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STATE OF THE ART REVIEW: PJBL, DEEP LEARNING, AND CRITICAL THINKING: A CAUSALITY MODEL FOR 21ST CENTURY COMPETENCIES

Masringgit Marwiyah Nst[1], Festiyed[2], Yerimadesi[3]

[1]Politeknik Adiguna Maritim Indonesia Medan, Indonesia
[2,3]Universitas Negeri Padang, Indonesia

Email: masringgitmarwiyahnst@poltek-amimedan.ac.id

Corresponding Author: Masringgit Marwiyah Nst
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ABSTRACT

This research focuses on the urgency of improving students' critical thinking skills, recognized as a crucial competency for facing 21st-century challenges. To address this challenge, the Project- Based Learning (PjBL) model has been identified as a strategic and effective pedagogical approach for fostering higher -order cognitive abilities. Previous literature has confirmed the positive contribution of PjBL to learning outcomes, but there is a significant research gap regarding the exploration of the internal mechanisms underlying this success, namely Deep Deep Learning Learning, which involves comprehensive understanding of meaning rather than mere memorization, is a crucial prerequisite for the authentic and transferable development of students ' critical thinking skills. Therefore, the primary objective of this research is to empirically test and analyze the effect of the PjBL model on improving students' critical thinking skills in relationships to the quality of the Deep Learning it facilitation. Using a quasi-experimental method, the results of this study is expected to provide clear theoretical and practical contributions, demonstrating that the effectiveness of PjBL in improving critical thinking skills stems from its ability to encourage students to engage in deeper knowledge processing.

Introduction

The demands of 21st-century competencies make critical thinking skills a primary goal in education (Hidayat, 2023). Critical thinking skills are fundamental skills for students to analyze, evaluate, and synthesize information rationally (Fatimah, 2021). To facilitate these complex skills, innovation in classroom learning models is needed (Sitompul, 2020).

Based Model Problem-Based Learning (PjBL) has been identified as a promising strategy for developing higher-order cognitive abilities (Supriyadi & Utomo, 2022). Various empirical studies have confirmed that the implementation of PjBL is effective in substantially improving students' critical thinking scores (Lubis, 2021). PjBL requires students to engage in authentic investigations and design solutions to real-world problems (Saragih & Siregar, 2020). This engagement directly requires students to use analysis and evaluation, which are at the heart of critical thinking (Tambunan et al. , 2020). et al. , 2023).

However, previous studies often focused only on the end result of improving critical thinking skills (Sitompul, 2020). Not much research has explored the mediating or cognitive enhancing factors behind the success of PjBL (Harahap & Gunawan, 2023). The cognitive mechanism that differentiates PjBL success is the quality of information processing known as Deep Learning . *Learning*) (Simanjuntak, 2019). Deep Learning is defined as students' efforts to understand fundamental meanings, connect ideas, and apply knowledge in new contexts (Nasution, 2022). This is in stark contrast to Surface Learning (*Surface Learning). Learning*) which focuses solely on memorization (Purba, 2021). The characteristics of PjBL that encourage intrinsic motivation and long-term problem solving should ideally trigger Deep Learning (Fatimah, 2021).

A major gap found in the literature is the lack of studies that explicitly test and integrate these three variables simultaneously (Hidayati & Ramadhan, 2022). Most studies ignore the role of Deep Learning as a cognitive bridge connecting PjBL with critical thinking skills (Saragih & Siregar, 2020). Therefore, the novelty of this study lies in testing an integrated causal model of the influence of the PjBL Model on students' critical thinking skills related to (or mediated by) Deep Learning (Situmorang, 2023). This research is expected to provide theoretical contributions regarding the synergy between constructivist learning models and deep learning styles in achieving critical outcomes (Lubis, 2021).

Research Methods

This research employed a qualitative approach with a State of the Art Review (SoAR) design through a Systematic Literature Review (SLR). This approach was chosen to obtain a comprehensive and up-to-date mapping of the relationship between Project-Based Learning (PjBL), Deep Learning, and Critical Thinking (CT) in the context of developing 21st-century competencies, particularly in science learning.

The literature review process was conducted systematically, adhering to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency, traceability, and replicability of the research process..

Results and Discussion

To obtain a comprehensive picture of the relationship between *Project- Based Learning* (PjBL), critical thinking skills (*critical thinking*), and deep learning (deep learning) in the context of science education, a review of eight review articles and meta-analyses published in internationally reputable journals was conducted. Each article provides a different but complementary perspective, ranging from a systematic analysis of PjBL design and strengthening higher-order thinking skills, a review of PjBL at various levels of education, to a study of technology integration in science projects. The focus of each study is then mapped to see how PjBL contributes to improving critical thinking skills . thinking and how this approach promotes deep learning in science. The following table summarizes the key findings from the eight articles as a basis for building a more focused theoretical synthesis.

Table 1. Article Analysis

No	Author & Year	Review Article Title	Focus of Study	Relationship with PjBL & CT	Relevance to Science Learning / Deep Learning
1	Loyens et al. (2023)	*Situation Higher - Order, Critical , and Critical-Analytic Thinking in Problem- and Project- Based Learning Environments : A Systematic Review*	Systematic on HOTS, Critical Thinking , and P(B)L design	Reviewing the concept & effectiveness of PjBL in improving CT	Discussing deep strategies learning through projects & analysis of science concepts
2	Guo et et al. (2020)	*A Review Project - Based Learning in Higher Education : Student Outcomes and Measures*	Review PjBL with a focus on learning outcomes & instruments	CT & problem-solving as the main outcome	Provides a basis for science project design that fosters conceptual understanding.
3	IJERE SLR (2024)	*Systematic Literature Review Project - Based Learning (2016–2023)*	Global PjBL research trends	Many studies show an increase in CT through projects.	Includes science domains and deep learning principles
4	PjBL Meta-analysis (2023)	*Effects Project - Based Learning on Critical Thinking Skills*	Meta-analysis of diverse PjBL studies	Moderate–high effect on CT	Many study samples come from science, especially physics & biology.
5	Hudha (2023)	*Project- Based Learning in Improving Scientific Literacy : A Literature Review*	Review project-based science literacy	CT emerged as an aspect of scientific literacy	Deep learning is achieved through exploration of science projects
6	Sanchez-García (2025)	*Enhancing Project- Based Learning : A Framework ...*	Review of modern PjBL design & framework	Including CT as a core competency	Explaining deep learning mechanisms with structured projects
7	Review Elementary School PjBL –Science (2023)	*Project- Based Learning in Early Science Education : A Systematic Review*	SLR PjBL for children's science learning	CT emerged as a result of learning in mini projects.	Explains how inquiry & reflection strengthen deep learning
8	Review PjBL & Technology (2024)	*Digital/ Multimodal Project- Based Learning Review*	Technology integration – PjBL	Technology strengthens CT through exploration & experimentation	AR/VR/simulation supports in-depth conceptual understanding of science

Discussion

Project-Based Learning as a Mechanism for Deep Learning in Science Project-based learning requires students to build conceptual understanding through investigative activities, so that the learning structure is more in-depth . learning), not just procedural (Loyens et al. , 2023). Another study confirmed that when projects were directed at scientific inquiry, students showed significant improvements in their understanding of complex science concepts (Guo et al. , 2020). Global SLR shows that deep Learning in science occurs because projects give students time to explore, analyze, and reflect on scientific phenomena (IJERE SLR, 2024).

A recent meta-analysis also confirmed that project experiences foster integration between empirical data and theoretical explanations, a key indicator of deep learning (PjBL Meta-analysis , 2023). In the context of scientific literacy , the use of projects allows students to connect theory with practice, thereby deepening their cognitive structures (Hudha, 2023).

Framework Modern PjBL also explains that deep learning occurs when projects are designed with stages of investigation, collaboration, feedback, and reflection (Sánchez-García , 2025). At the initial level, deep Learning also develops when students model scientific phenomena through mini-projects that require observation, prediction, and revision of ideas (Review PjBL SD–Science, 2023). Integration of technology such as AR/VR or simulation also accelerates the in-depth learning process through visual exploration and more authentic scientific experiences (Review PjBL & Technology, 2024).

The direct relationship between PjBL , CT, and Science Learning PjBL encourages critical thinking. thinking because it provides space for students to assess evidence, test hypotheses, and draw conclusions based on data (Loyens et al. , 2023). Learning outcomes in various projects show that CT increases especially when students are given autonomy in designing solutions to scientific problems (Guo et al. , 2020). The global SLR study stated that more than 70% of the analyzed PjBL studies reported improvements in higher-order thinking skills, including CT (IJERE SLR, 2024). Meta-analyses also showed that PjBL had moderate to high effects on CT, especially in science and STEM contexts (PjBL Meta-analysis , 2023).

literacy developed through projects requires students to evaluate evidence, which is the core of the CT process (Hudha, 2023). The PjBL development framework indicates that CT is a core competency developed through the stages of problem analysis and evaluation of project outcomes (Sánchez-García , 2025). In children's science education, CT is formed through project-based inquiry activities that emphasize scientific questions and reasoning (Review PjBL SD–Science, 2023). Technology, when combined with PjBL , enriches the CT process because it encourages students to conduct virtual experiments and interpret data (Review PjBL & Technology, 2024).

PjBL as a Learning Environment that Builds Critical Thinking Thinking

All articles confirm that PjBL consistently improves critical thinking skills. This occurs because projects require students to:

1. formulate the problem,
2. collect and evaluate data,
3. make evidence-based decisions,
4. revising solutions. The effects of CT enhancement have been demonstrated robustly Across a variety of science, STEM, and elementary education contexts.

PjBL as a Deep Strategy Learning in Science Learning

Deep Science learning thrives through experiential learning that demands a deep understanding of concepts, not memorization. Projects enable exploration of scientific phenomena, theory-data integration, and scientific reflection. Technologies such as simulation, AR/VR, or multimodal learning are used. Tools support this process by providing experiential experiences that are difficult to achieve traditionally.

CT and Deep Integration Learning in Science Projects

PjBL not only produces CT and deep learning separately, but building both in an integrated manner. Critical thinking becomes a mechanism that encourages deep learning, while deep Learning strengthens CT through richer interpretations of scientific phenomena. Modern PjBL frameworks (e.g. , Sánchez-García 2025) emphasize that these two aspects complement each other.

Project Design as a Determining Factor

The success of PjBL depends on:

- clarity of authentic issues,
- structure of investigation stages,
- scaffolding ,
- use of technology,
- enough time for exploration,
- reflection phase. Studies show that good project design will result in CT and deep strong learning . The explanation is given in the following table.

Table 2. Article Synthesis

Synthesis Theme	Key Findings	Supporting Articles
PjBL increases CT	Projects require students to analyze, evaluate, and make scientific decisions.	1, 2, 3, 4, 5, 6, 7, 8
PjBL produces deep learning in science	The project encourages a deep understanding of science concepts.	1, 2, 3, 4, 5, 6, 7, 8
CT & deep integration learning occurs in project activities	CT is used to reason about data; deep learning is formed through scientific interpretation	1, 3, 4, 5, 6, 7
The role of technology in PjBL IPA	Technology expands scientific exploration and strengthens CT	8, 2, 4
PjBL as a cross-level approach to science education	Effective in elementary, middle, high school, and college	2, 3, 4, 7

Analysis: The Meaning of CT (Critical Thinking) in Science Learning Based on PjBL & Deep Learning

1. Conceptual Meaning of CT

Critical Thinking (CT) is *a higher-order cognitive process* that students use to:

- analyze information,
- evaluate evidence,
- draw logical conclusions,
- solve problems systematically,
- and reflect on his own thought processes.

This means that CT is not just thinking quickly, but thinking in a focused, deep and reasoned way.

In science learning, CT is the foundation because science is oriented towards:

- scientific reasoning,
- hypothesis testing,
- experimental analysis,

- data interpretation.

2. The Relationship between CT and Deep Learning Learning)

Deep learning is an approach where students:

- understand concepts to the root (not just memorize),
- able to connect between concepts,
- using concepts to solve new problems,
- reflect on the learning process.

Direct relationship CT ↔ Deep Learning

What Students Do	Including CT	Including Deep Learning
Processing experimental data critically	✓	✓
Connecting old–new concepts	✓ (analysis)	✓ (integration)
Making decisions based on evidence	✓ (evaluation)	✓ (meaningful learning)
Asking in-depth questions	✓ (inquiry)	✓ (conceptual understanding)

3. The Relationship between CT and the Project- Based Model Learning (PjBL)

PjBL requires students to:

- solve *real problems* through the process of scientific inquiry,
- collect and analyze data,
- make products,
- do reflection.

The development of critical thinking skills in science learning is an important focus in various contemporary studies, especially when linked to the implementation of the Project-Based model. Learning (PjBL) and an orientation towards in-depth learning. (Amir & Santoso, 2021). This is in line with the needs of 21st-century education, which requires students not only to master concepts but also to be able to analyze, evaluate, and create new knowledge through scientific activities. (Rahmawati et et al. , 2020).

Several studies have shown that PjBL has a strong theoretical basis for enhancing critical thinking because it involves investigative, collaborative processes, and real-world problem-solving (Hidayat & Prabowo, 2022). Furthermore, the implementation of PjBL encourages students to integrate higher-order thinking skills through activities such as designing, testing, and evaluating science experiment-based learning products (Widodo et al., 2019). al. , 2021). This type of learning requires students to be actively and reflectively engaged, which ultimately strengthens the deep learning process. (Sari & Malik, 2021). From a pedagogical perspective, deep learning emphasizes conceptual understanding, connections between ideas, and the ability to apply concepts in authentic contexts. (Lestari et al. , 2022). PjBL supports this through challenging task structures, encouraging exploration, and opening up space for deeper scientific reflection. (Gunawan et al. , 2020). In science learning, the integration of scientific projects forces students to interpret natural phenomena through the lens of theory and empirical procedures, thereby developing their knowledge structures meaningfully. (Yuniarti & Fathurrahman, 2021).

Scopus- reviewed articles show that PjBL not only mechanically improves critical thinking skills, but also improves students' conceptual achievement and scientific literacy . (Rahmawati et al. al. , 2020). For example, research by Hidayat & Prabowo (2022) found that students who participated in project-based learning showed significant improvements in the interpretation, inference, and evaluation indicators in critical thinking measurements. (Hidayat & Prabowo, 2022).

Similar findings were also reported by Widodo et et al. (2021), who stated that developing experimental projects based on real environments encourages students to reconstruct science concepts in greater depth. (Widodo et al. et al. , 2021).

Furthermore, the orientation toward deep learning helps students develop scientific sensitivity to contextual issues, enabling them to understand the scientific rationale behind them rather than simply memorizing science procedures (Sari & Malik, 2021). This emphasizes that PjBL provides a rich learning environment, enabling the activation of various critical thinking domains such as cause-and-effect analysis, scientific argumentation, and evaluation of experimental evidence (Gunawan et al. , 2021). et al. , 2020).

In another article review, Lestari et al. (2022) emphasized that deep learning requires knowledge transfer, and PjBL provides an authentic context that strengthens this process. (Lestari et al. , 2022). The integration of these two approaches has been shown to provide substantive benefits, ranging from increased learning motivation, conceptual understanding, to the ability to solve complex problems in science learning (Amir & Santoso, 2021). Thus, the correlation between PjBL , critical thinking, and in-depth learning is not only theoretical but also empirical, as found in various studies (Yuniarti & Fathurrahman, 2021).

Overall, a review of eight Scopus articles consistently concludes that PjBL is a strategic approach to developing students' critical thinking skills while encouraging in-depth learning in the science context. (Rahmawati et al. al. , 2020). The combination of investigative activities, collaboration, experimentation, and critical reflection produces a learning experience that facilitates the construction of more meaningful knowledge. (Hidayat & Prabowo, 2022). Thus, it can be emphasized that the systematic implementation of PjBL in science learning is an effective pedagogical choice for strengthening critical thinking skills while realizing in-depth learning. (Amir & Santoso, 2021).

Conclusion

Project- Based Learning (PjBL) has consistently been proven to be an effective pedagogical approach to improving critical thinking skills . thinking) while encouraging deep learning (deep learning) in the context of science learning. All articles emphasize that the characteristics of PjBL —such as authentic inquiry, scientific problem solving, collaboration, data analysis, and reflection—directly facilitate the higher-order thinking processes necessary for developing CT. Project activities that require students to formulate questions, evaluate evidence, and develop scientific solutions provide space for the development of analytical, logical, and evaluative skills.

Deep learning in science is also achieved because Project-Based Learning (PjBL) provides opportunities for students to understand scientific concepts through hands-on experience, integrating theory with real-world observations, and exploring complex scientific phenomena. Several articles have shown that science projects enable students to develop more stable, meaningful, and networked knowledge structures , rather than simply memorizing superficially. This approach enriches conceptual understanding and improves students' ability to connect concepts between phenomena .

Meta-analysis and SLR related to PjBL showed that the positive effect on CT and deep Learning occurs at all levels of education, from elementary school to college, with the strongest impact in the science and STEM domains. The integration of technologies such as AR/VR, digital simulations, and multimodal platforms further strengthens the effectiveness of PjBL in improving critical thinking skills and deepening understanding of science concepts.

Overall, this study concludes that PjBL is a strategic approach to 21st-century science learning because it combines scientific reasoning processes, authentic learning experiences, and the development of higher-order cognitive competencies. PjBL not only enhances CT and deep learning separately, but rather building it simultaneously and integratedly, thus producing science learning that is more meaningful, in-depth, and relevant to the needs of the modern era.

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