithms to solve problems.	Connecting concepts within and outside the field of mathematics.

Table 1 shows the different indicators that are used to determine the level at which students can understand the concepts of mathematics. This includes restating a concept, grouping objects based on certain attributes, providing examples and non-examples of a concept, showing different forms of representation of a concept, and using a concept or algorithm to solve problems. Each indicator has specific criteria describing what is expected from a student. This table supports the teacher's judgment about the levels of understanding that students have achieved in concepts of mathematics and will provide guidance on areas where a review may be necessary.

Data Analysis

1. Descriptive Analysis

Descriptive analysis was conducted by processing data from the following: results of students' conceptual understanding tests; student involvement during learning activities; implementation of the teaching and learning process; students' responses to the instructional methods used; and the final outcomes of students' conceptual understanding. Besides, the percentage of the learning implementation was obtained by the following formula:

$$\text{(P)} = \frac{Number\ of\ \text{“}Yes\text{”}\ Answers}{Total\ Learning\ Steps} \times 100$$

The classification of the percentage of learning implementation is calculated into five levels based on Retnawati (2014) and will be explained further in Table 2 below.

Table 2. Criteria for Learning Implementation

Interval Shoes	**Criteria**
$90 \leq p \leq 100$	Very good
$80 \leq p < 90$	Good
$60 \leq p < 80$	Enough
$40 \leq p < 60$	Not enough
$0 \leq p < 40$	Very less

Information:
P: Percentage of learning implementation at each meeting

2. Inferential Analysis

The inferential statistical analysis of this study used a paired sample t-test by calculating the N-gain value. To verify that data were obtained from a normally distributed population, a normality test was conducted before testing the hypothesis. The results of the normality analysis are described in Table 3 below.

Table 3. Results of the Normality Test Using the Shapiro–Wilk Test

Experimental Class	Say.	Decision
Pre-test	0,089	Normally Distributed
Post-test	0,053	Normally Distributed

Based on the Shapiro–Wilk test results presented in Table 3, the significance values (Sig.) of both pre-test (0.089) and post-test (0.053) are above 0.05. It may be concluded that the data from both tests follow a normal distribution.

a. Paired Sample t-test

The paired sample t-test is a parametric test used to compare two related samples of data, commonly the pretest and posttest scores of the same group of subjects. The following formula is applied for the calculation of the paired sample t-test.

$$t = \frac{\bar{d}}{\frac{s_d}{\sqrt{n}}}$$

Where:
$\bar{d}$ = Mean difference between two paired samples
s_d = Standard deviation
n = Many samples

b. N-gain Value

Student performance was evaluated based on the school’s Learning Target Completion Criteria, which requires a minimum score of 75. Learning is considered effective when students achieve this benchmark. The effectiveness of learning was determined by analyzing the improvement in students’ scores from the pretest to the posttest using the Normalized Gain (N-gain) method. The N-gain value was calculated using the formula proposed by Hanč et al. (2025).

$$\langle g \rangle = \frac{S_f - S_i}{100 - S_i}$$

Where
$\langle g \rangle$ = Score N-Gain
S_f = Score of ability to understand concepts after learning (posttest)
S_i = Score of conceptual understanding ability before learning (pretest)

Table 4 presents the effectiveness categories based on N-gain values, according to Hake's classification (Hanč et al., 2025).

Table 4. N-gain Categorization

Interval Shoes	Criteria	Interpretation of Effectiveness
$\langle g \rangle \geq 0{,}7$	High	Very Effective
$0{,}3 \leq \langle g \rangle < 0{,}7$	Currently	Quite Effective
$\langle g \rangle < 0{,}3$	Low	Less Effective

The effectiveness criteria used are that there is a difference between the average scores of the pre-test and post-test regarding students' understanding of mathematical concepts, the N-gain value must reach at least the moderately effective category, and the implementation of learning using the RME approach with the help of GeoGebra must reach a minimum of 80%.

RESULTS

Descriptive Analysis

Overall, from the first to the third meeting, the learning activity proceeded without any obstacles. The learning implementation in the experimental class using the RME approach aided by GeoGebra was observed through an observation sheet completed by an observer. From the observation results, several learning steps were not carried out in full; one of these was that the teacher forgot to take attendance among the students. A summary of the observation results can be seen in Table 5 below.

Table 5. Percentage of Learning Implementation

Meeting Number -	Percentage of Teacher Activity (%)	Percentage of Student Activity (%)	Values (%)
1	100	100	100
2	95	95	95
3	100	100	100
Values (%)	98.33	98.33	

In the first and third meetings, both teacher and student activities reached 100%. But in the second meeting, the teacher failed to record the students' attendance; thus, the activity percentage was recorded as 95%. Referring to data presented in Table 2, the implementation of learning activities according to the learning module went smoothly and effectively. Overall, the integration of RME approach supported by GeoGebra was implemented successfully and gave a positive contribution to the learning process.

Data on students' pre-test and post-test scores related to their conceptual understanding of mathematics are presented in Figure 1 below.

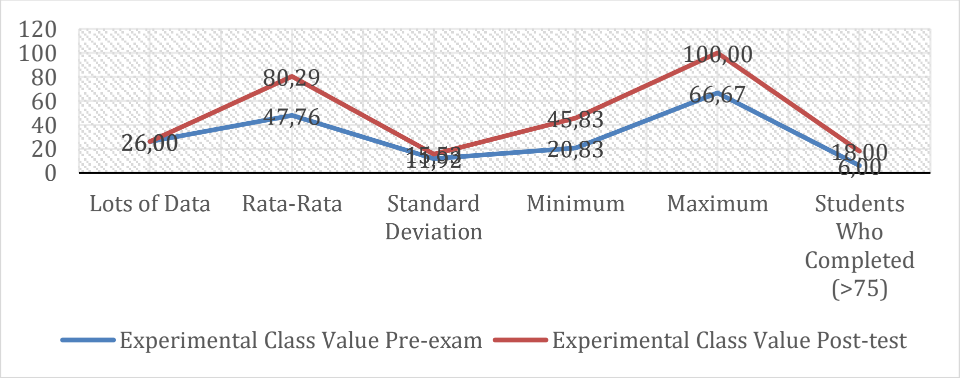


Figure 1. Results of Students' Mathematical Concept Understanding Ability

Figure 1 shows the comparison of students' conceptual mathematics understanding before and after the application of the GeoGebra-assisted RME approach. The average rose from 47.76% in the pretest to 80.29% in the posttest, increasing by 32.53%. Besides this, the number of students achieving the KKTP score of 75 increased significantly from 6 students (23%) at pretest to 18 students (69%) at the posttest, depicting an increase threefold. This score represents more than half of the total 26 students who participated in the learning process using the GeoGebra-assisted RME approach. Its minimum and maximum within the improvement scale also increased. The minimum rose from 20.83 to 45.83, while its maximum rose from 66.67 to 100, meaning that nearly all students improved, both in the lower and upper performance groups. On the other hand, the standard deviation increased accordingly from 11.92 to 15.53, indicating that the variation of post-test scores is wider; this level of variation, however, remains within a reasonable range. Overall, data in Figure 1 show that the GeoGebra-assisted RME approach positively influences students in conceptual mathematics understanding. The findings support the reasoning that a learning strategy which embeds realistic contexts with interactive visualisations can increase student engagement and support deeper geometric conceptions among students. Figures 2 below show the percentage of achievement for each question item.

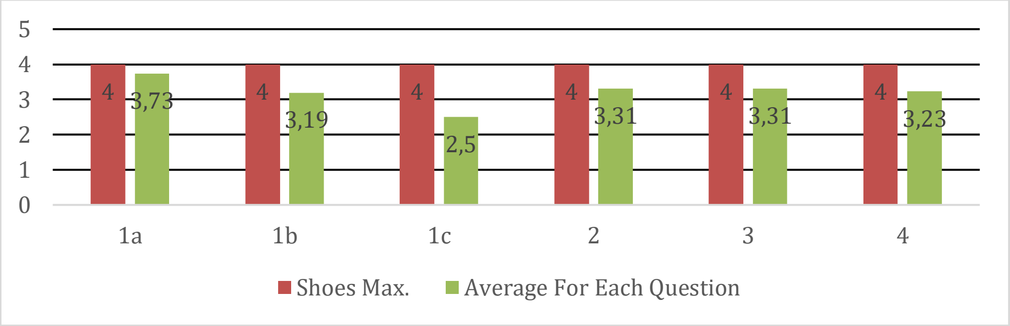


Figure 2. Achievement in Mathematical Conceptual Understanding After the Treatment

Figure 2 presents that the highest average score was recorded in Question 1a, with an average of 3.73. This question tested the students' ability to repeat the definition of a concept, falling under the category of high conceptual understanding. Likewise, high average scores were also recorded for Questions 2 and 3, with each having an average of 3.31, which tested students' ability to group objects, provide examples, and non-examples. The lowest score was recorded for Question 1c, with an average of 2.50, wherein students were required to apply higher-level concepts or thinking, which proved to be the most challenging for them. These results support that while basic conceptual understanding seems strong in students, the application and analysis skills are yet to be more fully developed. Percentage of achievement per indicator of mathematical concept comprehension after treatment, as presented in Figure 3.

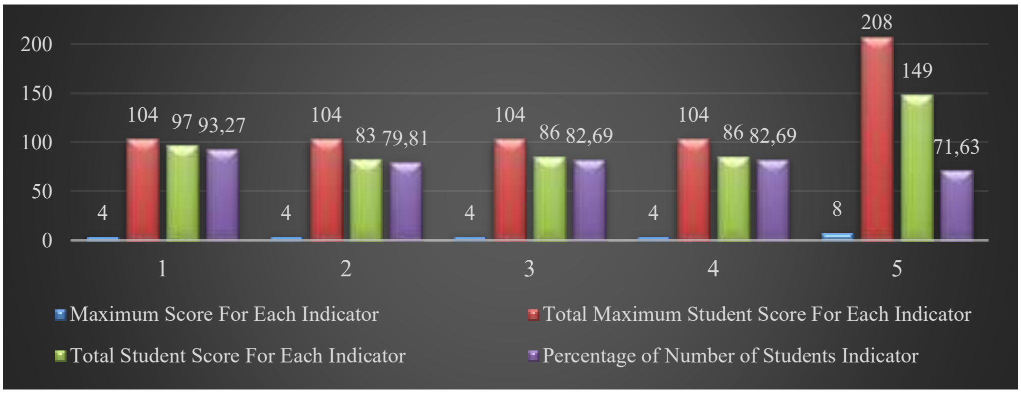


Figure 3. Percentage of Achievement for Each Indicator After the Treatment

Figure 3 gives a view that at each indicator, all students show mastery of the skills, especially in the first indicator (93.27%), third indicator (82.69%), and fourth indicator (82.69%). Such high attainment in these aspects means that most students could restate the definition of the concepts, provide examples and non-examples, and then represent concepts in other forms appropriately. However, among all the indicators, the ability to apply concepts or algorithms to solve problems was the poorest, with students completing an average of 71.63% of the problems. Despite this, after the intervention, the experimental group significantly improved their conceptual understanding regarding flat-sided spatial figures. These results further mean that students have acquired a good declarative conceptual understanding but need further reinforcement in applying concepts to solve problems. This finding points to the importance of integrating the RME approach with GeoGebra visual tools for more effective building of higher-order thinking skills.

The RME approach supported with GeoGebra has been found to enhance conceptual understanding in students through several key strategies. First, posing real-life problems at the commencement of a lesson puts learning into context for students, motivating them and thus making engagement meaningful (Van den Heuvel-Panhuizen & Drijvers, 2020; Gravemeijer et al., 2017). This is further supported by concept construction through discussions among peers and by collaboration during group work under the teacher's guidance. For example, students were engaged in the creation of nets using real objects such as milk cartons, which helped them visualize surface area and volume in a more concrete way. The integration of GeoGebra allows the process of moving from physical manipulations to dynamic digital visualizations, which may further enhance students' learning about geometry (Birgin & Uzun Yazıcı, 2021; Ziatdinov & Valles, 2022). The effects of applying GeoGebra-assisted RME can be seen in Figure 4. This approach not only helps improve conceptual understanding but also encourages active participation and supports critical thinking during the learning process.

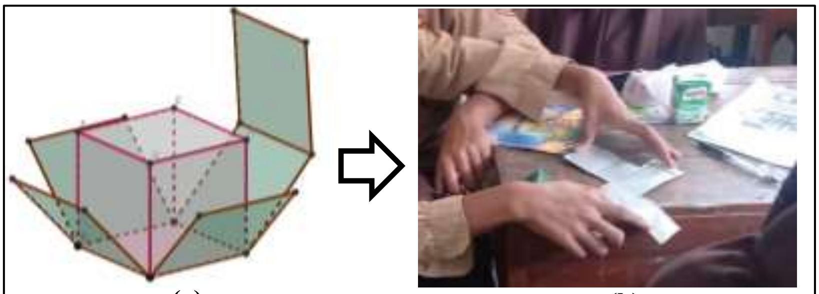

(a) **(b)**

Figure 4. GeoGebra Visualization

Figure 4a shows that the GeoGebra application is an effective tool for visualizing, dynamically, how to construct nets of cubes and other types of flat-sided geometric shapes. Unfolding three-dimensional objects as two-dimensional nets becomes more meaningful with such a visualization. When the students have grasped the idea, they can then begin the process of identifying and representing any net in concrete materials, for instance, using a cube-shaped milk carton, as shown in Figure 4b. As a visualization tool, GeoGebra allows constructing geometric nets but also facilitates the identification of geometric elements and calculation of the surface area and volume of flat-sided solids (Birgin & Uzun Yazıcı, 2021).

Students reported that using RME alongside GeoGebra enhanced their understanding of concepts. This is reflected in the fact that most students showed a significant improvement in their problem-solving skills on the post-test compared to the pre-test. They also displayed stronger signs of mathematical understanding when working through problems, particularly those involving plane figures like cubes and cuboids. These findings indicate that the GeoGebra-assisted RME approach not only strengthens students' conceptual understanding but also encourages them to think more deeply and reason more effectively when solving geometry problems, as shown in Figure 5 below.

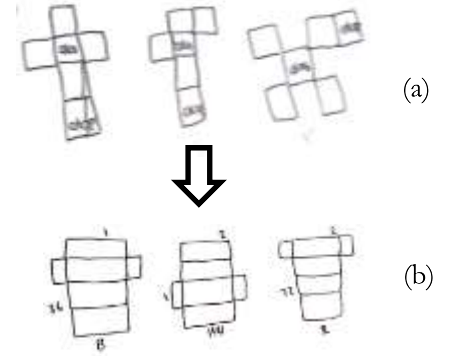
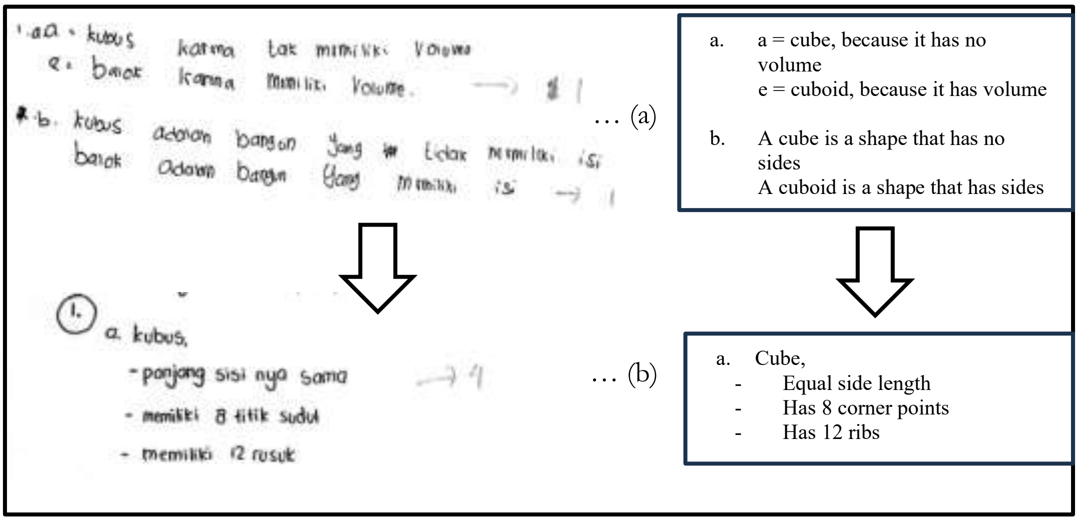


Figure 5. Students' Answers About Geometric Nets

Figure 5a shows that many students struggled to understand the structure of cube nets and the components of geometric shapes. This suggests that their grasp of three-dimensional geometry especially regarding flat-sided figures was still underdeveloped. However, after the implementation of the RME approach embedded in GeoGebra use, students' understandings improved significantly. As shown in Figure 5b, the majority of the students showed improvement in accurately identifying and understanding the nets and elements of plane-sided geometric figures. The synergy of contextual learning via the RME approach and the interactivity of GeoGebra visualizations made for a deeper, stronger, and more meaningful understanding of concepts in geometry.

Other students' responses reflect their prior knowledge of three-dimensional shapes having flat faces. In this part, students were asked questions about the attributes of cubes and rectangular prisms to cover two indicators: the ability to categorize objects using specific characteristics consistent with underlying concepts and the ability to rephrase a concept. Figure 6 presents the sample response of a student.



1. a. a. kubus karna tak mimiliki volume
e. balok karna memiliki volume. → 1

b. kubus adalah bangun yang tidak memiliki isi
balok adalah bangun yang memiliki isi → 1

… (a)

a. a = cube, because it has no volume
e = cuboid, because it has volume

b. A cube is a shape that has no sides
A cuboid is a shape that has sides

① a. kubus,
- panjang sisi nya sama → 1
- memiliki 8 titik sudut
- memiliki 12 rusuk

… (b)

a. Cube,
- Equal side length
- Has 8 corner points
- Has 12 ribs

Figure 6. Students' Answers About Geometric Properties

Figure 6a shows that many students still made errors in explaining geometric properties, which means that their initial understanding about the material was limited and needed to be further reinforced. On the other hand, after the implementation of the RME approach integrated with GeoGebra, there was an improvement in students' understanding. As shown in Figure 6b, most students were able to accurately state the geometric properties, such as the number of vertices, edges, and the equal side lengths of a cube.

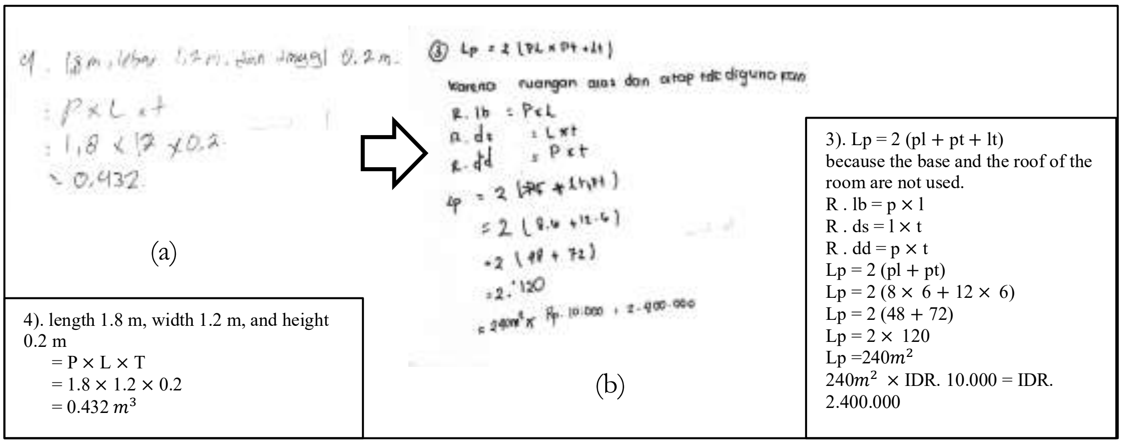
To indicate the application of problem-solving concepts or algorithms, students were given the following pre-test question:

"A spring mattress measures 1.8 meters in length, 1.2 meters in width, and 0.2 meters in height. Calculate the surface area of fabric required to cover the mattress."

In the post-test, the question was:

"A hall has the shape of a rectangular with dimensions of 12 meters in length, 8 meters in width, and 6 meters in height. The walls will be painted at a cost of IDR 10,000 per square meter. Calculate the total cost of painting the entire hall."

Thus, students' responses regarding this indicator are shown in Figure 7.



4). length 1.8 m, width 1.2 m, and height 0.2 m
= P × L × T
= 1.8 × 1.2 × 0.2
= 0.432 m^3

3). Lp = 2 (pl + pt + lt)
because the base and the roof of the room are not used.
R . lb = p × l
R . ds = l × t
R . dd = p × t
Lp = 2 (pl + pt)
Lp = 2 (8 × 6 + 12 × 6)
Lp = 2 (48 + 72)
Lp = 2 × 120
Lp =240m^2
240m^2 × IDR. 10.000 = IDR. 2.400.000

Figure 7. Students' Answers About Problem Solving

As shown in Figure 7a, students still had difficulty understanding the concept of surface area. They assumed that surface area was the same as volume. This is evident from their responses, as they applied the formula for volume to calculate surface area, showing that the latter two basic geometric concepts were still undifferentiated at that point. The responses in the posttest reveal an improvement in understanding. In Figure 7b, students applied the correct formula and were thus able to calculate the area of each face of the solid and then add them to find the total surface area. It would appear that the use of the RME approach combined with GeoGebra improved the students' conceptual understanding. The approach supported students in learning mathematical concepts both visually and contextually, while also strengthening their ability to apply these concepts in real-life problem-solving situations.

Inferential Analysis

Before testing the hypothesis on the effect of the GeoGebra-supported RME approach on students' mathematical conceptual understanding, a normality test was first conducted. The results of this test are shown in Table 3. After confirming that the data were normally distributed, the hypothesis test was carried out. This test aimed to determine the effectiveness of the GeoGebra-assisted RME approach by analyzing improvements in students' conceptual understanding. The impact of the treatment was assessed by comparing the mean pretest and posttest scores of the experimental group using a paired sample t-test. The results of this analysis are presented in Table 6.

Table 6. Results of paired sample t-test on students' mathematical concept understanding ability

Class	Means	T	df	P_{mark}	Decision
Before Treatment	47.756	-11.530	25	<.001	H_0 rejected
After Treatment	80.288				

The average ability to understand mathematical concepts before treatment was 47.756 as shown in Table 6. After treatment, the average increased to 80.288. The value t_{count} is -11.530 And p_{value} obtained is less than 0.001. Because p_{value} less than 0.05 or t_{count} as big as -11.530 smaller than $-t_{table}$ from -2.060, for H_0 rejected. The results of the analysis showed a significant difference in the average ability of students' mathematical concept understanding before and after the application of the treatment in the classroom. Thus, the results in Table 6 provide empirical evidence that the GeoGebra-assisted RME approach is effective in improving students' mathematical concept understanding. This result is in line with the increase in students' average scores shown in Table 6, and supports the findings in previous studies regarding the effectiveness of contextual learning strategies and interactive visual technology.

Based on the study of students' pretest and posttest results, the average N-gain became 63.39%. This value was calculated by determining each student's N-gain and then averaging the results to obtain the overall improvement percentage. According to Hake's categorization, moderate is considered an average N-gain of 63.39%. This indicates that learning margins by using the GeoGebra-assisted RME approach had a moderate effect on students' conceptual understanding. The large gain in score from the pretest to the posttest implies that a significant amount of increase occurred in those subjects' understanding following use of this approach.

The results of the study reveal that, the GeoGebra-supported RME approach was found to be successful in enhancing mathematical conceptual understanding of students. This could be inferred from the paired-sample t-test analysis where students' conceptual understanding appeared to significantly increase following learning intervention. In addition, the mean N-Gain was 63.39%, which lies in the moderate effective range. Furthermore, the rate of learning process implementation was highly satisfactory (98.33%), exceeding the pre-set minimum level of implementation.

DISCUSSION

The RME curriculum emphasized contextualization mathematics learning based on reality and relevant to students' daily life. Instead of dealing with math as a set of abstract concepts, RME considers mathematics as a means for thinking and solving problems of everyday life. In application, this method prompts teachers to establish challenging and cognitive learning activities, where students are actively engaged in investigating, exploring, and structuring their own meaning of mathematical knowledge with the help of the teacher. This in turn provides students with a more profound understanding of mathematical concepts as well as the modern-day skills they will need for their future, including critical thinking, creative thought, and problem-solving. These results justify the findings of a study conducted by Putranto and Marsigit (2018) in which RME encourages students to take an active part, allowing them, including slow learners, to comprehend mathematical concepts in better ways. Fredriksen (2021) concurred that RME used in relation to student characteristics helps learners better understand and represent mathematical concepts. In the following experiment, students achieved the core elements of relational understanding including defining mathematical concept, giving examples and non-examples and translating these meanings into symbolic or visual representations.

It is argued that RME could be more effective by incorporating digital technology and GeoGebra in particular. With GeoGebra, students can analyze properties of 3D figures dynamically and interactively to promote spatial reasoning, problem-solving skills, and computational thinking (Ridha et al., 2020; Gurmu et al., 2024; Saragih et al., 2025). Exploring and manipulating visual formalisms, the students observe patterns, make predictions, and create algebraic representations that will aid in mathematization according to the RME framework as described in Figure 4. More generally, GeoGebra use in RME encourages students to be active learners by collaboratively discussing and exploring ideas with other students. It promotes independence, creativity, and collaboration to understand mathematical concepts more effectively as well as developing other competences required for the 21st century (Gravemeijer et al., 2017; Arends, 2012). These findings in this research revealed that the RME with GeoGebra was effective for improving students' learning achievement on math concepts, especially for topics of mathematics such as three-dimensional figures with flat surfaces. This is shown by the increase in average scores from pre-tests to post-tests, significant statistical analysis, and indicators of conceptual understanding achieved. Most students reached the definitional, example/non-example, and representational levels, while their performance concerning applying concepts or algorithms to solve problems remained unsatisfactory as higher-order thinking processes could not be expected in full scale yet.

The improvement of the students' conceptual understanding in mathematics can be attributed to the innovative application of learning strategies, considering the influence of integrating the RME approach with GeoGebra. This is in agreement with Supriadi et al. (2021), and also Panjaitan et al. (2024), where it was reported that the RME approach situates the problems of mathematics in familiar, real contexts, thus making it more meaningful and accessible to learners of mathematics. By applying this approach, learners will be able to relate mathematical concepts to their daily experiences, which will enable them to learn about mathematics in a more enjoyable and relevant way. For instance, this study supports previous findings that RME-based teaching significantly enhances students' conceptual understanding. In addition, Ridha et al. (2020) added that GeoGebra use as a visualization tool within mathematics learning significantly improves conceptual understanding when it is applied interactively and continuously throughout the process.

Classroom observations also revealed several challenges. Lack of pre-skill and poor attendance levels are an impediment to participation by students in the learning experiences for some students. Additionally, one copy of the SAS was provided per group reducing the effectiveness of group discussions. Frequent use of mobile phones within classes, however, resulted in considerable distractions, and time was wasted throughout class activity. Nevertheless, in the light of these constraints established by this study, GeoGebra-based RME is likely to be a beneficial alternative where students' concept comprehension and mathematics learning outcomes are concerned.

CONCLUSION

The use of GeoGebra within RME approach successfully developed the students' conceptual understanding of flat-sided spatial objects. This was also supported by much improvement in the post-test scores in comparison with the pre-test results, having gained 63.39% and percentage of learning implementation reached 98.33%. These findings exceed numbers as they show how combining context mathematics learning with interactive use of visual tools may result in a richer pedagogy. Practically, by means of this active and contextualized utilization of GeoGebra, the teaching subject matter becomes more meaningful, interesting, and accessible for the students. Articulating mathematical ideas through GeoGebra and digital tools strongly promotes the learning of activity in dealing with general mathematical concepts, and it enhances reasoning-developing practices being promoted by 21st-century education. To support this state of affairs, the active proliferation of this treatment and continual training in using GeoGebra should be encouraged. Subsequent assessment may be needed with quasi-experimental designs having control groups to enhance the validity of results. RME-GeoGebra can be studied from various points of view and standpoints ultimately building a wider empirical base for this tool using instructional innovation.

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