



The effectiveness of deep learning in enhancing senior high school students' critical thinking skills in physics learning

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ABSTRACT

This study aimed to analyze the effectiveness of the Deep Learning approach in improving senior high school students' critical thinking skills in physics learning, particularly on dynamics material. This study used a pretest-posttest control group design and a quasi-experimental methodology. 64 students made up the sample, and they were divided into two groups: the experimental group and the control group. The experimental group was instructed using a Deep Learning approach consisting of the stages of understanding, applying, and reflecting, whereas the control group participated in conventional instructional activities. Research instruments included a critical thinking skills test covering analysis, evaluation, inference, and scientific reasoning, as well as an observation sheet of learning implementation. The findings revealed that the implementation of Deep Learning was classified as very high, achieving an average implementation percentage of 92%. Students in the experimental group showed greater improvement in critical thinking skills, as indicated by the increase in mean scores from 54.21 ± 7.35 to 82.47 ± 6.18 , with an N-gain value of 0.61 categorized as moderate-high. In comparison, the control group obtained an N-gain value of 0.33, which fell into the moderate category. These results suggest that Deep Learning-based instruction was more effective than conventional teaching methods in improving students' critical thinking skills and conceptual understanding in physics learning.

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INTRODUCTION

Critical thinking skills are among the essential competencies required in the 21st century, particularly for students who must face increasingly complex global challenges (Andr & Ceballos, 2024). In science education, especially physics, critical thinking is not merely an intellectual ability but also a fundamental aspect of analyzing phenomena, evaluating arguments, and solving evidence-based problems. Previous studies have demonstrated that successful physics learning is not only measured by students' mastery of concepts but also by their ability to reason, evaluate, and apply knowledge in real-life situations (Ubaidillah et al., 2023). Therefore, the development of

critical thinking skills should become a major priority in physics instruction at the secondary school level (Hikmah et al., 2021).

However, the development of students' critical thinking skills in physics learning still encounters various obstacles. Abstract physics concepts, such as dynamics, energy, and waves, are often taught through conventional memorization-oriented approaches. As a result, students tend to master procedural aspects without achieving deep conceptual understanding (Musliman & Kasman, 2022). Several studies have also reported that students experience difficulties in scientific reasoning processes that require analysis, synthesis, and evaluation (Musliman & Kasman, 2022). This condition reflects a gap between the competencies expected by the curriculum and students' actual achievements in the classroom (Ubaidillah et al., 2023).

To overcome these problems, a systematic learning approach is required to encourage students to develop higher-order thinking skills (Al-Zahra, 2026). Learning models that merely emphasize information delivery have proven ineffective in fostering students' analytical and reflective abilities. Consequently, physics education should be oriented toward pedagogical strategies that provide opportunities for idea exploration, active engagement, and meaningful knowledge construction. One promising approach that may achieve these goals is Deep Learning (Sumarni & Okyanida, 2025).

In the educational context, Deep Learning is defined as an instructional approach that prioritizes profound conceptual understanding over the mere memorization of factual information. (Coyle & Meyer, 2023). This approach highlights conceptual connections, critical reflection, and the application of knowledge in challenging situations. In physics learning, Deep Learning can assist students not only in understanding fundamental principles but also in applying them to solve contextual problems, evaluate scientific arguments, and construct meaningful understanding. Therefore, Deep Learning is considered capable of strengthening conceptual mastery while simultaneously improving students' critical thinking skills (Coyle & Meyer, 2023). Deep Learning contributes to strengthening students' knowledge construction by encouraging learners to actively connect prior knowledge with new scientific concepts through contextual problem-solving, reflective discussion, and conceptual exploration. In physics learning, students are not merely passive recipients of information but actively construct understanding through reasoning, collaboration, and scientific inquiry processes. This instructional approach enables students to develop deeper conceptual understanding and meaningful learning experiences.

Despite curriculum policies emphasizing the importance of higher-order thinking skills, many senior high school students still demonstrate limitations in critical thinking when learning physics (Wahyuni & Swandi, 2025). Students often rely on procedural memorization without engaging in deep reasoning regarding the concepts they study (Syafril & Aini, 2022). One factor contributing to this situation is the dominance of traditional teacher-centered instruction focusing on expository material delivery. Such learning patterns tend to prioritize examination preparation rather than the development of critical and reflective thinking skills.

Although Deep Learning has increasingly attracted attention in educational literature, its implementation in senior high school physics learning remains limited. Most studies focus on innovative instructional models such as problem-based learning, inquiry learning, or collaborative learning, while only a few studies systematically investigate the effectiveness of Deep Learning in improving critical thinking skills. The lack of empirical evidence causes teachers to hesitate in broadly adopting this approach in physics classrooms (Erlangga & Fitriyah, 2025).

Based on these issues, this study aimed to analyze the effectiveness of Deep Learning in developing senior high school students' critical thinking skills in physics learning. Specifically, this study sought to: (1) Analyze how students' critical thinking abilities have improved after engaging in Deep Learning-based instruction; and (2) determine the aspects of critical thinking skills, including analysis, evaluation, and inference, that develop most significantly through this

approach; and (3) provide pedagogical recommendations for physics teachers in designing instructional strategies oriented toward higher-order thinking skills development.

The novelty of this study lies in the integration of the Deep Learning framework into senior high school physics instruction through the structured stages of understanding, applying, and reflecting to specifically enhance students' critical thinking skills in dynamics learning. Unlike previous studies that primarily focused on problem-based or inquiry-based learning, this study empirically investigates how Deep Learning facilitates conceptual understanding, scientific reasoning, and reflective thinking within physics classrooms. Unlike previous studies emphasizing problem-based or inquiry-based learning, this study positions Deep Learning as a pedagogical framework designed to encourage students to construct deep conceptual understanding while enhancing higher-order thinking skills.

From an academic perspective, this research contributes to expanding the literature regarding the effectiveness of Deep Learning in science education, particularly physics. Practically speaking, the results should be used as a guide for physics teachers in designing learning activities that emphasize not only content mastery but also the development of critical thinking skills relevant to 21st-century educational demands.

RESEARCH METHODOLOGY

Research Design

This study employed a quasi-experimental method with a pretest-posttest control group design. This design was chosen because it allows the measurement of students' critical thinking skills before and after treatment while comparing the results between the experimental group receiving Deep Learning-based instruction and the control group taught using conventional approaches.

Population and Sample

The population of this study consisted of all senior high school students in Yogyakarta City, Indonesia. Cluster random sampling was employed to determine the research sample. Two classes from Senior High School X were selected. Two classes were selected because they possessed relatively similar academic characteristics, learning achievement levels, and classroom conditions based on school records and teachers' recommendations. One class was assigned as the experimental group and the other as the control group to enable comparison between Deep Learning-based instruction and conventional teaching under comparable learning conditions. Each class consisted of 32 students. The sample size of 64 students was considered sufficient for statistical analysis because quasi-experimental studies in educational research commonly employ sample sizes ranging from 30 to 60 participants per group to identify significant differences between instructional treatments. Furthermore, the number of participants fulfilled the minimum requirement for conducting parametric statistical tests, including the independent sample t-test, which assumes adequate sample representation and normal data distribution.

Research Instruments

The research instruments included a physics critical thinking skills test and an observation sheet for learning implementation. The critical thinking test measured students' abilities in analysis, evaluation, inference, and scientific reasoning. Meanwhile, the observation sheet was used to assess the implementation quality of Deep Learning instruction.

Data Analysis Technique

The collected data were analyzed descriptively and inferentially. Descriptive statistics were used to determine the mean and standard deviation of students' pretest and posttest scores. The degree of progress in students' critical thinking abilities was assessed using the normalized gain

(N-gain) technique. In addition, to determine whether there was a significant difference, an independent sample t-test was used between the experimental and control groups.

RESULTS AND DISCUSSIONS

Critical Thinking Skills Achievement

The descriptive analysis of students' critical thinking skills before and after the implementation of Deep Learning is presented in Table 1.

Table 1. Mean scores of pretest and posttest critical thinking skills

Group	Pretest (Mean \pm SD)	Posttest (Mean \pm SD)
Experimental	54.21 \pm 7.35	82.47 \pm 6.18
Control	53.68 \pm 7.12	68.92 \pm 6.85

Table 1 demonstrates that the experimental and control groups had relatively equivalent initial critical thinking abilities before treatment. The similarity of the pretest scores indicates that both groups started from comparable levels of conceptual understanding and reasoning skills in physics learning. Following the instructional intervention, both groups experienced improvements in their posttest scores; However, the improvement demonstrated by the experimental group was significantly greater than that of the control group.

The substantial increase in the experimental group suggests that Deep Learning-based instruction effectively facilitated students' engagement in meaningful and reflective learning processes. Students were encouraged to connect concepts, evaluate evidence, and apply scientific reasoning to contextual dynamics problems. Deep Learning contributed to students' ability to connect physics concepts to real-life contexts by presenting contextual dynamics problems closely related to students' daily experiences, such as motion, force, and acceleration phenomena. Through the stages of understanding, applying, and reflecting, students were encouraged to analyze real situations using scientific principles, thereby enabling them to relate abstract physics concepts to authentic problem-solving situations. This process strengthened conceptual understanding and improved students' ability to apply scientific reasoning in meaningful contexts. In contrast, students in the control group primarily focused on procedural problem-solving activities, resulting in a lower level of conceptual understanding and analytical reasoning.

N-gain Analysis

The normalized gain (N-gain) was computed to gauge how much the students' critical thinking abilities had improved. The results are presented in Table 2.

Table 2. N-gain scores of critical thinking skills

Group	N-gain	Category
Experimental	0.61	Moderate-High
Control	0.33	Moderate

The findings indicate that the experimental group achieved a moderate-to-high N-gain category, whereas the control group remained within the moderate category. This result demonstrates that the Deep Learning approach was more effective in improving students' critical thinking skills than conventional instruction.

The improvement in the experimental group can be attributed to the systematic implementation of the three instructional stages of Deep Learning, namely understanding, applying, and reflecting. During the understanding stage, students analyzed contextual dynamics problems and identified relevant physical variables such as force, mass, and acceleration. This stage encouraged students to construct conceptual understanding rather than merely memorizing formulas.

At the applying stage, students collaboratively solved physics problems using Newton's laws and scientific reasoning. Students were required to explain the rationale behind their solutions and evaluate alternative approaches. This activity strengthened students' analytical and inferential thinking skills. Furthermore, collaborative discussions promoted active participation and knowledge construction among students.

The reflecting stage played a crucial role in developing evaluative thinking. Students reviewed their solutions, defended scientific arguments, and reflected on their reasoning processes. Teachers facilitated reflective learning by providing guiding questions and feedback that encouraged students to reconsider their conceptual understanding. These reflective activities contributed significantly to the improvement of students' higher-order thinking skills.

Hypothesis Testing

To determine whether the difference between the two groups was statistically significant, an independent sample t-test was performed on the posttest scores. The analysis produced a t-value of 8.31 with $df = 62$ and $p < 0.05$. Therefore, the null hypothesis was rejected.

These findings indicate that Deep Learning-based instruction had a significant effect on students' critical thinking skills. The statistical significance confirms that instructional approaches emphasizing conceptual understanding, contextual application, and reflective learning are more effective in fostering critical thinking abilities compared to conventional teaching methods.

Implementation of Deep Learning in Physics Learning

The implementation of Deep Learning in the experimental class was categorized as very high, with an average implementation percentage of 92%, indicating that the instructional procedures were consistently conducted according to the designed learning stages. This high implementation rate suggests that the Deep Learning model can be applied systematically and reliably in physics classroom settings. The instructional process consisted of three major stages: understanding, applying, and reflecting.

At the understanding stage, students were presented with contextual physics problems related to dynamics concepts encountered in everyday life. This stage stimulated students to activate prior knowledge and identify relationships among physical variables such as force, mass, and acceleration. Students demonstrated active participation in formulating problems and constructing initial conceptual understanding (Ramadhani & Andriani, 2025).

During the applying stage, students collaboratively solved contextual dynamics problems by applying scientific principles and mathematical equations (Pranata, 2024). This activity encouraged students to explain the logical basis of their problem-solving strategies rather than merely memorizing formulas. Students in the experimental group demonstrated stronger reasoning abilities and more coherent scientific explanations compared to those in the control group.

At the reflecting stage (Aitzhan et al., 2023), students evaluated their solutions (Jin, 2022), defended their arguments using scientific evidence, and reflected on the reasoning processes they employed throughout learning activities. Teachers acted as facilitators by providing reflective questions and constructive feedback. This stage played a crucial role in strengthening students' evaluative and inferential abilities.

The successful implementation of Deep Learning indicates that the approach effectively created a learning environment that promoted active engagement, conceptual understanding, and reflective thinking (Suardin et al., 2025). These findings align with the principles of student-centered learning, which emphasize knowledge construction and higher-order thinking development.

Discussion

The findings of this study confirm that Deep Learning provides meaningful contributions to the development of critical thinking skills in physics learning (Mulyani et al., 2025). Students

who participated in Deep Learning-based instruction demonstrated stronger analytical, evaluative, and inferential abilities compared to those who learned through conventional instruction. This improvement occurred because Deep Learning emphasizes active engagement, conceptual connections, and reflective reasoning throughout the learning process (Sastrawati & Nizaar, 2025).

The results are consistent with previous studies indicating that student-centered instructional approaches effectively enhance higher-order thinking skills (Saputra et al., 2025). Through contextual problem-solving and reflective discussions, students became more capable of analyzing relationships among physical concepts and applying scientific principles logically (Haris et al., 2025). Such activities encouraged students not only to focus on obtaining correct answers but also to understand the scientific reasoning underlying their solutions (Kahar et al., 2021).

Moreover, the implementation of Deep Learning created a learning environment that fostered meaningful conceptual understanding (Carli, 2025). Students actively constructed conceptual understanding through collaborative exploration, scientific discussion, and reflective reasoning processes. This finding supports the view that meaningful learning occurs when students engage cognitively and emotionally in the learning process.

In contrast, conventional instruction tended to focus on teacher explanations and procedural exercises, limiting students' opportunities to develop reflective and evaluative thinking. As a result, although the control group demonstrated some improvement, the development of critical thinking skills was less optimal compared to the experimental group.

Overall, the findings suggest that Deep Learning may serve as an effective pedagogical approach for improving critical thinking skills in physics education (Sofa et al., 2025). By integrating understanding, application, and reflection into instructional activities, teachers can create learning experiences that foster deeper conceptual understanding and scientific reasoning among students.

CONCLUSION

Based on the findings and discussion, it can be inferred that the Deep Learning approach effectively improves students' critical thinking abilities in senior high school physics education, particularly in dynamics material. The experimental group demonstrated significantly higher improvement compared to the control group, as indicated by the posttest scores and N-gain values. Students who participated in Deep Learning-based instruction achieved an N-gain score of 0.61 categorized as moderate-to-high, whereas the control group obtained an N-gain score of 0.33 categorized as moderate.

The implementation of Deep Learning through the stages of understanding, applying, and reflecting successfully encouraged students to engage in deeper cognitive processes. Students were not only able to understand physics concepts procedurally but also capable of analyzing problems, evaluating solutions, constructing scientific arguments, and drawing conclusions based on scientific reasoning. Furthermore, the high level of instructional implementation indicates that the Deep Learning approach can be applied consistently and effectively in physics classrooms.

Therefore, this study demonstrates that the development of critical thinking skills is strongly influenced by the quality of instructional processes that encourage reflective, analytical, and concept-based learning experiences. The implementation of Deep Learning also implies that sustainable development of higher-order thinking skills can be achieved through continuous engagement in reflective, analytical, and contextual learning activities. By consistently integrating understanding, application, and reflection into physics instruction, students may develop long-term critical thinking habits that are transferable to other scientific and real-life problem-solving situations.

Future research is recommended to investigate the effectiveness of Deep Learning across different educational levels, including elementary, junior high school, and university contexts, to examine its broader pedagogical impact on higher-order thinking skills development. Further

studies may also explore the integration of Deep Learning with digital technologies, virtual laboratories, and inquiry-based learning models in various scientific disciplines. In addition, longitudinal studies are needed to evaluate the sustainability of critical thinking skill development resulting from Deep Learning implementation over extended instructional periods.

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