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The Integration of Deep Learning and Problem-Based Learning to Enhance Critical Thinking in Elementary Science Education

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Abstract: This study investigates the integration of a Deep Learning approach with the Problem-Based Learning (PBL) model to enhance critical thinking and conceptual understanding in Grade 6 science learning. A qualitative descriptive design was employed involving one teacher and 23 students at SDI Tirtayasa. Data were collected through classroom observations, semi-structured interviews, and document analysis, and analyzed using Miles and Huberman's interactive model. The findings reveal that the integration of Deep Learning principles—namely, meaningful, mindful, and joyful learning—with structured PBL phases significantly increased students' engagement, collaborative inquiry, and conceptual connection to real-life contexts, particularly in the topic of the human movement system. Students demonstrated improved questioning skills, argumentation, and reflective thinking. The teacher's facilitative role was crucial in scaffolding deeper inquiry and metacognitive processes. Despite limitations in time allocation and laboratory facilities, adaptive strategies enabled effective implementation. This study contributes empirically by demonstrating how the synergy between Deep Learning and PBL can operationalize student-centered science learning in elementary settings. The findings support the sustainable implementation of integrative pedagogical models to promote higher-order thinking in primary science education.

Keywords: Critical thinking; Deep learning; Elementary science; Problem based learning; Student engagement

Introduction

Education plays a strategic role in enhancing the quality of human life by equipping individuals with the cognitive abilities, competencies, and dispositions required to address increasingly complex social and global challenges. In the Indonesian context, Law No. 20 of 2003 on the National Education System mandates that education should develop learners who are intellectually capable, creative, independent, and socially responsible. This orientation aligns with contemporary educational research emphasizing the development of higher-order thinking skills and meaningful knowledge construction in the 21st century (Fiorella, 2023; Mystakidis, 2021).

At the elementary school level, science education is crucial because it lays the foundation for scientific literacy, critical thinking, and problem-solving competencies. Early exposure to inquiry-oriented and concept-rich science learning has been shown to significantly enhance students' reasoning ability and application of scientific knowledge to real-world situations. Studies indicate that inquiry-based learning models not only improve students' critical thinking skills in science but also promote active engagement with scientific concepts through questioning, investigation, and reflection (Aras et al., 2024; Muliyadi

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et al., 2023; Prasanti & Suniasih, 2023). Structured, student-centered science instruction significantly enhances conceptual understanding and engagement. Rahmah et al. (2025) stated that differentiated science materials improve students' conceptual mastery. Furthermore, Noviati et al. (2025) stated that problem-based STEM modules strengthen students' problem-solving skills in a contextual learning environment.

Science instruction in many elementary schools remains predominantly teacher-centered and content-oriented, with learning activities largely focused on information transmission rather than knowledge construction. Such instructional practices often restrict students' opportunities to engage in inquiry, reflection, and conceptual integration. Empirical studies indicate that lecture-based science instruction significantly reduces student engagement and limits active participation in classroom discourse (Kang & Keinonen, 2017; Lazonder & Harmsen, 2016).

Research further emphasizes that meaningful science learning requires structured inquiry environments in which students actively formulate questions, investigate phenomena, construct explanations, and reflect on their understanding. Inquiry-based and problem-centered instructional approaches have been shown to enhance conceptual depth, reasoning skills, and metacognitive awareness when supported by appropriate teacher scaffolding (Kang & Keinonen, 2017; OECD, 2023). These findings suggest that shifting from transmissive teaching toward inquiry-oriented pedagogy is essential for fostering deeper conceptual engagement in elementary science classrooms.

The Deep Learning approach offers a promising alternative for shifting science instruction toward deeper conceptual understanding and meaningful knowledge construction. Deep learning emphasizes sustained cognitive engagement, integration of ideas, reflective thinking, and higher-order reasoning. Research in educational psychology has shown that instructional environments fostering deep cognitive engagement are associated with more elaborated conceptual understanding and stronger retention of scientific concepts compared to surface-oriented instruction (Zepeda et al., 2015). Moreover, recent studies highlight the importance of metacognitive processes—such as planning, monitoring, and evaluating one's own thinking—in facilitating deeper learning and knowledge transfer (Mok et al., 2024).

To operationalize deep learning principles in classroom practice, an instructional model that facilitates authentic inquiry and collaborative problem solving is required. Problem-Based Learning (PBL) has been widely recognized as such a model in science education. Recent research indicates that PBL promotes critical thinking, reasoning ability, and deeper conceptual understanding when supported by effective instructional scaffolding and structured facilitation (Dolmans et al., 2016; Kang & Keinonen, 2017). A systematic review of inquiry-based science teaching further confirms that structured inquiry approaches enhance students' scientific thinking, engagement, and contextual application of concepts (Alarcon et al., 2023).

Furthermore, international assessments and empirical studies emphasize the importance of situating science learning within real-world contexts to promote meaningful engagement. The OECD (2023) report on science literacy underscores that real-world problem solving and contextualized learning tasks significantly improve students' abilities to apply scientific knowledge. These findings suggest that inquiry oriented and problem-centered pedagogies are essential for fostering not only cognitive competence but also metacognitive awareness and sustained interest in science learning.

Although numerous studies have examined deep learning principles and PBL independently, there remains limited research that empirically investigates their pedagogical integration in elementary science classrooms particularly in Indonesian primary schools. Most existing studies focus on learning outcomes quantitatively, with fewer analyzing classroom interaction patterns, engagement dynamics, and teacher facilitation strategies that support deep conceptual understanding.

Addressing this gap, the present study integrates deep learning principles within the stages of the PBL model to enhance critical thinking, engagement, and meaningful learning experiences in Grade 6 science education, specifically on the topic of the human movement system. This research contributes empirically by examining not only conceptual gains but also the processes of engagement and instructional practices that support deep and meaningful science learning.

Method

Research Design

This study employed a qualitative case study design to explore in-depth the implementation of the Deep Learning approach integrated with the Problem - Based Learning (PBL) model in Grade 6 science learning at SDI Tirtayasa. A qualitative approach was selected to obtain a comprehensive understanding of classroom processes, interaction dynamics, and participants' experiences in natural settings without manipulating variables.

The research followed the interactive analysis model of Miles et al. (2014), which includes three concurrent flows of activity: data condensation, data display, and conclusion drawing/verification. This design enabled systematic interpretation of classroom phenomena related to deep learning principles and PBL stages.

Research Setting and Participants

The study was conducted at SDI Tirtayasa during the 2024-2025 academic year. Participants consisted of: (1) One Grade 6 science teacher who implemented the Deep Learning PBL approach. (2) Twenty hree Grade 6 students (12 boys and 11 girls).

Participants were selected using purposive sampling, with the criteria that the class had implemented the Deep Learning approach through PBL in the topic of the human locomotor system.

Data Collection Techniques

Data collection was conducted in three stages: (1) Preliminary observation, initial classroom observation to identify existing teaching practices and learning conditions. (2) Implementation observation, direct observation during the application of the Deep Learning–PBL approach across multiple meetings. Field notes were taken to document classroom interactions, student responses, and teacher facilitation. (3) Interviews and documentation, in-depth interviews were conducted after the learning sessions. Interviews were audio-recorded and transcribed verbatim. Relevant documents were collected to support triangulation.

Instruments

In qualitative research, the researcher acted as the primary instrument. To ensure systematic data collection, the following supporting instruments were used:

Observation sheet

a) Indicators of PBL stages (problem orientation, investigation, group discussion, presentation, reflection).
b) Indicators of deep learning (conceptual integration, reflection, knowledge transfer).
c) Student engagement and critical thinking behaviors.

Interview guide

a) Semi-structured questions for the teacher (instructional planning, scaffolding strategies, challenges).
b) Semi-structured questions for students (learning experience, engagement, understanding).

Documentation checklist

a) Lesson plans and teaching modules.
b) Student worksheets.
c) Photos of classroom activities.
d) Reflective notes.

To enhance credibility, the observation instrument was reviewed by two science education experts before use.

Data Analysis

Data were analyzed using (Miles et al., 2014) interactive model: data collection, data reduction, data display, and conclusion drawing/verification. Coding procedures were applied to categorize student behaviors (e.g., questioning, reasoning, collaboration, reflection) and teacher facilitation strategies.

Trustworthiness of Data

Data validity was ensured through source and method triangulation, prolonged engagement, peer debriefing, and an audit of supporting documents. Credibility, transferability, dependability, and confirmability criteria were applied to ensure research trustworthiness.

Result and Discussion

The present study aimed to examine how the implementation of Deep Learning principles through the Problem-Based Learning (PBL) model facilitates higher-order thinking and meaningful engagement in biology learning, particularly on the topic of the human locomotor system. The findings indicate that structured PBL phases problem orientation, collaborative investigation, analysis, presentation, and reflection created a learning environment that shifted classroom dynamics from passive reception toward active knowledge construction. Students were not merely recalling anatomical terms but were engaged in interpreting cases, evaluating causal relationships, and constructing biologically coherent explanations.

One of the most salient findings concerns the quality of students' reasoning during collaborative discussions. Students demonstrated the ability to identify causal mechanisms underlying musculoskeletal disorders, relate structure to function, and propose preventive strategies grounded in scientific reasoning. These behaviors reflect higher-order cognitive processes, including analysis, evaluation, and explanation construction. Such findings are consistent with meta-analytic evidence showing that inquiry oriented instructional approaches significantly enhance critical thinking in science education. Arifin et al. (2025), synthesizing 36 empirical studies, reported a substantial overall effect size of inquiry-based learning on students' critical thinking skills. Their review emphasized that instructional designs requiring interpretation of data, justification of claims, and formulation of explanations produce stronger cognitive outcomes than conventional lecture-based approaches. The present study's classroom observations provide micro-level confirmation of these macro-level statistical findings.

Similarly, Strelan et al. (2020) conducted a comprehensive meta-analysis on problem-based learning and found that PBL demonstrates a positive and significant effect on conceptual understanding and long-term retention. Importantly, their discussion highlighted that PBL is most effective when students encounter problems before receiving explicit instruction, as this sequence stimulates cognitive restructuring rather than passive information intake. The learning design implemented in this study followed a similar pattern: students were first exposed to contextual video cases related to locomotor disorders before teacher clarification. This approach encouraged learners to activate prior knowledge, identify gaps in understanding, and collaboratively negotiate meaning. The observable shift from fragmented responses in early discussion phases to coherent, evidence-based explanations during presentation suggests that conceptual reorganization occurred through inquiry.

Beyond cognitive engagement, the present findings also indicate enhanced affective involvement. Students appeared enthusiastic during group discussions and actively participated in defending their ideas. While this study did not quantitatively measure motivation, observable behavioral indicators suggest increased engagement and persistence. Student-centered, problem-driven learning approaches—including problem-based and project-based learning—produce small to moderate positive effects on students' motivation, particularly in competence beliefs and task value perceptions (Wijnia et al., 2024). This evidence strengthens the interpretation that the observed classroom enthusiasm was not incidental, but theoretically grounded in the motivational dynamics of inquiry based instruction.

Contextual grounding emerged as another critical factor in promoting deep learning. Students demonstrated stronger conceptual understanding when discussions connected locomotor system disorders to daily posture habits, sports injuries, and ergonomic practices. This aligns with Lusiani et al. (2026), who reported significant learning improvements when students interpreted scientific concepts within authentic contexts rather than abstract formulaic representations. Their findings suggest that contextualization enhances transferability of knowledge across situations. In the current study, students were able to apply anatomical concepts to real-life preventive strategies, indicating that understanding extended beyond textbook definitions.

The importance of structured facilitation also became evident. Although PBL promotes student autonomy, effective implementation requires guided scaffolding. Ismaniati et al. (2025) found statistically significant differences in critical thinking outcomes when structured problem-based digital learning was applied (Wilks' Lambda = 0.118; $p < 0.05$). Their discussion emphasized that teacher guidance and carefully designed inquiry tasks are essential to sustain analytical engagement. Consistent with this argument, the teacher in the present study provided probing questions and structured worksheets to prevent superficial discussion. Without such scaffolding, collaborative inquiry might risk becoming unstructured conversation rather than focused reasoning.

When comparing these findings with previous research, a consistent pattern emerges across methodological approaches. Meta-analytic studies (Arifin et al., 2025; Strelan et al., 2020) provide strong statistical evidence supporting the effectiveness of inquiry and PBL models in fostering higher-order thinking. Experimental studies (Ismaniati et al., 2025; Lusiani et al., 2026) demonstrate measurable improvements within specific contexts. However, fewer studies document how deep learning processes manifest behaviorally in classroom interaction. The present study contributes by offering qualitative evidence of epistemic practices, including argument construction, peer questioning, evaluation of alternative explanations, and revision of claims. These behaviors indicate that deep learning is observable not only through post-test gains but also through dialogic reasoning patterns.

From a theoretical perspective, the findings reinforce the idea that deep learning is characterized by mindful, meaningful, and joyful engagement. Mindful learning was evident in students' analytical processing of biological mechanisms. Meaningful learning emerged when concepts were linked to everyday experiences. Joyful learning was reflected in active participation and collaborative enthusiasm. The integration of these dimensions suggests that deep learning is multidimensional, encompassing cognitive, affective, and social aspects simultaneously. This multidimensionality is supported by Wijnia et al. (2024), who argued that sustained engagement in PBL environments arises from the interplay between cognitive challenge and psychological ownership.

Nevertheless, the discussion also highlights important implementation considerations. Strelan et al. (2020) cautioned that poorly structured PBL may not automatically yield significant gains. Effectiveness depends on alignment between problem design, facilitation quality, and reflection opportunities. The positive outcomes observed in this study likely resulted from coherent sequencing of inquiry phases and explicit reflection sessions. Reflection allowed students to consolidate understanding and correct misconceptions, strengthening conceptual integration. Therefore, fidelity of instructional design appears to be a decisive factor in translating deep learning principles into tangible classroom outcomes.

Another significant implication concerns the measurement of higher-order thinking. While many studies rely primarily on standardized test scores, the present research demonstrates the value of examining classroom discourse as an indicator of cognitive depth. Arifin et al. (2025) emphasized that assessment of critical thinking should capture reasoning processes rather than isolated factual recall. Observational evidence from this study aligns with that recommendation by documenting how students justified claims, critiqued peer responses, and synthesized information collaboratively. Such evidence strengthens the argument that deep learning can be identified through qualitative indicators of reasoning quality.

The convergence of findings from international meta-analyses and classroom-level evidence strengthens the external validity of this study. Inquiry based and problem-based models consistently demonstrate positive effects across contexts, yet their successful implementation depends on contextual adaptation. In the Indonesian elementary school context, integrating Deep Learning principles with PBL proved feasible and effective. This suggests that globally validated instructional strategies can be meaningfully localized when aligned with curriculum goals and classroom realities.

The novelty of this study lies in its explicit operationalization of Deep Learning constructs within structured PBL phases in biology education. While previous research has demonstrated the effectiveness of inquiry models quantitatively, this study illustrates how deep learning becomes visible in classroom epistemic practices. By integrating macro-level evidence from meta analyses with micro-level classroom observation, this research bridges the gap between statistical effectiveness and pedagogical enactment. It shows not only that PBL works, but how and why it works in fostering higher-order thinking.

In summary, the findings confirm that Problem-Based Learning aligned with Deep Learning principles promotes conceptual depth, analytical reasoning, and meaningful engagement in biology learning. The integration of authentic problems, contextual grounding, structured scaffolding, and reflective dialogue created conditions conducive to higher-order cognition. Supported by international meta-analytic evidence (Arifin et al., 2025; Strelan et al., 2020) and longitudinal findings on motivation (Wijnia et al., 2024), the present study contributes contextualized classroom evidence demonstrating that deep learning is not merely a theoretical aspiration but an observable pedagogical reality. These findings provide practical and theoretical implications for science educators seeking to cultivate critical and transferable thinking skills in elementary education.

Conclusion

This study demonstrates that integrating Deep Learning principles with Problem-Based Learning provides a structured yet flexible framework for fostering critical thinking and meaningful conceptual understanding in elementary science classrooms. The study contributes theoretically by clarifying how Deep Learning can be operationalized through PBL stages, and practically by offering an adaptable instructional model for primary educators. However, broader implementation requires improved time allocation, teacher professional development, and adequate learning facilities. Future research employing mixed-methods or quasi-experimental designs is recommended to strengthen causal inferences.

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Author Contributions

Conceptualization, T.M. and H.S.; methodology, T.M.; validation, S.U.S. and H.S.; formal analysis, R.A. and R.N.H.; investigation, O. and R.P.S.; data curation, R.A.; writing—original draft preparation, T.M.; writing—review and editing, H.S.; supervision, H.S.; project administration, S.U.S. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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