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DEEP LEARNING–BASED PROBLEM-BASED LEARNING: AN EFFORT TO ENHANCE THE MATHEMATICAL REFLECTIVE ABILITIES OF JUNIOR HIGH SCHOOL STUDENTS

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Abstract

This study aims to investigate the implementation of learning using a Problem-Based Learning (PBL) approach based on deep learning to improve students' mathematical reflective thinking skills. The population of the study consisted of all eighth-grade students of a junior high school in the odd semester of the 2024/2025 academic year, with one class selected as the research subject. The sample was taken using a purposive sampling technique. This study employed a quantitative approach with a quasi-experimental design of the One-Group Pretest–Posttest type. The data were collected through tests of students' mathematical reflective thinking skills and classroom observations, and analyzed using descriptive and inferential statistics. The results showed that the average pretest score was 58.96, which increased to 74.96 in the posttest. Classroom observations indicated that students actively engaged in problem identification, group discussions, evaluation of solution strategies, and reflective reasoning during the learning process. The Kolmogorov–Smirnov normality test indicated that the data were normally distributed (p = 0.20), and Levene's test showed homogeneous variances (p = 0.20). The paired-sample t-test revealed a significant improvement in students' reflective thinking skills (t = -59.084; p < 0.05). The Normalized Gain (N-Gain) calculation showed an average of 0.40, categorized as medium. Thus, the implementation of PBL based on deep learning can significantly enhance students' mathematical reflective thinking skills.

Keyword: *Deep Learning, Mathematical Reflective Thinking, Problem-Based Learning*

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INTRODUCTION

Mathematical reflective thinking is the ability of students to review the manner in which they solve mathematical problems [1]. This ability enables students to understand the reasoning underlying their answers and to consciously correct errors [2]. In mathematics education, reflective thinking plays a crucial role, as it assists students in connecting procedures, concepts, and logical reasoning, thereby rendering learning more meaningful and continuous [3]. Furthermore, within mathematics education, reflective thinking serves as a foundation for the development of higher-order thinking skills, as it encourages students to analyze, evaluate, and synthesize information more deeply [4].

However, in practice, many students still experience difficulties in reflecting upon the steps involved in problem-solving. Instruction that is overly focused on procedures and final answers tends to result in superficial and less meaningful understanding. Students are rarely encouraged to reexamine the decisions they have made, evaluate errors, or consider alternative and more efficient strategies, even though such activities constitute the core of higher-order and reflective thinking. This is consistent with research [5], which states that reflective thinking is often neglected due to excessive emphasis on final answers, thereby indicating that students require greater ability to evaluate and reconstruct their problem-solving processes. Similar findings were reported by [6], showing that most students are not yet capable of effectively evaluating problem-solving steps, leading to the recurrence of similar errors. Furthermore, research [7] emphasizes that low levels of mathematical reflection are closely associated with teacher-centered instructional patterns, which limit students' opportunities to construct understanding independently [6]. In addition, students' low academic achievement indicates that classroom instruction remains dominated by an expository approach, in which the teacher serves as the primary source of information, resulting in students being passive and less engaged in deep thinking processes [8].

These findings reinforce the view that mathematical reflective ability remains an aspect requiring further development; therefore, an instructional model that facilitates deeper processes of analysis, evaluation, and reconstruction of problem-solving strategies is needed. As a response to this issue, the Problem-Based Learning (PBL) model is considered capable of enhancing the quality of mathematics instruction. Problem-Based Learning (PBL) is a contextual learning model that employs problems as the central focus of instruction and can be implemented to increase students' learning activities [9]. In learning through the PBL model, students are presented with a problem to be examined from the outset [10]. This approach encourages students to design learning strategies, assess their thinking processes, and reflect on the extent to which the decisions they make are effective throughout the learning process [11].

Hayun and Syawaly (2020), as cited in [12], explain that the PBL model consists of five principal stages: introducing students to the problem to be examined, organizing students'

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learning activities, providing guidance both individually and in groups, facilitating the development of observational results and the presentation of group reports, and conducting analysis and evaluation of the problem-solving process that has been undertaken.

The PBL model also possesses several limitations. In its implementation in the topic of Systems of Linear Equations in Two Variables (SPLDV), students are required to connect their prior understanding of single-variable linear equations with the concept of two variables within real-world problem contexts. When students have not yet mastered the fundamental concepts of linear equations, they tend to encounter difficulties in identifying variables, constructing mathematical models, and determining appropriate solution methods. Moreover, some students are not accustomed to conducting information searches or preliminary studies from various sources to assist in problem-solving. Consequently, differences in students' prior abilities influence the accuracy with which they relate previously learned concepts to new situations or problems [13]. To address this issue, the implementation of a deep learning approach is required, as it encourages students to develop a more profound conceptual understanding, establish connections among concepts, and apply knowledge in authentic contexts. This approach also facilitates students in evaluating the solution processes they undertake, identifying errors, and reflecting on the appropriateness of the strategies employed. Thus, the limitations of PBL related to minimal information exploration and insufficient integration of knowledge can be mitigated [14].

Deep learning in the field of education is an instructional approach that emphasizes profound understanding through active engagement, reflection, and the development of higher-order thinking skills [15]. The deep learning approach is grounded in three principal tenets: mindful, meaningful, and joyful learning [16]. Mindful learning requires students to maintain focus and full awareness of the learning process, enabling them to reflect upon and understand their own patterns of thinking [17]. The principle of meaningful learning lies in efforts to connect instructional material with real-life situations that are closely related to students' experiences, so that the information learned is not only understood conceptually but can also be applied, retained longer, and perceived as beneficial in everyday contexts [18]. Joyful learning is a principle that emphasizes the creation of an enjoyable learning environment; its implementation in the classroom involves presenting interactive and engaging learning activities to enhance students' involvement [15].

In the context of this study, the deep learning approach is relevant to the development of mathematical reflective thinking skills, which encompass the ability to interpret cases based on mathematical concepts, identify concepts or formulas in non-routine problems, evaluate the validity of arguments, analyze and generalize mathematical ideas, and solve problems. The mindful principle encourages students to be aware of and examine their thinking processes when determining the concepts employed

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and evaluating the correctness of solution steps. The meaningful principle assists students in connecting mathematical concepts with real-life situations, enabling them to interpret cases and generalize ideas more profoundly. Meanwhile, the joyful principle fosters a learning environment that supports discussion and reflection, allowing students to be more open in identifying errors and refining problem-solving strategies. Thus, these three principles directly support the indicators of mathematical reflective thinking ability examined in this study.

The effectiveness of PBL can be further optimized when integrated with an approach that emphasizes deep understanding and continuous reflective processes, such as deep learning [19]. The PBL and deep learning models share similar paradigmatic foundations, both being oriented toward active, meaningful, and student-centered learning [20], [21]. In PBL, students engage in the exploration of real-world problems to discover solutions through dialogue and collaborative work [20]. Deep learning emphasizes learning experiences that are mindful, meaningful, and joyful [22]. The deep learning approach enhances the success of PBL by helping students grasp the conceptual meaning underlying the problems they solve, rather than merely obtaining answers [23]. When students encounter contextual problems in PBL, deep learning encourages them to reflect on the strategies employed, connect learning experiences with real-life situations, and construct personal meaning of the mathematical concepts studied [24].

Nevertheless, the implementation of these two approaches remains infrequently optimized in mathematics instruction, particularly for enhancing mathematical reflective thinking, which has been shown to remain low in various previous studies [5]. In fact, mathematical reflective ability requires deep thinking, reanalysis of solution steps, and awareness in evaluating the strategies employed—elements directly facilitated by the combination of PBL and deep learning [19],[23]. Therefore, the application of a Deep Learning–based Problem-Based Learning model represents a relevant and urgent solution for implementation. Through this integration, students are expected to critically review their thinking processes, understand the meaning behind each problem-solving step, and connect mathematical concepts in a deeper and more meaningful way. Based on this rationale, the present study aims to investigate whether the implementation of Deep Learning–based Problem-Based Learning can enhance the mathematical reflective thinking abilities of junior high school students.

METHOD

This study employed a quantitative approach with a quasi-experimental design of the One-Group Pretest–Posttest type. This design was chosen because the researchers used only a single group without a control group, yet administered both a pretest and posttest to examine the effect of the treatment on students' mathematical reflective thinking abilities [25]. Moreover, according to [26], this design is effective for

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observing changes in students' abilities before and after receiving the treatment, thereby facilitating the researchers' assessment of the effectiveness of the implemented instructional model.

Research Design Scheme:
O_1 — X — O_2
Description:
- **O_1** : Pretest of Mathematical Reflective Thinking Ability
- **X** : The treatment consisted of Deep Learning–based Problem-Based Learning instruction.
- **O_2** : Posttest of Mathematical Reflective Thinking Ability

The subjects of this study were eighth-grade students at a junior high school in Cilegon City. The sample was selected using purposive sampling [26], choosing a class that met the criteria of learning readiness and schedule suitability. The number of students in the selected class was 25. Students were administered a pretest to determine their initial abilities, then received treatment in the form of Deep Learning–based Problem-Based Learning instruction, and subsequently were given a posttest to assess the improvement in their mathematical reflective thinking abilities following the intervention. This study involved two main variables: the independent variable, namely the Deep Learning–based Problem-Based Learning model (PBL-DL), which refers to the implementation of problem-based instruction integrated with deep learning strategies to promote students' deep thinking processes [4], [27], [28]; and the dependent variable, namely students' mathematical reflective thinking ability, defined as their capacity to review, evaluate, and improve the mathematical problem-solving processes they undertake [1].

The implementation of the Deep Learning–based Problem-Based Learning model (PBL-DL) in this study was carried out through several stages: (1) orientation to contextual problems related to students' real-life experiences (meaningful), (2) organization of students into groups to discuss and identify relevant concepts, (3) investigation and collection of information from various sources, (4) development and presentation of discussion results, and (5) analysis and evaluation of the problem-solving process.

The research instrument consisted of a test of mathematical reflective thinking ability, developed based on the reflective thinking indicators according to [29], which include the ability to interpret cases based on the involved mathematical concepts, identify concepts or formulas in non-routine problems, evaluate the validity of arguments based on the properties or concepts used, analyze and generalize mathematical ideas, and solve mathematical problems. This instrument was structured in the form of five essay items representing each of these indicators. In addition to the test of mathematical reflective thinking ability, the study also employed an observation sheet to monitor the implementation of the Deep Learning–based PBL model during the learning process. The observation sheet was used to ensure that the principles of mindful, meaningful, and joyful learning were carried out in accordance with the designed instructional syntax.

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The pretest and posttest data were analyzed using descriptive and inferential statistics. Descriptive analysis was employed to observe the increase in mean scores. This increase was calculated using the N-gain formula, as follows:

$$N-gain = \frac{Skor\ Posttest - Skor\ pretest}{Skor\ maksimal - Skor\ pretest}$$

Table 1. N-Gain Categories [30]

N-gain Score (g)	**Category**
g > 0,7	High
0,3 ≤ g ≤ 0,7	Medium
g < 0,3	Low

Meanwhile, inferential analysis was conducted using a paired sample t-test with the assistance of IBM SPSS to determine the significant difference between the pretest and posttest scores. The testing was carried out at a significance level of $\alpha = 0.05$, so a difference was considered significant if the p-value < 0.05. Prior to the t-test, the Kolmogorov–Smirnov test for normality and the Levene Test for homogeneity were conducted. If the test results indicated a significance value less than 0.05, the null hypothesis (H_0) was rejected, meaning the data did not meet the tested assumptions. Conversely, if the significance value was greater than 0.05, H_0 was accepted, indicating that the data met the assumptions of normality and homogeneity and were therefore suitable for analysis using the paired sample t-test [26].

RESULTS AND DISCUSSION

This study aimed to determine whether the implementation of Deep Learning–based Problem-Based Learning (PBL-DL) can improve junior high school students' mathematical reflective thinking abilities. To assess the attainment of students' reflective thinking ability, a descriptive analysis was conducted on the pretest and posttest scores.

Table 2 Descriptive Analysis Results

Variable	**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**
Pretest	25	58.96	4.266	0.853
Posttest	25	74.96	5.342	1.068

The average pretest score of students' reflective thinking ability was 58.96, while the average posttest score increased to 74.96. This improvement was not only evident quantitatively but was also supported by observational results during the implementation of Deep Learning–based Problem-Based Learning. Based on the observations, the learning process was active and student-centered. At the problem orientation stage, students appeared able to identify key information from the given contextual problems and began to formulate the variables involved in

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the two-variable linear equation model (SPLDV).

During the group discussion and investigation stage, students engaged in the exchange of ideas and arguments regarding the appropriate solution steps. Some students demonstrated the ability to explain the rationale for using the elimination method and to verify the results obtained through substitution. This indicates the presence of reflection and evaluation processes on the solution steps.

Furthermore, during the presentation and reflection stage, students began to explain solution patterns and compare strategies used among groups. This activity demonstrates that the learning process focused not only on the final results but also on thinking processes and conceptual understanding. Overall, Deep Learning–based PBL was implemented effectively and fostered the development of students' reflective activities.

After obtaining a descriptive overview of the data and observations, the next step was to conduct normality and homogeneity tests to ensure that the data met the assumption of a normal distribution before performing the t-test.

Table 3. Results of the Kolmogorov–Smirnov Normality Test

Variable	**K-S Statistic**	**df**	**Sig.**
Pretest	0,084	25	**0,20**
Posttest	0,083	25	**0,20**

Table 4. Results of the Levene's Test for Homogeneity

Score	**Levene's Test for Equality of Variances**		**df**	**Std. Error Difference**
	F	**Sig.**		
Equal variances assumed	1.689	0.200	48	1.36743

The normality test using the Kolmogorov–Smirnov method showed that the significance value for the pretest data was 0.20 and for the posttest data was 0.20, indicating that the posttest data were normally distributed (Sig. > 0.05). The homogeneity test using Levene's test showed a significance value of 0.200, which is greater than 0.05, indicating that the variance between the pretest and posttest scores was homogeneous. Since the data met the assumptions of normality and homogeneity, it was appropriate to perform a t-test. Subsequently, a paired-sample t-test was conducted to compare the pretest and posttest scores.

The test results showed a t-value of -59.084 with Sig. (2-tailed) = 0.000 < 0.05, indicating that there was a significant increase in students' reflective thinking ability after participating in Deep Learning–based Problem-Based Learning. This improvement was further supported by observation results during the learning process, which showed that students actively identified problems, discussed solution strategies, evaluated the steps taken, and reflected on the outcomes

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obtained. These activities align with the indicators of reflective thinking.

Table 5. Results of the Paired-Sample t-Test

Paired Variables	**Mean Difference**	**Std. Dev**	**Std. Error**	**t-Value**	**df**	**Sig. (2-tailed)**
Pretest – Posttest	–16,08	1,41	0,28	–59,084	24	0,000

Pedagogically, the Deep Learning–based PBL model is effective because it encourages students to construct deep understanding through the exploration of contextual problems and collaborative discussion. The learning process focuses not only on the final answers but also on the analysis, evaluation, and reflection conducted by the students. Thus, the effectiveness of Deep Learning–based PBL in enhancing mathematical reflective thinking ability is demonstrated not only statistically but also through the dynamics of classroom learning processes.

To determine the magnitude of the increase in students' reflective thinking ability, an analysis was subsequently conducted using Normalized Gain (N-Gain).

Table 6. N-Gain Test Results

Statistic	**Pretest**	**Postest**
Mean	58,96	74,96
Maximum Score	100	100
N-Gain	0,40	Medium Category

The increase in students' reflective thinking ability was calculated using Normalized Gain (N-Gain). The average N-Gain of the students was 0.40, which falls into the medium category. This indicates that the implementation of the Deep Learning–based Problem-Based Learning model was able to significantly enhance students' reflective thinking ability compared to their pre-instructional condition.

As an illustration of the improvement in reflective thinking indicated by the statistical data, the example of a student's answer sheet in Figure 1 shows how students not only wrote the final answers but also explained the steps and considerations they followed during the problem-solving process.

Figure 1 displays a student's answer in solving a two-variable linear equation problem (SPLDV). From this worksheet, it is evident that the student was able to interpret the case by understanding the problem context and formulating mathematical equations according to the given conditions. The student also successfully identified the relevant mathematical concepts or formulas, namely algebraic concepts and the elimination and substitution

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techniques for solving the equations. Additionally, the student was able to evaluate and verify the validity of the arguments by substituting the value of x into the original equation to ensure that the value of y was correct. The worksheet also demonstrates the student's ability to generalize and analyze generalizations, as the steps taken were systematic and could be applied to other SPLDV problems with similar patterns. Ultimately, the student successfully solved the mathematical problem by finding the final solution, x = 4 and y = 2, through a complete and logical procedure, thereby fulfilling all indicators of mathematical reflective thinking. This aligns with the significant increase in posttest scores, confirming that the implementation of Deep Learning–based PBL effectively enhances students' reflective thinking ability.

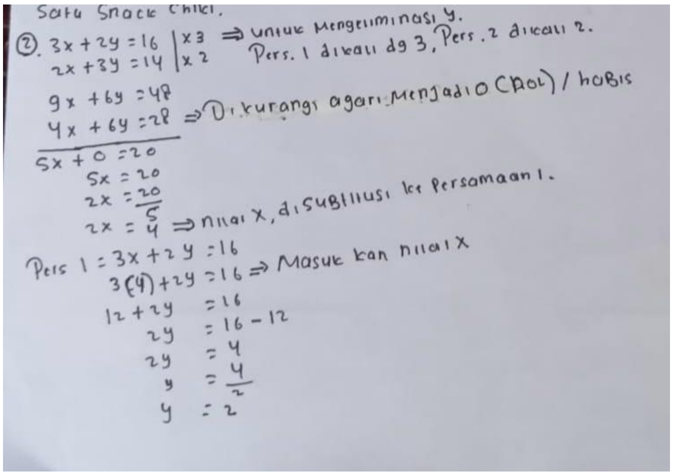

Figure 1. Student Worksheet Solving a Two-Variable Linear Equation Problem (SPLDV)

The findings from the student worksheets align with the results of the quantitative analysis, which showed an overall increase in reflective thinking ability. The average pretest score of 58.96 indicates that students' reflective thinking was relatively low at the initial stage. After the intervention using Deep Learning–based Problem-Based Learning, the average posttest score increased to 74.96. This improvement indicates that the learning not only enhanced the accuracy of students' answers but also strengthened their reflective processes in checking, reviewing, and justifying the steps taken in problem solving.

The improvement in students' mathematical reflective thinking ability following the implementation of Deep Learning–based Problem-Based Learning is clearly evident from the statistical results, where the posttest scores showed a significant increase compared to the pretest. This aligns with findings that PBL is effective in enhancing students' higher-order thinking skills [31]. Analysis of students' responses also demonstrated their ability to interpret problems, construct mathematical models, and independently evaluate the correctness of their solution steps, consistent with findings [32] indicating

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that PBL facilitates deep reflection and evaluation of strategies, and supported by studies [32] showing that the PBL approach can develop conceptual understanding through analytical and reflective activities.

The implementation of Deep Learning–based Problem-Based Learning contributes significantly to the enhancement of reflective thinking ability because both approaches inherently require students to engage in higher-order thinking processes [33]. The PBL model encourages students to organize information, identify relationships between concepts, and make strategic decisions through discussion and independent investigation [10]. Meanwhile, the deep learning approach emphasizes in-depth analysis, re-examination of the steps taken, and justification of the chosen solutions [34]. Therefore, the combination of both approaches creates a learning environment that not only guides students on how to solve problems but also enables them to understand the reasoning behind each step taken.

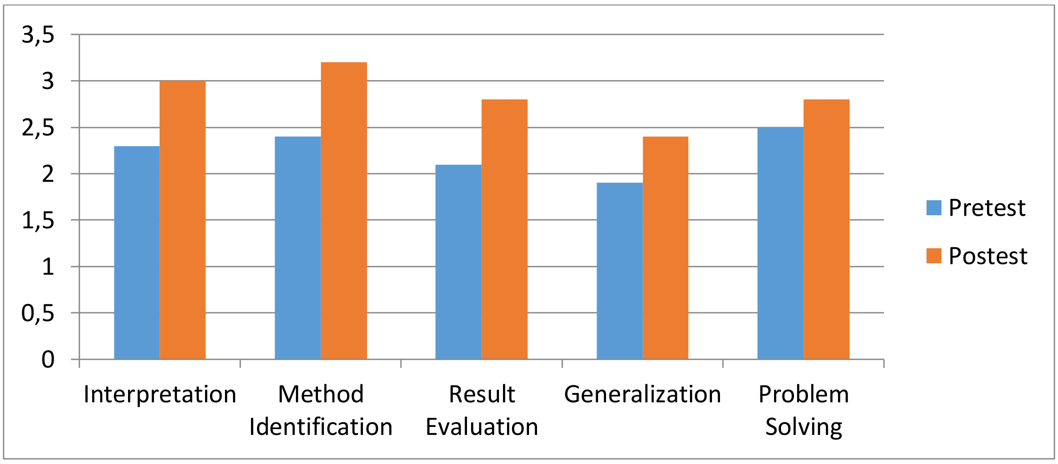

Figure 2. Comparison of Average Pretest and Posttest Scores for Each Indicator of Mathematical Reflective Thinking Ability

Based on Figure 2, all indicators of mathematical reflective thinking ability showed improvement, as evidenced by higher average posttest scores compared to the pretest. This increase reflects students' progress in understanding problem contexts, constructing two-variable linear equation models (SPLDV) using appropriate methods, logically re-evaluating the correctness of solutions, and generalizing solution patterns to similar situations. Thus, the score improvements are not merely numerical but indicate a tangible development in the quality of students' reflective thinking processes.

Overall, this study demonstrates that Deep Learning–based PBL is capable of enhancing reflective thinking ability while also providing a foundation for further efforts to strengthen students' reflection processes. Nevertheless, several limitations of the study should be noted.
These results should be interpreted considering the limited sample size and

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the context of a single school, meaning that their generalizability needs to be tested in a broader population.

These findings have practical implications, suggesting that mathematics teachers need to design PBL scenarios that require in-depth analysis, reflection on solution steps, and justification of answers, as these have been shown to enhance students' reflective thinking ability. Overall, this indicates that Deep Learning–based Problem-Based Learning is effective in improving the mathematical reflective thinking skills of junior high school students.

CONCLUSION

The implementation of Deep Learning–based Problem-Based Learning (PBL) can enhance the mathematical reflective thinking ability of junior high school students. Based on pretest and posttest results as well as classroom observations, students' reflective thinking ability improved after participating in PBL with a deep learning approach. Nevertheless, this study was limited to a single class and specific material, so the results cannot yet be generalized broadly. Further research is recommended to examine the application of Deep Learning–based PBL on other topics or at different educational levels.

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