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PAPER

Enhancing Junior High School Students' Reasoning of Linear Equations Using GeoGebra Software

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ABSTRACT

The important role of visual representations in supporting students' learning of geometry concepts and their reasoning is well established. GeoGebra is dynamic and interactive software that can assist students in exploring mathematical concepts effectively. This research aims to examine the effectiveness of GeoGebra in enhancing eighth-grade students' mathematical reasoning on the topic of linear equations. The study used a quantitative approach with a non-equivalent control group design by applying GeoGebra. Data were obtained through interviews and a mathematical reasoning ability test. The interviews were analyzed descriptively, and the reasoning test was analyzed using dependent t-tests. The findings revealed that GeoGebra significantly helps students' to have a better understanding of linear equation properties, such as the gradient of parallel, coincident, perpendicular, and intersecting lines. The mathematical reasoning test revealed that learning with GeoGebra can improve students' mathematical reasoning skills, specifically in linear equations. Teachers are encouraged to incorporate GeoGebra, as its visualization function enables students to explore linear equation properties.

KEYWORDS

GeoGebra, linear equation, mathematical reasoning ability

1 INTRODUCTION

Mathematical reasoning is a fundamental component of learning mathematics and is considered one of its proficiencies. Mathematical reasoning, also called adaptive reasoning, is one of the interrelated processes of conceptual understanding, procedural fluency, strategic competence, and productive disposition. The National Council of Teachers of Mathematics (NCTM) [1] has identified several abilities related to mathematical reasoning, such as (1) drawing logical conclusions, (2) providing explanations for models, facts, properties, relationships, or patterns, (3) estimating answers and solution processes, (4) using relationship patterns to analyze situations or make analogies, generalizations, and conjectures, (5) proposing counterexamples,

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(6) following rules of inference, examining argument validity, proving, and constructing valid arguments, and (7) constructing mathematical proofs by direct, indirect, and mathematical induction methods.

Reasoning is the process of thinking to draw conclusions based on previous statements after the truth has been proven. Reasoning is a special form of thinking in an effort to draw conclusions described by premises. Mathematical reasoning ability helps students to conclude and prove a statement, build new ideas, and solve problems in mathematics. Reasoning skills are essential for understanding mathematics and constructing mathematical knowledge. This ability is needed to solve every day life's problems. Students who have good reasoning skills will easily solve problems [2].

To enhance students' mathematical reasoning, teachers should create an engaging yet challenging learning environment [2] where students engage in making and testing conjectures, proofing their conjectures, and drawing correct and accurate conclusions. However, most students have low mathematical reasoning abilities, which need to be improved [3]. International comparative assessments, such as the PISA 2018 data, showed a similar finding that the mathematical reasoning ability of Indonesian students was relatively low [4]. Jusmawati [3] reported that Indonesian secondary students tend to be passive in their reasoning. More specifically, Yenmez [5] noted students' difficulties in formulating problems and drawing conclusions to answer questions.

Linear equation is a year 8 topic in the Indonesian mathematics curriculum, and it is a foundation for studying subsequent topics. However, most students encounter difficulties in determining the gradient of a known linear equation, the gradient when one line is parallel or perpendicular, and the equation of a linear line when the gradient and one of its points are known, the steps to solve problems, and the formula to be used [6]. The topic of linear equations is essential for learning other mathematics topics. Students should be accustomed to reasoning on this topic of linear equations. In other subjects, this topic is also very much needed, such as physics, biology, astronomy, and economics. It is also widely used to solve problems in everyday life [6]. The simple media, such as Power Point slides, used by teachers in mathematics learning, particularly in geometry, are still limiting students' experiences and their engagement in discovering concepts [7].

The rapid development of technology makes it utilized in all aspects of life, including teaching and learning processes. The development of technology has become popular with students at any educational level [8]. More than 50% of educational applications are targeted at students [9]. The use of digital technology can improve the learning process, both formal and informal [10] [11]. Many studies have revealed that students are familiar with digital devices, so it becomes an opportunity for teachers to use them in learning [12]. Many teachers are looking for new ways to use technology (computers) to improve the quality of their classes [13] [14].

This paper aims to reveal the increase in students' mathematical reasoning abilities after being taught using GeoGebra, especially for the topic of straight line equations. Learning by using GeoGebra is expected to increase students' understanding.

2 LITERATURE REVIEW

Computer-assisted learning integrates environmental education by linking two independent ideas in student cognition through computer functionality (text, and images) so that students have opportunities to combine knowledge and action to fundamentally promote digital literacy [15]. Technology can be used in the learning process to improve mathematical ability [16]. Abstract concepts, particularly in geometry, can pose a significant challenge for students to learn [17], and to make the learning meaningful, the objects need to be visualized [18].

GeoGebra is a tool for students to explore mathematical concepts [19] through explorations and visualizations [20]. This software was developed by Markus Hohenwarter in 2001, and it had four interesting views, namely algebra, 2D and 3D graphics, as well as statistics, simultaneously displayed on a big screen [21]. The potential uses of GeoGebra include allowing students to: (1) produce geometric drawings quickly, accurately, and accurately; (2) display animation or manipulation movements on an object and provide visual experiences for students in understanding mathematical concepts; (3) serve as an evaluation tool to ensure that the graphs created are correct; (4) investigate the properties applied to a geometric object; and (5) engage in discovery-based learning activities. Therefore, GeoGebra has the potential to enhance students' abilities to propose, prove, and communicate appropriate mathematical arguments.

GeoGebra is embedded in the course content and previous teaching through practicals, tutorials, and simulations to achieve teaching goals [20]. Computer-assisted teaching can reduce students' time to study and can contribute to mathematical reasoning and thinking [22]. GeoGebra's ability to build relationships between geometry and algebra can help students understand mathematics by activating problem-solving ideas and diagnosing their learning difficulties and misunderstandings [23]. Integrating GeoGebra with the mathematics curriculum can help student satisfaction, train students with important skills for work, and provide active learning experiences for students [24].

GeoGebra can also improve student performance in learning coordinate geometry. Velichova [24] has demonstrated the potential of this application in visualizing the component graphs of functions of a single complex variable. It visualizes interactive 3D figures and surfaces, and it has been used as a tool for the proof and explanation of the Pythagorean Theorem [25]. GeoGebra was also effective in increasing their understanding of student learning in Ghana [26]. The effectiveness of GeoGebra is also reported in improving students' understanding of geometric shapes [17] [27], solving word linear optimization problems [28], parametric curve modeling [24], and the representation of complex functions [29].

Previous research found that GeoGebra offers a dynamic and engaging learning environment [30] [31], with a positive impact on students' attitudes, interest in and learning motivation, and it assists students in visualizing abstract geometry concepts [32]. Zulnaidi [33] reported an increase in interest and learning outcomes of spatial geometry using GeoGebra. However, research on how the use of GeoGebra improves students' mathematical reasoning abilities when exploring the concept of linear equations is still new.

In previous studies, GeoGebra was used to visualize function graphs and geometric shapes. Açıkgül conducted research on the use of GeoGebra for the topic of polygons [19]. Doğan [23] studied the topic of triangles, while Tay [26] researched circle theorems. There are still a few studies that use GeoGebra to assist students in constructing concepts, especially on the topic of linear equations. This paper explains how students understand the concept of parallel and perpendicular lines with the assistance of GeoGebra. Therefore, this research aimed to examine the use of GeoGebra in constructing the concept of linear equations to improve students' mathematical reasoning abilities.

3 METHOD

3.1 Research design

The research was designed using quantitative methods using nonequivalent control-group design experiments by applying GoeGebra Assisted Learning Community Learning to mathematics learning. This research examined the use of GeoGebra in teaching the concept of linear equations. The software was expected to assist students in rediscovering the properties of linear equations, namely gradients of parallel, coincident, perpendicular, and intersecting lines. This research examined the use of GeoGebra software in teaching the concept of linear equations. The software was expected to assist students in rediscovering the properties of linear equations, namely gradients of parallel, coincident, perpendicular, and intersecting lines. This research is quasi experimental in nature. The research design used was the static group pretest-posttest design. In this research design, a sample group was selected to be taught by applying a learning model using GeoGebra. The research design is presented in Table 1.

Table 1. Research design

Group	Pre-test	Treatment	Post-Test
Experiment	T	X	T

Notes: X: Learning by using GeoGebra; T: Test of students' understanding of mathematical concepts.

3.2 Participants

This research involved 31 eighth-grade students from SMPN 7 Padang. The experiment was carried out with the assistance of their concerned subject teacher.

3.3 Research instruments

Data were obtained through interviews and tests of mathematical reasoning ability. Problems on the test are arranged based on indicators of mathematical reasoning ability.

3.4 Data analysis technique

Reasoning tests were given before and after the experiment was carried out. Moreover, descriptive techniques were used to describe data from interviews, namely data reduction, presentation, and conclusion.

Statistical hypothesis:

$$\begin{aligned} &H_0: \mu_1 = \mu_2 \\ &H_1: \mu_2 > \mu_1 \end{aligned} \tag{1}$$

Description:

μ_1: Mean mathematical reasoning ability before using GeoGebra
μ_2: Mean mathematical reasoning ability after using GeoGebra

The mathematical reasoning test data were analyzed using a dependent t-test formula:

$$t = \frac{\bar{d}}{S_d / \sqrt{n}} \text{ where } d_i = x_2 - x \tag{2}$$

For $\bar{d}$ value, the formula is:

$$\bar{d} = \frac{\sum_{i=1}^{n} d_i}{n} \tag{3}$$

Meanwhile, the standard deviation of the difference between the pre-test and post-test scores is obtained from,

$$S_d = \sqrt{\frac{\sum_{i=1}^{n} (d_i - \bar{d})^2}{n-1}} \tag{4}$$

Description:

x_1: Pre-test score
x_2: Post-test score
d: Difference in post-test and pre-test score
S_d: Standard deviation of the difference in post-test and pre-test score
n: Total students

The basis for decision-making:

If $t_{count} < t_{table} = t_{(\alpha, df)}$ with $df = n - 1$ then H_0 is accepted.
If $t_{count} > t_{table} = t_{(\alpha, df)}$ with $df = n - 1$ then H_0 is rejected.

There is an improvement in students' mathematical reasoning ability after using GeoGebra when H_0 is rejected. In this analysis, the percentage of scores for each mathematical reasoning indicator was also calculated. It aimed to determine the change in percentage increase for each mathematical reasoning indicator before and after using GeoGebra, and the score for each indicator can be calculated using the formula:

$$M_i = \frac{S}{I} \times 100\% \tag{5}$$

Description:

M_i: Percentage score for each indicator
S: Total score for each indicator for all students
I: Ideal score

4 RESULTS AND DISCUSSION

Students were directed to discover the properties of linear equations through exploration activities on GeoGebra based on the given instructions. Subsequently, high-ability, medium-ability, and low-ability students were labeled as students 1, 2, and 3.

4.1 GeoGebra helps reinvent the concept of gradient of parallel and coincident lines

In this activity, a problem was given on the savings graph of five students from Sukamaju Junior High School to participate in a tour about the concept of parallel and intersecting line gradients. Furthermore, students were required to pose questions after observing the problem. The teacher could provide leading questions, such as "*What is the shape of the linear equation for each of the five graphs? What is the position of the five lines? Determine the gradient of each graph.*" Students were asked to provide their conjectures for the problem before knowing the correct steps.

Each point was inputted into the GeoGebra, and the Line icon was used to determine the linear equation for the graph. Student 1 was able to understand the problem, while student 2 inputted several points passed by each line. After receiving instructions that only two points were necessary to determine the linear equation, Student 2 comprehended the explanation and proceeded to work on the worksheet. Student 3 encountered confusion when attempting to determine the linear equation passing through two points. Consequently, guidance was provided for identifying two points, as evidenced by the following conversation:

Researcher: *You seem confused, do you have a question?*
Student 3: *I am confused about which point to input, ma'am.*
Researcher: *Now try to pay attention to this (while pointing to line k on the Student Worksheet).*
From this line k, try to determine the two points through which it passes.
Student 3: *So, I am free to determine the point, ma'am?*
Researcher: *Yes, but the point should be crossed by the line k.*
Student 3: *I select* $A(-8, 0)$ *and* $B(-7, 2)$*, is that okay or not ma'am?*
Researcher: *Okay, fine. Please input both points in GeoGebra then determine the equation of the straight line. Do you still remember how to connect the two points?*
Student 3: *Yes, by clicking Line.*
Researcher: *Good. Do the same way to determine the equation of another straight line.*
Student 3: *Okay, ma'am.*

During the learning process, the students exhibited enthusiasm by coloring each linear equation graph. The study by Mthethwa [34] found that the use of manually or automatically movable image displays, as well as the use of colors in images, could attract students' interest in learning mathematics. Upon being instructed to utilize the software for drawing linear lines, students exhibited a high level of enthusiasm toward the task. Students displayed hesitancy and embarrassment in attempting the task, but upon receiving motivation and witnessing their peers' success, they exhibited a strong willingness to undertake the activity.

The students were directed to determine the gradient of the five lines by clicking the angle on the toolbar and selecting the slope. Based on their analysis of the data displayed on the GeoGebra screen, the students concluded that each of the five lines has a gradient of 2, as illustrated in Figure 1a. Furthermore, parallel lines had similar gradients. In the subsequent activity, students were tasked with discovering the property of a coincident line gradient by moving one line (*k*) closer to another (*l*) until the two coincided. In conclusion, coincident lines had the same gradient and constant, as shown in Figure 1b. It could be achieved because GeoGebra assisted the process of discovery and experimentation in the classroom. The visualization features could effectively help students propose various mathematical conjectures [35].

a) b)

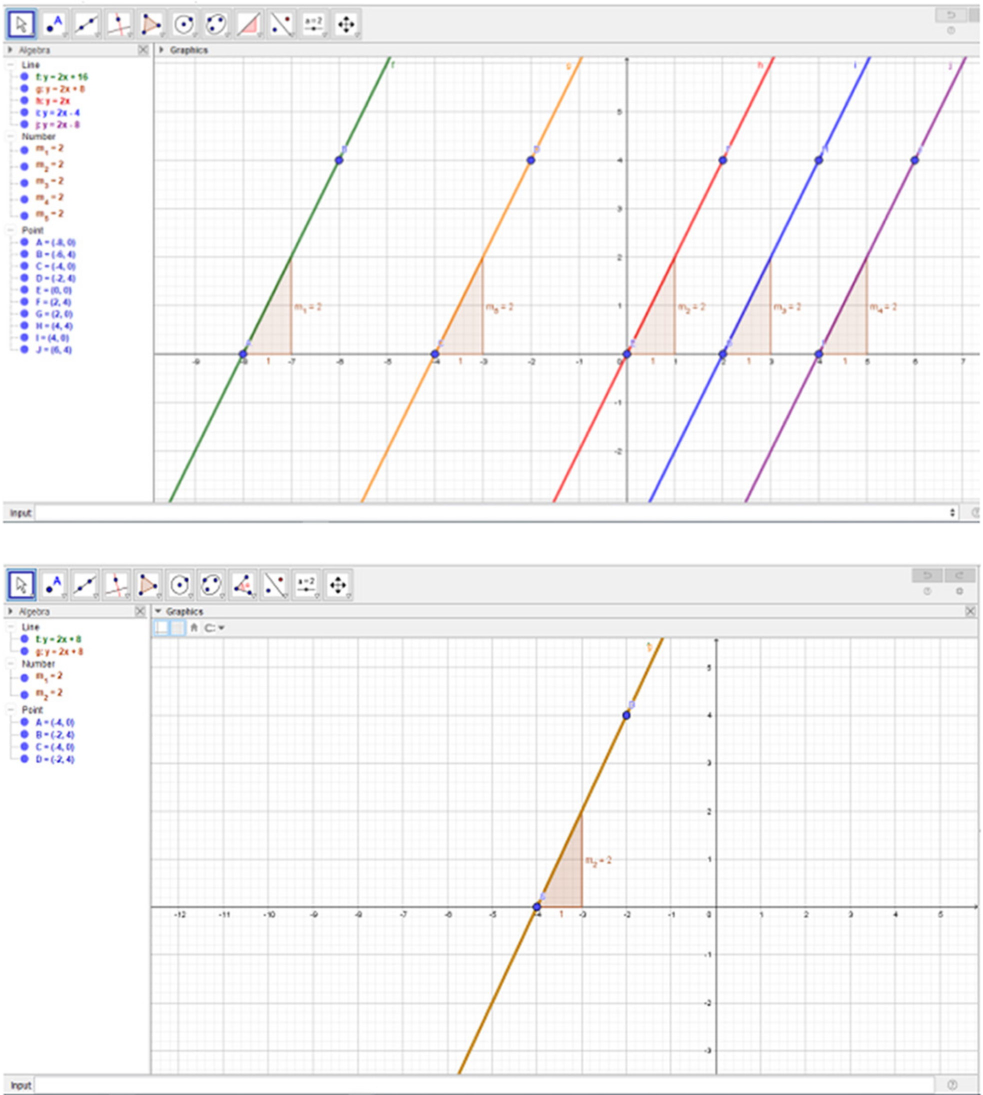


Fig. 1. Parallel (a) and coincident (b) line gradient

Learning on the topic continued while working on practice questions that represented indicators of compiling evidence, providing reasons for the correctness of solutions, and checking the validity of an argument. In this problem, given two straight-line equations, students are asked to investigate whether the two lines are parallel to each other or not. If yes, determine the value of the gradient, and if not, give reasons, as shown in Figure 2.

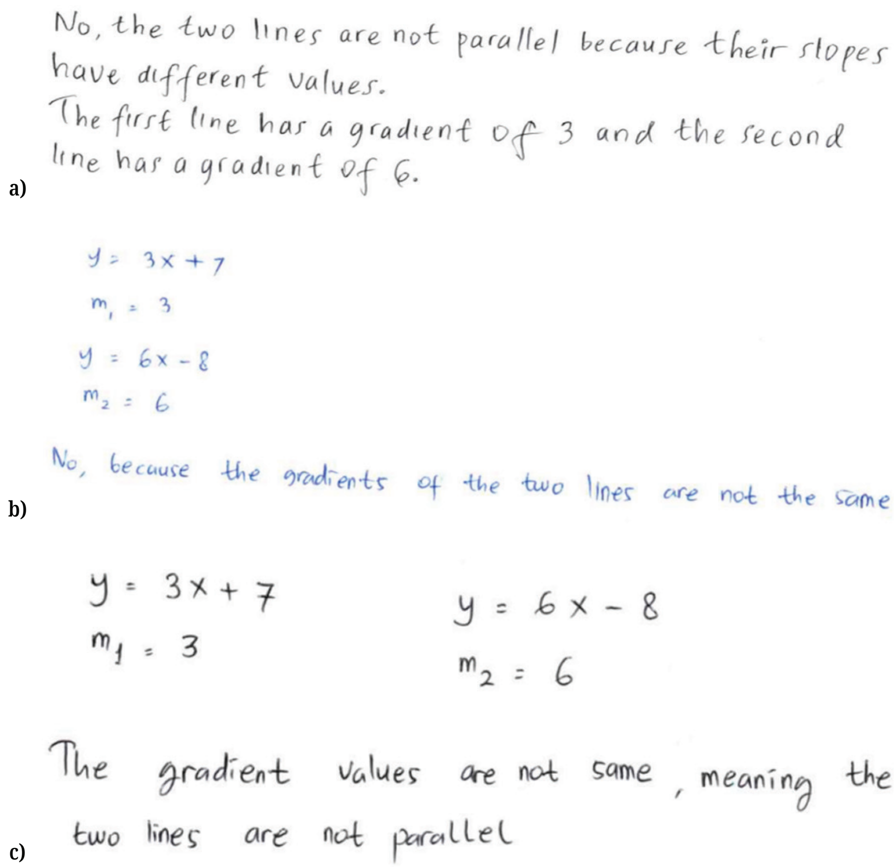


Fig. 2. Answers of students 1 (a), 2 (b), and 3 (c)

As can be seen in Figure 2, all three students reached a unanimous conclusion. All students started by computing the gradient of the given linear equations and subsequently proceeded to establish the correlation between the two lines with different gradients. This accomplishment was facilitated by prior exposure to the concept of parallel line gradients through GeoGebra. According to Mudaly [36], the use of the software enabled students to easily comprehend the linear equation concept through visualizations.

4.2 GeoGebra helps reinvent the concept of perpendicular and intersecting line gradient

The subsequent task instructed the students to comprehend the issue concerning the income graph of two third-year students subjected to private mathematics lessons. The objective of this activity was to familiarize the students with the concepts of perpendicular and intersecting line gradients. Furthermore, they were asked to determine the linear equation on both income graphs. The students attempted to input two points and determine the linear equation, as conducted in the preceding steps. Confusion was encountered in determining the points to be entered into GeoGebra. They were able to proceed with their work effectively after proper guidance was provided. There was no difficulty when using the software, as step-by-step instructions were available in the user manual.

After obtaining the linear equation, the intersection point was determined by selecting Intersect and clicking both lines. Since the two lines intersected, the angle formed can be known by clicking Angle on the toolbar, then points B, E, and C. After the angle size appeared on the GeoGebra screen, students determined the gradient of John and Mary's income graph by clicking Angle on the toolbar, then selecting Slope. Students can determine the presence of a positive or negative gradient in a given line through a detailed analysis of the gradient values on John and Mary's income graph. In particular, a line was deemed to have a positive and negative gradient when sloping toward the right and left. The students were tasked with finding the result of multiplying both gradients of John and Mary's income graphs. By observing the changes on the GeoGebra screen, students could conclude that the income graphs were perpendicular, $m_1 \times m_2 = -1$, as shown in Figure 3a.

Student 1 was able to complete and follow the given steps until the conclusion was obtained. This was different from students 2 and 3, who needed guidance and direction to follow the steps; hence, the purpose of the steps was explained, and students were asked to recall the learned material. Previous knowledge and experience enabled students to understand new concepts faster, retain their knowledge effectively, and transfer it to new situations more easily [37].

The next activity guided students to find the intersecting line gradient. They were asked to move point D on Mary's income graph up or down and observe the changes. To acquire information regarding the intersection of the two graphs, details on the angle formed should be provided. Likewise, it can be deduced that the two lines intersected when $m_1 \times m_2 \neq -1$ as shown in Figure 3b. According to Tatar [22], GeoGebra's interesting visualization, such as moving and changing its shape and size, could accommodate exploration and observation activities carried out by students more easily. The software provides features that are suitable for linear equation material, including the creation of points and linear lines as well as the determination of the equation of any arbitrary line.

a)

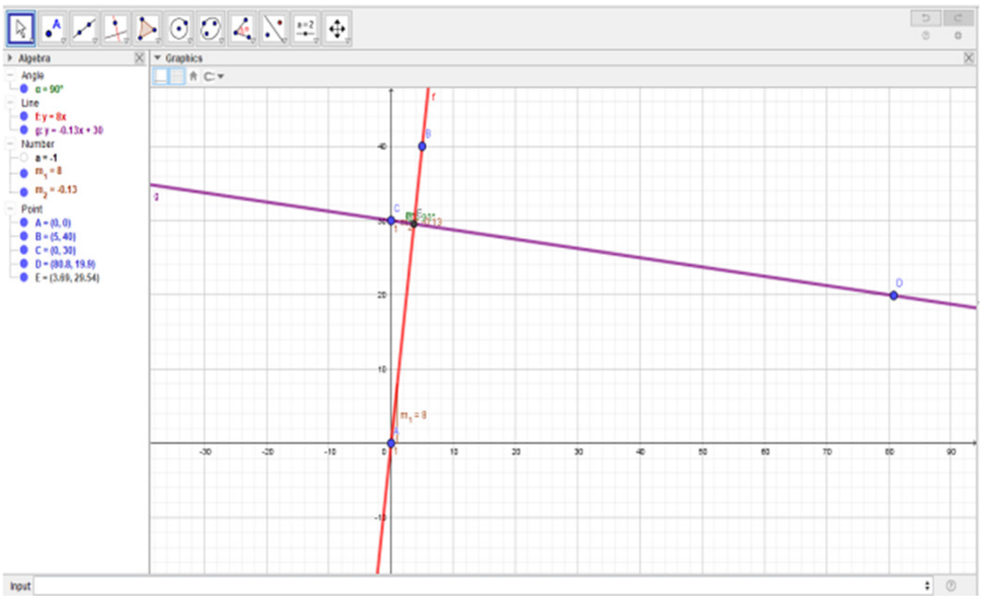
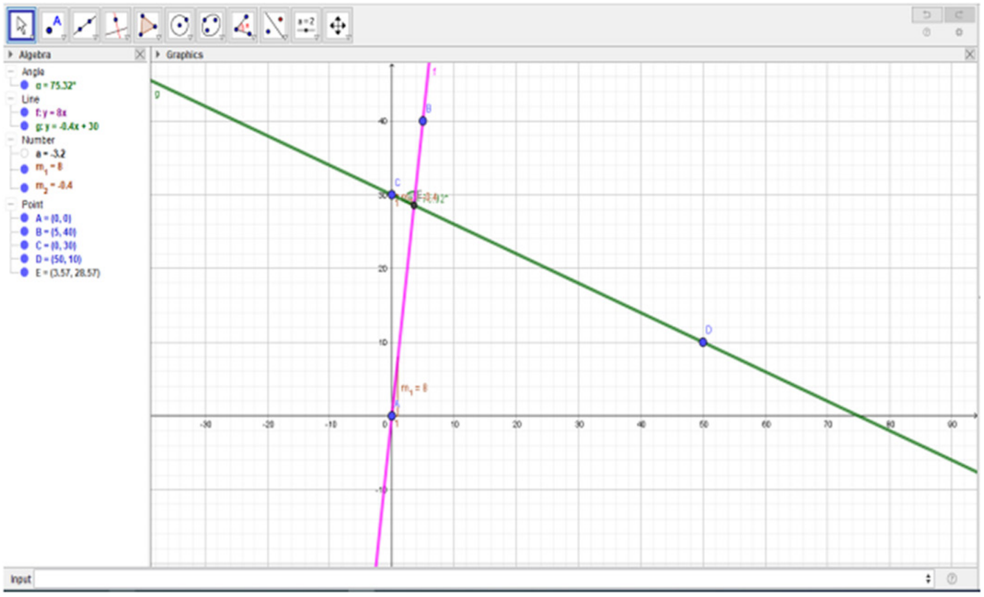


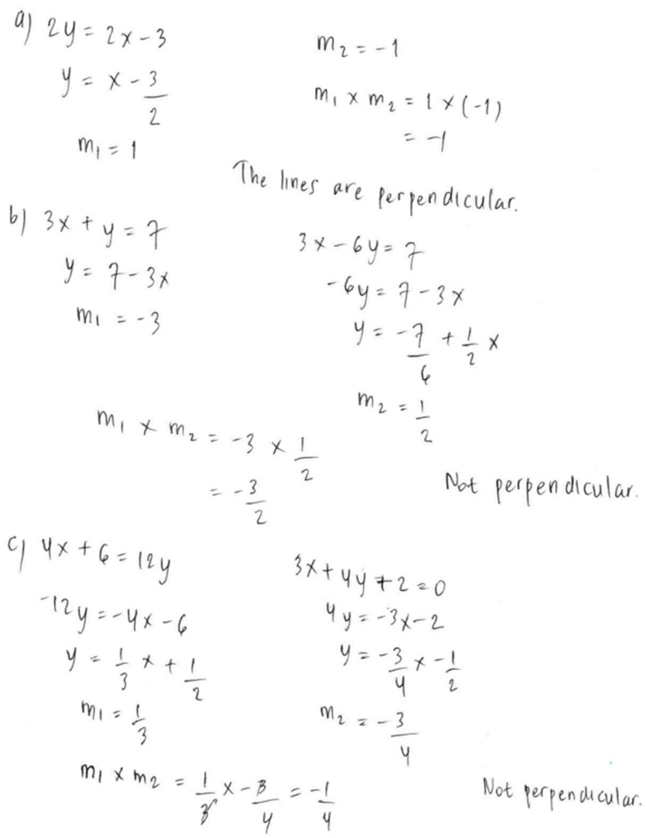
Fig. 3. *(Continued)*



b)

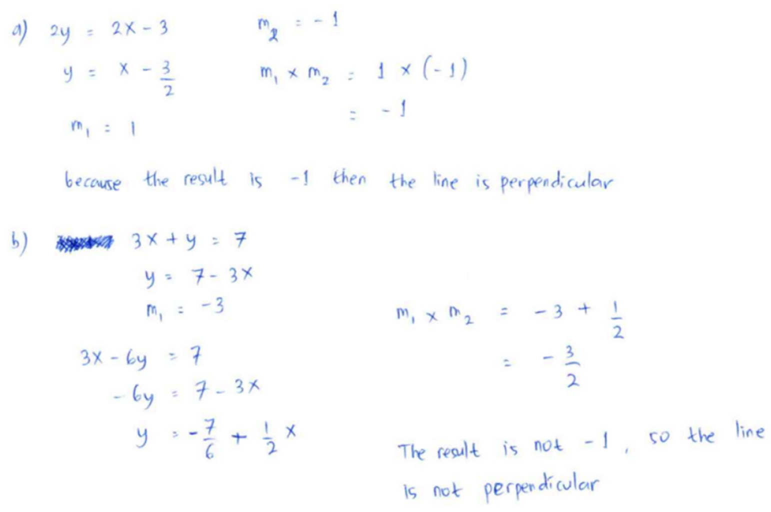
Fig. 3. Perpendicular (a) and intersecting (b) line gradient

Students carried out exercises that represented indicators of compiling evidence, providing reasons or evidence for the correctness of solutions, and drawing conclusions from statements. In this problem, students are asked to prove whether the straight-line equations given are perpendicular to each other or not, as shown in Figure 4.

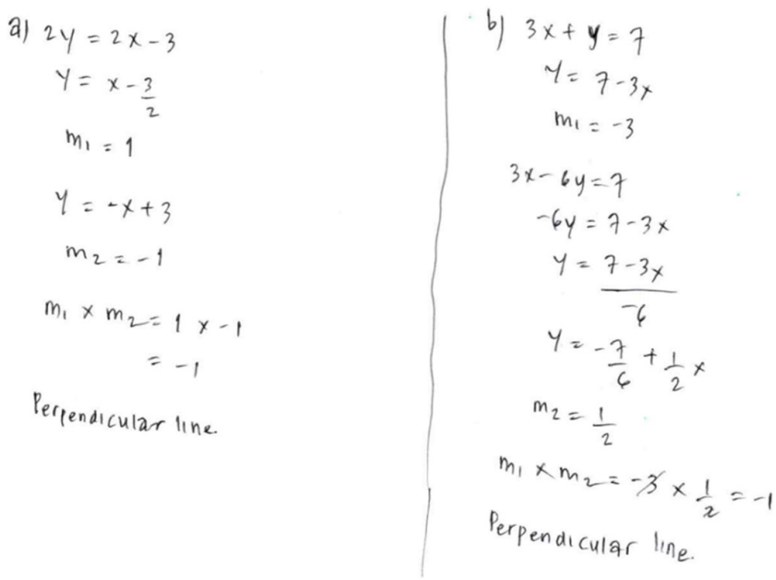


a)

Fig. 4. *(Continued)*



b)



c)

Fig. 4. Answers of Students 1 (a), 2 (b), and 3 (c)

Figure 4 shows that student 1's answer is in line with the expectation. Student 2 was already able to determine the gradient of each given line and draw a conclusion from the statements, but the answer to the third question was not visible. Meanwhile, student 3 was less careful in performing calculation operations, and the conclusion drawn became incorrect. The impact of using GeoGebra on students' mathematical reasoning ability was also observed, and the descriptive statistics of pre-test and post-test scores are shown in Table 2.

Table 2. Descriptive statistics of pre-test and post-test scores

Test	N	$\bar{x}$	s^2	Max Score	Min Score
Pre-test	31	48.12	202.35	70.83	16.67
Post-test	31	74.96	216.14	100	52.38

According to Table 2, the post-test average was higher than the pre-test average, with a difference of 26.84. GeoGebra assisted in improving students' after working on linear equation material provided in discovery learning and, thereby, was able to improve their mathematical reasoning ability. Based on the analysis of pre-test and post-test scores using the dependent t-test formula, $t_{count} = 5.064$ and $t_{table} = 1.697$ were obtained with a significant level $\propto = 0{,}05$ and degrees of freedom $(df) = 30$. Since $t_{count} > t_{table}$, H_0 was rejected, the students' mathematical reasoning ability improved after participating in discovery learning assisted by GeoGebra. Furthermore, the analysis of the percentage increase in the score of each ability indicator before and after using the software is presented in Table 3.

Table 3. Percentage of scores for each indicator of mathematical reasoning ability

Test	Percentage of Scores for Each Indicator (%)				
	1	3	4	5	6
Pre-test	80.65	36.29	46.24	37.10	40.30
Post-test	90.32	81.45	79.57	51.61	67.74
Increase	9.67	45.16	33.33	14.51	27.44

Table 3 shows that the percentage of scores for each mathematical reasoning ability indicator increased after participating in discovery learning assisted by GeoGebra. From these effectiveness test analysis results, it was concluded that the use of GeoGebra had a positive impact on mathematical reasoning ability, specifically in linear equation material. It was supported by Singh [38], who found a significant difference between the achievement of the experimental and control classes that followed learning with GeoGebra and the conventional method. Similarly, Celen [31] found that the use of the software made the mathematics learning process enjoyable and helped students concretize abstract concepts encountered in mathematics.

The use of digital media during learning was also very helpful in making students understand the material in a comfortable learning atmosphere [16]. The use of GeoGebra has enabled students to directly visualize the changes in position, shape, and size of geometry objects [39]. By employing GeoGebra in mathematics classes, which are generally perceived as difficult and abstract, the subject becomes more concrete, meaningful, and easily comprehensible [40]. Jelatu [41] and Öçal [42] supported the use of GeoGebra in geometry learning as it assists students to explore concepts more comprehensively and enhances their knowledge.

The use of the GeoGebra software helps students construct knowledge and check their answers. Students can obtain straight-line concepts from several problems that they solve with the help of the GeoGebra application. In addition, students can also construct their knowledge with the help of GeoGebra. This is in line with the findings of Umi [43], who mentioned that learning with the support of the GeoGebra application helps students draw graphs quickly. This provides opportunities for students to explore a wider variety of functions and allows them to make connections between symbolic and visual representations [44].

It can be concluded that the use of GeoGebra is effective in increasing the mathematical reasoning abilities of students. GeoGebra-assisted learning also gives students the ability to guess, analyze, manipulate, compile, and generalize. GeoGebra-assisted learning improves students' mathematical reasoning abilities [29]. Computers can act as learning aids. A number of studies have shown that GeoGebra can encourage student discovery and experimentation in the classroom. Its visualization feature can effectively help students propose various mathematical conjectures (Will You Know?) [45]. The use of GeoGebra offers students a greater understanding of algebra and geometry [46].

Students can better understand mathematical concepts and procedures through visuals and graphics in GeoGebra [47]. Learning using GeoGebra can make the learning process more active and increase interaction between teachers and students. For this reason, GeoGebra can be used in learning mathematics, especially calculus, to increase student achievement [33]. Furthermore, GeoGebra creates a fun and interesting environment and facilitates students' ability to concretize abstract concepts [22].

5 CONCLUSIONS AND RECOMMENDATIONS

This study found that GeoGebra is a valuable tool for students in discovering the fundamental properties of linear equations, specifically concerning the gradients of parallel, coincident, perpendicular, and intersecting lines. A positive impact on students' capacity for mathematical reasoning, particularly concerning the topic of linear equations, was evident in this study. Moreover, students are more actively engaged in the learning process due to the discovery of concepts, resulting in better retention of material. Therefore, this research recommends that teachers incorporate GeoGebra in teaching other mathematical concepts, particularly those that require students to engage in exploration of properties leading to making conjectures and proofs. GeoGebra is able to visualize abstract mathematical concepts. With the help of these visuals, students can use reasoning to solve problems. Students can easily visualize and check the graphs of functions to gather the information needed to draw conclusions. GeoGebra is a highly powerful tool for learning the topic of linear equations. Teachers are expected to use it in the learning process of mathematics.

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7 LIMITATION

This study has limitations in that students are not familiar with using GeoGebra in learning. It takes time to train them to use it. Computer facilities are also still limited, so it takes a lot of effort to be able to carry out the learning process.

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