Improving high school students' critical thinking ability in linear programming through problem based learning assisted by GeoGebra

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Abstract. Critical thinking is one of the important abilities in learning mathematics, but the fact shows most high school students in Aceh have not developed the thinking skill yet. One of the causes is the mathematics learning that is carried out does not pay attention to critical thinking skills. This study aims to determine the increase in students' critical thinking skills in linear programming learning through the Problem Based Learning (PBL) model assisted by GeoGebra Software in SMA Negeri 2 Teupah Barat. This research is a semi-experimental study with one group pre-test post-test design. The population in this study were all 24 students of class XI at SMA Negeri 2 Teupah Barat. A sample of 10 students was selected using the purposive sampling technique. The instrument used was the pre-test and post-test questions on critical thinking skills. The data were analyzed using SPSS 25 software including data description, normality test, paired sample t-test, and N-Gain score. The results showed that the use of the PBL model assisted by GeoGebra software can improve students' critical thinking skills on linear programming material at SMA Negeri 2 Teupah Barat with an average increase in students' critical thinking skills of 50.05%, a minimum increase of 36.53% and a maximum increase of 63.57%.

Keywords: Critical Thinking Ability, Problem Based Learning (PBL) Model, GeoGebra Software

1. Introduction

Mathematics is one of the important subjects for students at every level. Mathematics subjects need to be given to equip students with the ability to think logically, analytically, systematically, critically and creatively, as well as the ability to work together [1]. NCTM [2] defines five standards for mathematical abilities that students must have, namely problem solving skills, communication skills, connection skills, reasoning skills, and representation skills. In the Education Unit Level Curriculum (KTSP) it is stated that mathematics subjects need to be given to all students starting from elementary school to equip students with the ability to think logically, analytically, systematically, critically, and creatively, and the ability to work together [3].

One of the effects obtained from studying mathematics is the formation of critical thinking skills. This critical thinking ability is not only needed in learning at school, but it is also very necessary in everyday life. As we know, currently, technological developments can allow a person to get information easily just by using internet access. However, whether the information obtained is true or not is a
problem in the social environment, especially in the environment of students who sometimes cannot distinguish which information can be trusted or not. Therefore, critical thinking is needed to overcome this problem. Asari [4] states critical thinking enables each individual to sort and select valid and reliable information that is mixed with hoax information (lies).

Ennis [5] defines, “critical thinking is reasonable and reflective thinking focused on deciding what to believe or do”. Furthermore, Facione [6] states that critical thinking is the ability to express, analyze, evaluate, conclude, explain and self-organize. Another opinion expressed by Hidayah et al. [7], states that the ability to think critically is the ability to think logically, reflectively, systematically and productively which is applied in making good judgments and making decisions. Based on the above opinions, critical thinking skills are important for students because the skills allow someone to interpret a problem, analyze arguments logically, reflectively, systematically and productively, evaluate or provide judgments, and make conclusions.

However, in reality, the critical thinking skills of students in Indonesia have not showed encouraging results. Based on the results of the 2018 Program for International Student Assessment (PISA) survey that was presented by The Organization for Economic Co-operation and Development (OECD) on December 3, 2019, it shows that the scores of Indonesian children in mathematics are still below average and has decreased compared to the previous year. The PISA score in Indonesian mathematics in 2018 ranges from 379 to the average PISA score of 489 OECD member countries and is ranked 72 out of 78 participants [9]. Whereas in the previous year 2015 the PISA score in Indonesian mathematics was around 386 from the OECD member countries' average PISA score of 490 and was ranked 63 out of 69 participants [8].

Based on the PISA results, The author made direct observations by providing critical thinking questions on the material of the two-variable linear equation system to 24 students of class XI at SMA Negeri 2 Teupah Barat on January 18, 2020 as follows.

Given the following two-variable system of linear equations.

(a) \[
\begin{align*}
    x + y &= 4 \\
    x + y &= -1 
\end{align*}
\]

Does the two-variable system of linear equations have a solution?

Describe and accompanied by graphs or other.

Student answers obtained from the test results of critical thinking skills through the Two Variable Linear Equation System questions can be seen as in the picture below.

![Figure 1.1 Student Answer Sheet (S1) results from initial observations.](image-url)
The student's answer (S1) in Figure 1.1 above shows that the student is able to interpret the problem by changing the form of a two-variable system of linear equations into graphs of two straight lines and analyzing the problem by sorting the two equations then looking for the relationship through the graphs. After being asked why he answered that way, the student answered "like this I know sir".

![Image of graph]

**Figure 1.2** Student Answer Sheet (S2) preliminary observation results.

The student's answer (S2) in Figure 1.2 above shows that the student performed the analysis by eliminating the two equations so that the x and y variables were vanished.

Based on the two students' answers above, students are only fixated on solving the equation, but do not pay attention to the questions carefully. Because these questions can be answered only by paying attention to the problem by using reasoning. Some of the factors that cause students' critical thinking skills to be unsatisfactory according to the author include: (1) learning is still centered on the dominating teachers, causing students to be dependent and not independent; (2) lack of innovation made by teachers in learning, both related to models, approaches, and techniques; (3) inadequate media or teaching aids at school to complement learning activities; (4) students' lack of understanding of mathematics so that it hinders their critical thinking skills; and (5) students consider mathematics difficult; (6) mathematics lessons are abstract.

Responding to the problems above, one of the actions that can be taken to facilitate students in practicing critical thinking skills is by applying the Problem Based Learning (PBL) model in their learning. Glazer [10] states that the PBL model emphasizes learning as a process that involves problem solving and critical thinking in an actual context. Glazer further argued that the PBL model provides opportunities for students to study a broader range of subjects that focus on preparing students to become active and responsible citizens. Furthermore, Sumarno [11] suggests that one of the learning approaches to motivate students to think critically is by proposing problems as outlined in the form of questions. Then Hmelo-silver & Barrows [12] states that the problems that arise in PBL learning do not have a single answer, meaning that students must be involved in exploration with several paths of solution.

Another cause of the lack of critical thinking skills that the writer suspects is that the media or teaching aids in schools are still lacking in revitalizing learning activities. One of the learning media solutions that can be used in learning mathematics is GeoGebra software. Hohenwarter et al. [13] revealed "GeoGebra is a dynamic mathematical software that combines geometry, algebra and calculus". This program can be used freely and for free which can be downloaded from [www.geogebra.com](http://www.geogebra.com). Furthermore, Hohenwarter et al. [13] added that the GeoGebra program is very beneficial for both teachers and students. Unlike the use of commercial software which can usually only be used in schools, GeoGebra can be installed on personal computers and used anytime and anywhere by students and teachers.

Based on the description above, the authors are interested in directly examining the effect of collaboration between PBL models and GeoGebra software in improving students' critical thinking skills. Previous research has been carried out by other researchers regarding the PBL model to improve critical thinking skills, namely research conducted by Firdaus, Kailani, Bakar and Bakry [14]. Furthermore, Sari et al. [15] research on improving students' critical thinking skills in mathematics.
through problem-based learning. Then Schaver's [16] research, on the effect of GeoGebra on student achievement scores, critical thinking / problem solving skills of students, and student involvement / motivation. While the research to be carried out in this study aims to determine the level of students' critical thinking skills through the application of the PBL model assisted by GeoGebra software. The hypothesis raised in this study is that there is an increase in students' critical thinking skills after the application of the Problem Based Learning (PBL) learning model assisted by GeoGebra Software on linear programming material in SMA Negeri 2 Teupah Barat.

2. Method
This type of research is a quasi-experimental research with one group pretest-posttest design, which aims to determine the increase in students' critical thinking skills before and after the application of problem-based learning models assisted by GeoGebra software on linear programming material. Sugiyono [17] one group pretest and posttest design is a technique to determine the effects before and after treatment. The research was conducted on students of class XI at SMAN 2 Teupah Barat, with a sample consisting of 10 students from 24 students in total. The 10 students selected have different abilities based on their learning outcomes. According to Sugiyono [18], this kind of sample selection is a purposive sampling technique.

This research was conducted on July 13, 2020 to July 16, 2020. The study began with giving a pretest to students to find out their initial score of critical thinking skills. The learning carried out in the computer lab was followed by 10 students who were the participants in this study. Learning is carried out by the author himself for 4 meetings with a time allocation of 2 times 45 minutes per meeting. Then after carrying out the learning, the researcher gave the students a post-test. The post-test was carried out with the aim of knowing the final score of students' critical thinking skills to see whether there was an increase in students' critical thinking skills before and after the application of the PBL model assisted by GeoGebra software in learning linear programming for class XI at SMAN 2 Teupah Barat.

Learning is carried out by applying the steps / syntax of the problem-based learning model (PBL). A problem in everyday life is given to students through student worksheets, then students are asked to solve the problem by answering each question. GeoGebra software is used to evaluate graphical images of the problem-solving areas on student worksheets. In addition, the GeoGebra software is also used by students to explore these graphic images.

Learning with the PBL model is carried out in a computer laboratory room. Students consisting of 10 people each are provided with 1 computer that has GeoGebra software installed during the learning process. Learning with the GeoGebra Software assisted PBL model cannot be carried out in full according to the syntax set out in the RPP because it coincides with the Covid-19 pandemic period. So, because they have to comply with health protocols recommended by the government, LKS which should be done in groups, in this learning is done individually.

The instruments used in this study were pre-test and post-test questions with indicators of critical thinking questions. Before giving questions to students, the pre-test and post-test questions were validated first by the validators. Furthermore, the validation results are revised according to the suggestions of the validator. The revised pre-test and post-test questions were then used as instruments in this study. In addition to the research instruments in the form of pre-test and post-test questions, there is a learning tool in the form of a learning implementation plan which is used as a guide in conducting research.

Critical thinking indicators containing pre-test and post-test questions in this study include interpretation, analysis, evaluation and conclusions. The following instruments are used in this study.
Tabel 2.1. Research Instruments

Critical Thinking Problem

1. A public shopping area has a 260 sq m parking area. It is known that the road area in the parking lot is 68 square meters, the average parking area for motorbikes is 3 square meters and the ratio of parking areas for motorbikes and cars is 1:4. The parking lot only accepts 40 vehicles per hour. Parking fees for motorbikes are IDR 1,000 / hour and for cars IDR 5,000 / hour. If in 1 hour there are no vehicles going and coming, then determine the maximum income from the parking space in 1 hour! Please answer each question below!

a. In your opinion, what information is needed to solve this problem?

b. Are there any obstacles to solving the problems above? If so, write down the constraints!

c. How do you solve the problem? Write down how and how to solve it!

d. How do you evaluate the right or wrong of the completion process that you are doing?

e. What conclusions did you reach?

2. Find the minimum value \( f(x, y) = 3 + 4x - 5y \) for \( x \) and \( y \) that satisfy

\[
\begin{align*}
-x + y &\leq 1 \\
x + 2y &\geq 5 \\
2x + y &\leq 10
\end{align*}
\]

Check the answers to these questions in the table below by providing information (true / false) and providing reasons/explanations!

| Answer Given | Student Responses |
|--------------|-------------------|
| Given the constraints to get the minimum value of \( f(x, y) = 3 + 4x - 5y \) is \(-x + y \leq 1, x + 2y \geq 5, \) and \( 2x + y \leq 10. \) | True/False Reason/Explanation |
| (i) \(-x + y \leq 1\) | \(\begin{array}{c|c}
x & y \\ \hline 0 & 1 \\ -1 & 0 \end{array}\) |
| The inequality boundary (i) intersects the x and y axes at the point respectively \((0,1)\) and \((-1,0)\) | |
| (ii) \(x + 2y \geq 5\) | Line equation \(x + 2y = 5\) through point \((0,\frac{5}{2})\) dan \((5,0)\) |
| (iii) \(2x + y \leq 10\) | \(\begin{array}{c|c}
x & y \\ \hline 0 & 10 \\ 5 & 0 \end{array}\) |
In your opinion, is the shaded area in the graphic above the settlement area?

- Point A is at the intersection of lines ii and iii
  \[
  x + 2y = 5 \quad \times 2 \quad 2x + 4y = 10 \\
  2x + y = 10 \quad \times 1 \quad 2x + y = 10 \\
  \]
  \[
  = 10 \\
  \]
  \[
  3y = 0 \\
  y = 0 \rightarrow x = 5
  \]
  Obtained point A(5,0)
  In your opinion, is the statement above correct?

- Point B is the intersection of lines i and iii
  \[
  -x + y = 1 \\
  2x + y = 10
  \]
  \[
  3x = 9 \\
  x = 3 \rightarrow y = 4
  \]
  Obtained point B(3,4)

| (x, y) | f(x, y) = 3 + 4x - 5y |
|--------|------------------------|
| A(1,2) | -3                     |
| B(3,4) | -5 \rightarrow Minimum |
| C(5,0) | 17                     |

So the minimum value is at point B(3,4), which is -5

3. Look carefully at the image below!

In your opinion, how is the relationship between each settlement area (in terms of inequality) in the graphic above? Write down each step you took to answer the question!
3. Results and Discussions

3.1. Research result

3.1.1. Data Description Students' Critical Thinking Ability. The following is the analysis of data descriptions of students' critical thinking skills before and after implementing the PBL model assisted by GeoGebra Software at SMA Negeri 2 Teupah Barat based on pre-test and post-test data using SPSS 25.

**Table 3.1** Deskripsi Data Hasil Penelitian Kemampuan Berpikir Kritis menggunakan SPSS 25

|          | N   | Minimum | Maximum | Mean  | Std. Deviation |
|----------|-----|---------|---------|-------|----------------|
| Pre-test | 10  | 3.32    | 29.62   | 14.79 | 8.46           |
| Post-test| 9   | 24.20   | 77.60   | 56.40 | 19.35          |

The data above shows that the number of subjects in this study amounted to 10 people. The number of subjects who took the pre-test was 10 people with a minimum score of 3.32, a maximum score of 29.63, an average value of 14.79, and a standard deviation of 1.45. While the number of subjects who took the post-test was 9 people with a minimum score of 24.20, a maximum score of 77.60, an average value of 56.40, and a standard deviation of 19.34.

3.1.2. Normality Test of Pre-Test and Post-Test Data on Critical Thinking Ability. The following shows the results of the Kolmogorov-Smirnov and Shapiro-Wilk normality test using SPSS 25. The basis for decision making in the Kolmogorov-Smirnov and Shapiro-Wilk normality test, namely:
- If the significance value > 0.05, then the data is normally distributed
- If the significance value < 0.05, then the data are not normally distributed

**Table 3.2** Normality Test Using Kolmogorov-Smirnov and Shapiro-Wilk

|       | Kolmogorov-Smirnov | Shapiro-Wilk |
|-------|--------------------|--------------|
|       | Statistics df Sig. | Statistics df Sig. |
| Pre-test | 0.171 9 0.200     | 0.961 9 0.813 |
| Post-test| 0.210 9 0.200     | 0.911 9 0.321 |

Based on table 4.2 above, it is known that the significance value (Sig.) of the pre-test data on the Kolmogorov-Smirnov test is 0.200 > 0.05 and the Shapiro-Wilk test is 0.813 > 0.05, so it can be concluded that the pre-test data is normally distributed. Furthermore, the significance value (Sig.) Of the post-test data on the Kolmogorov-Smirnov test 0.200> 0.05 and the Shapiro-Wilk test 0.32> 0.05 so it can be concluded that the post-test data is normally distributed. Because the two data are normally distributed, we can then do the paired sample t-test to analyze the research data.

3.1.3. Paired Sample t-Test. Paired sample t test is used to determine whether there is a difference in the mean of the two paired samples, namely the pre-test and post-test scores of students' critical thinking skills before and after learning using the Problem Based Learning (PBL) learning model assisted by GeoGebra Software with basic hypothesis of decision making as follows.

- $H_0$ : there is no difference between the mean score of the pre-test and the average post-test score of students' critical thinking skills
- $H_a$ : there is a difference in the average pre-test score and the average post-test score of students' critical thinking skills
If the value is Sig. (2-tailed) < 0.05, then reject $H_0$, meaning that there is a significant difference between students' critical abilities in the pre-test and post-test data. Meanwhile, if the value is Sig. (2-tailed) > 0.05, then $H_0$ is accepted, meaning that there is no significant difference between students' critical abilities in the pre-test and post-test data. The following are the results of the paired sample t test using SPSS 25.

| Pair   | Pre-test – Post-test | Mean  | Std. Deviation | Std. Error | 95% Confidence Interval of the Difference | t     | df  | Sig.(2-tailed) |
|--------|----------------------|-------|----------------|-----------|------------------------------------------|-------|-----|----------------|
| 1      |                      | -41.21| 11.70          | 3.90      | -50.20 to -32.22                         | -10.57| 8   | 0.000          |

Based on the results of the paired sample t-test using SPSS 25, the Sig. (2-tailed) of 0.00 < 0.05 (reject $H_0$), it can be concluded that there is a significant difference between the average student learning outcomes before and after learning using the Problem Based Learning (PBL) learning model assisted by GeoGebra Software.

3.1.4. **N-Gain Score of Students' Critical Thinking Ability.** The N-Gain score aims to determine the increase in students' critical thinking skills after the application of the Problem Based Learning (PBL) learning model assisted by GeoGebra Software on Linear programming material at SMA Negeri 2 Teupah Barat.

The formula for calculating the N-Gain score value:

$$N Gain = \frac{Posttest Score – Pretest Score}{Ideal Skor – Skor Pretest}$$

| N-Gain Value (%) | Category  |
|------------------|-----------|
| $g > 70$         | High      |
| $30 \leq g \leq 70$ | Moderate |
| $g < 30$         | Low       |

Source: Melzer in Syahfitri [19]

The following is the N-Gain score data for students' critical thinking abilities, including each student's N-Gain score, the average N-Gain score, the minimum N-Gain score, and the maximum N-Gain score. Based on the calculation of the N-Gain score using SPSS 25, it shows that the average N-Gain score is 50.05% with a minimum N-Gain score of 36.53% and a maximum N-Gain score of 63.57%. So it can be concluded that there is an increase in students' critical thinking skills after the application of the Problem Based Learning (PBL) learning model assisted by GeoGebra Software on linear programming material at SMA Negeri 2 Teupah Barat. Because the average N-Gain score of 50.05 is in the range of $30 \leq g \leq 70$, the increase in students' critical thinking skills after implementing learning using the Problem Based Learning (PBL) model assisted by GeoGebra Software is in the "medium" category.
### Table 3.5 Calculation Results of the N-Gain Score for Critical Thinking Ability using SPSS 25

| No. | N-Gain Score (%) |
|-----|------------------|
| 1   | 68.17            |
| 2   | 70.78            |
| 3   | 64.83            |
| 4   | 40.72            |
| 5   | 52.92            |
| 6   | 21.60            |
| 7   | 31.17            |
| 8   | 61.00            |
| 9   | 39.26            |
|     | Average          | 50.05            |
|     | Minimum          | 21.60            |
|     | Maximum          | 70.78            |

### 3.2. Discussion

Based on the results of data analysis and statistical tests, it is known that there is a significant difference between the average student learning outcomes before and after the application of learning using the Problem Based Learning (PBL) learning model assisted by GeoGebra software. Furthermore, based on the calculation of the N-Gain score, it was obtained an increase in students’ critical thinking skills after carrying out learning using the Problem Based Learning (PBL) model assisted by GeoGebra Software in the "medium" category with an average increase of 50.05%. Therefore, the application of the PBL model assisted by GeoGebra software has the effect of increasing students’ critical thinking skills. The findings of this study are in line with the findings of previous research conducted by Firdaus, Kailani, Bakar and Bakry [14], that there is a positive effect of using PBL-based mathematics learning modules on the improvement of students’ critical thinking skills in mathematics.

The Problem Based Learning (PBL) learning model can hone students' critical thinking skills through the stages of learning. Stage 1, provides orientation about actual and authentic problems to students. At this stage, students must clearly know the objectives that must be mastered, accept and understand what is learned from the problem to be sought for a solution. Along with this stage, students are indirectly honing their critical thinking skills, namely interpretation. Stage 2, organizing students to learn. At this stage, students will identify, organize learning tasks related to the given problem and create boundaries to be studied. Along with this stage, students carry out an analysis by investigating the intent of the problem. The analysis process carried out at this stage is an indicator of critical thinking. Stage 3, guiding individual and group investigations. Students collect appropriate information, carry out experiments to get explanations and problem solving. Similar to stage 2, at this stage students carry out an analysis by investigating the correct information from various sources, then linking it. Stage 4, develops and presents the work. At this stage, students will compile a report and present it in a class discussion. Along with this stage, students are required to select the information needed, and arrange it according to the stages to get a solution. The indicator of critical thinking at this stage is to make conclusions. Stage 5, analyzes and evaluates the problem-solving process. At this stage, students together with the teacher reflect or evaluate their investigations and the processes they use. The critical thinking indicator that is honed at this stage is that students can check and test the truth of the results of the investigations they have done.

Furthermore, because the subject matter in this study is linear programming, the GeoGebra software can be used by students in evaluating the graphic images of the settlement area that they draw manually. In addition, students can also use geogebra software to explore every possibility that occurs when the graphic images are altered. Therefore, this learning media can be collaborated with problem-based learning models to improve students’ critical thinking skills, especially on linear program material.
4. Conclusion
The results showed that there was an increase in students’ critical thinking skills after the application of the Problem Based Learning (PBL) learning model assisted by GeoGebra software on the linear programming material at SMA Negeri 2 Teupah Barat with the “medium” category of N-gain. The average increase in students’ critical thinking skills was 50.05%, a minimum increase of 36.53% and a maximum increase of 63.57%. For further research from the results of this study what can be done is whether the increase in test scores is caused by PBL alone, the results of the collaboration between PBL and GeoGebra software, or by other factors.

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