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The Effectiveness of Deep Learning based PjBL on Student's Scientific and Critical Thinking Skills at Indonesia

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Abstract: Many studies have examined the effect of project-based learning on students' scientific and critical thinking skills, but no research has examined the effect size of the Deep Learning-based PjBL model on students' scientific and critical thinking skills in Indonesia. The integration of deep learning principles into Project-Based Learning (PjBL) gave birth to the Deep Learning-based PjBL model that encourages students to construct knowledge through real projects, continuous reflection, and collaboration. This study aims to determine the learning model of project-based learning based on deep learning on students' scientific and critical thinking skills. This type of research is quantitative research with a meta-analysis method. The inclusion criteria in this study are research data derived from journals indexed by Sinta or Scopus, articles published in 2021-2025, research must be experimental or quasi-experimental methods, relevant research, data obtained through the Google Scholar, ERIC, ScienceDirect, and Taylor of Francis databases, and published journals have complete data to calculate the effect size value. Data analysis using the JASP application. This study analyzed 17 relevant articles. The results concluded that the summary effect size value was d = 0.88; t = 8.26; p < 0.005, a high effect size category. These findings explain the significant influence of the deep learning-based PjBL model on students' scientific and critical thinking skills in learning. aspects to tackle this issue, particularly in low- and middle-income countries.

Keywords: Critical Thinking; Pjbl; Deep Learning; Scientific Thinking; Meta-analysis

Introduction

21st century skills are an important foundation for learners in facing complex, dynamic, and technology-based global challenges (Zulyusri, Elfira, et al., 2023). According to the Framework for 21st Century Learning, students are not only required to master basic literacy such as reading and writing, but must also have critical thinking, creativity, collaboration, and communication skills to adapt to the development of a knowledge-based economy (Dewanto et al., 2024; Zulyusri, Santosa, et al., 2023). This is relevant to the demands of the Industrial Revolution 4.0 and Society 5.0 era which emphasizes the integration of digital technology, data, and artificial intelligence in all aspects of life, so learning in schools needs to prepare students to be able to solve real problems with a multidisciplinary approach (Safiah et al., 2025; Wahyuni et al., 2025; Zhang & Ma, 2023). In addition, 21st century skills also emphasize mastery of higher-order thinking skills (HOTS) that enable learners to analyze, evaluate, and create innovative solutions (Ahmad et al., 2024). Several studies show that students trained with high-level thinking skills are better prepared to enter the global job market and deal with socio-economic uncertainties. Therefore, the integration of a curriculum that prioritizes critical thinking skills,

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digital literacy, and collaborative learning is an urgent need in the Indonesian education system so that graduates are not only academically competent, but also adaptive, creative, and able to become lifelong learners in the midst of rapid change (Kee et al., 2025; Saeliang & Chatwattana, 2025).

The conventional learning model in many Indonesian schools is still dominated by teacher-centered lecture methods (Hanafi et al., 2025). This approach places students as passive recipients of information thus reducing opportunities for exploration, collaboration, and problem-solving that are essential for 21st century skills development. When the learning process focuses on delivering material alone, students tend to only memorize concepts without internalizing deep understanding or connecting them to real-life contexts (Rahman et al., 2023). These limitations hinder critical and creative thinking skills that should develop through inquiry, discussion, and experimentation (Santosa et al., 2024). Not only that, conventional methods are also reflected in the achievements of science literacy and critical thinking skills of Indonesian students at the international level. The results of the Programme for International Student Assessment (PISA) 2022 show that Indonesia's science literacy score is at an average of 396, far below the OECD average of 489. Similar findings were reported by the 2019 Trends in International Mathematics and Science Study (TIMSS), where the science ability of Indonesian students ranked 45th out of 58 countries.

This data confirms that the dominance of lecture methods with minimal exploration is not able to encourage the higher-order thinking skills (HOTS) needed to face complex global challenges. Therefore, there is a need for an effective learning model to help teachers improve students' scientific thinking and critical thinking skills, one of which is the PjBL model. Project-Based Learning (PjBL) is an innovative learning model that places students at the center of the learning process through the completion of real projects that are relevant to the context of life. PjBL emphasizes collaboration, problem-solving, and the application of cross-disciplinary concepts to encourage critical thinking and better communication skills. By integrating inquiry, reflection, and creative exploration, students not only understand concepts theoretically, but also develop metacognitive abilities that are essential for lifelong learning. This approach is very much in line with the demands of the 21st century, as it facilitates active learning and challenges students to design innovative solutions to complex problems (Ahmed et al., 2024).

Various empirical studies show that PjBL is effective in improving students' scientific and critical thinking skills. For example, a meta-analysis study by Suryani et al. (2024); Sutaryani et al. (2024) found that the application of PjBL significantly improved scientific reasoning skills and science learning outcomes compared to conventional methods. Research in the Southeast Asian context has also shown significant improvements in critical thinking skills and problem-solving abilities when students engage in inquiry-based collaborative (Anchunda & Kaewurai, 2025; Wardani & Fiorintina, 2023). These findings confirm that PjBL is not only an alternative pedagogy, but also an effective strategy to prepare learners to face knowledge-based global challenges (Fitrianingsih et al., 2025; Habibah et al., 2025; Indahwati et al., 2023). Therefore, there is a need for an effective learning model to help teachers improve students' scientific thinking and critical thinking skills, one of which is the PjBL model.

Project-Based Learning (PjBL) is an innovative learning model that places students at the center of the learning process through the completion of real projects that are relevant to the context of life (Badaruddin et al., 2024; Nilada et al., 2024). PjBL emphasizes collaboration, problem-solving, and the application of cross-disciplinary concepts to encourage critical thinking and better communication skills. By integrating inquiry, reflection, and creative exploration, students not only understand concepts theoretically, but also develop metacognitive abilities that are essential for lifelong learning. This approach is very much in line with the demands of the 21st century, as it facilitates active learning and challenges students to design innovative solutions to complex problems. Various empirical studies show that PjBL is effective in improving students' scientific and critical thinking skills. For example, a meta-analysis study that the application of PjBL significantly improved scientific reasoning skills and science learning outcomes compared to conventional methods.

Research in the Southeast Asian context has also shown significant improvements in critical thinking skills and problem-solving abilities when students engage in inquiry-based collaborative projects. These findings confirm that PjBL is not only an alternative pedagogy, but also an effective strategy to prepare learners to face knowledge-based global challenges (Hafeez, 2021). The deep learning approach in the context of education is not just an artificial intelligence technology, but a learning orientation that emphasizes deep conceptual understanding, interconnectedness, critical reflection, and the ability to transfer knowledge to new situations (Zhang et al., 2024). Through deep learning, students are encouraged to interpret information, connect learning experiences with real-life contexts, and develop metacognitive insights. This process is in contrast to surface learning which tends to focus on memorizing and reproducing facts without deep meaning. Therefore, deep learning is an important foundation in shaping the critical, analytical, and creative thinking skills needed in the 21st century (Hikmah et al., 2023).

The integration of deep learning principles into Project-Based Learning (PjBL) gave birth to the Deep Learning–based PjBL model that encourages students to construct knowledge through real projects, continuous reflection, and collaboration. Research shows that the application of deep learning strategies in PjBL is able to improve deeper conceptual understanding, metacognition skills, and the ability to apply science concepts to real-world problems. By placing students as active agents in the process of investigation and problem-solving, Deep Learning–based PjBL helps them not only master the material, but also internalize the value of lifelong learning and readiness to face complex challenges in the era of Industrial Revolution 4.0 and Society 5.0 (Luciana et al., 2024; Syafruddin et al., 2024). Although Project-Based Learning (PjBL) and deep learning approaches have been widely researched in various countries, empirical studies that specifically combine the two to develop students' scientific and critical thinking skills in Indonesia are still very limited (Pertiwi et al., 2024). Existing research generally only highlights the effectiveness of conventional PjBL without examining the integration of deep learning strategies that emphasize deep reflection and concept transfer.

Some local studies also tend to focus on improving basic cognitive outcomes, so the evidence on the influence of deep-learning-based PjBL on higher-order thinking skills is insufficient to be used as a reference for national education policy development. This condition shows that there is a gap between the needs of 21st century learning and the research available in the Indonesian context. To fill this gap, rigorous and measurable quantitative research is needed to provide stronger empirical evidence on the effectiveness of deep learning-based PjBL on students' scientific and critical thinking abilities. Experimental or quasi-experimental design with pre-test and post-test measurements can help ensure a causal relationship between learning models and the improvement of critical thinking skills. Valid and reliable quantitative research results will be an important foundation for teachers, curriculum developers, and policymakers to adopt and expand Deep Learning–based PjBL practices more widely in the Indonesian education system. Based on this, this study aims to find out the deep learning-based project-based learning model for students' scientific and critical thinking skills.

Method

Research Design

The design of this study uses quantitative meta-analysis, which is a statistical approach that aims to systematically synthesize the results of empirical studies on the effectiveness of Deep Learning-based Project-Based Learning (PjBL) on scientific thinking skills and critical thinking of students in Indonesia. Meta-analysis was chosen because it was able to integrate findings from various relevant primary studies, resulting in a more accurate and reliable estimate of the combined effect size than a review of the narrative literature alone (Ntais & Talias, 2024). By combining quantitative data from various educational contexts and levels, this design allows researchers to assess the strength of relationships between variables, identify consistent patterns, and evaluate the heterogeneity of findings, thereby providing comprehensive evidence to support pedagogical decision-making and evidence-based education policies.

Data Sources and Search Strategies

The literature search in this meta-analysis study was conducted systematically through various reputable databases to ensure comprehensive and relevant source coverage. The databases used include Google Scholar, ERIC, ScienceDirect, and Taylor of Francis, because all seven provide a collection of international and national scientific articles that are indexed and peer-reviewed. The search strategy uses Boolean logic with the main keywords "deep learning" AND "project-based learning" AND "critical thinking" AND "scientific thinking" AND Indonesian, accompanied by synonym variations such as "PjBL", "project-based", "higher-order thinking", and "HOTS" to capture different but commensurate terms. Search limits are set for publications published between 2021–2025 to obtain the latest data, with the criteria of document types in the form of journal articles that have gone through a peer review process, scientific proceedings, and published theses or dissertations, so that the data sources analyzed have scientific validity and high contextual relevance.

Inclusion and Exclusion Criteria

This meta-analysis study applied strict inclusion and exclusion criteria to guarantee the validity of the data synthesis. Included studies must be quantitative research with experimental or quasi-experimental designs that test Deep Learning–based Project-Based Learning (PjBL) models, or PjBL with explicitly stated deep learning components. In addition, studies must report sufficient statistical data for effect size calculations, such as mean values, standard deviation, sample size (N), or test statistics (t/F). The context of the research is limited to Indonesian students ranging from elementary school to university levels to be relevant to the geographical focus. In contrast, purely qualitative research, review or theoretical articles with no empirical data, as well as duplicate publications or incomplete reports are excluded. The study selection procedure follows the PRISMA guidelines which include four stages: identification, namely the collection of all search results from the database; screening, namely the elimination of duplication and initial examination through titles and abstracts; eligibility, in the form of a full text review based on inclusion and exclusion criteria; and final inclusiveness, namely the determination of a list of studies that are eligible to be analyzed in the meta-analysis. This systematic approach ensures that only relevant, high-quality empirical evidence is used as the basis for estimating the combined effects. From the results of data filtering, 17 relevant studies were obtained.

Data Analysis

Data analysis in this meta-analysis study was carried out through effect size calculation using Cohen's (d) with the JASP application. Effect size analysis was done using Cohen's (d) for continuous data, allowing for more precise cross-study comparisons with different sample sizes. The statistical model chosen is a random-effects model with the DerSimonian–Laird approach, because it is assumed that each primary study has heterogeneous effect variability due to differences in context, population, and implementation of Deep Learning–based PjBL. The level of heterogeneity between studies was analyzed using Q-test as a significance test and I^2 statistical to estimate the proportion of variance that was not explained by sampling errors. In addition, an optional moderation analysis was conducted to explore the potential influence of factors such as education level, intervention duration, and research design on the magnitude of the effect. This approach provides a more reliable estimation of combined effects and allows for an in-depth interpretation of the conditions that affect the effectiveness of the study learning model. The criteria for effect size values in this study are as follows Table 1.

Table 1. Effect Size Value Criteria

Effect Size	Criteria
0.0≤ Effect Size ≤ 0.20	Poor
0.21≤ Effect Size ≤ 0.50	Low
0.51≤ Effect Size ≤ 0.10	Medium
1.11 ≥ Effect size	High

Source: (Ayaz & Söylemez, 2015)

Data on research samples, effect size, standard errors, heterogeneity tests and publication bias are presented in the form of a table. Meta-analysis was carried out by calculating heterogeneity using random effect size to find out the average variables that affect the variables of character value strengthening in students. The publication bias test uses a p-value of > 0.05 by conducting a funnel plot analysis and an egger's test. If the results of the funnel plot analysis and egger's test > 0.05, it means that there is no publication bias.

Result and Discussion

Based on the results of data search through the database, 17 studies/articles met the inclusion criteria. The effect size and error standard can be seen in Table 2.

Tabel 1. Characteristics of a Meta-Analysis Study

Journal Code	Education Level	Variable	Source	Effect size(g)
KT 1	Secondary School	Critical Thinking	ERIC	0.81
KT 2	Secondary School	Scientific	Google Scholar	1.42
KT 3	University	Scientific	ScienceDirect	0.42
KT 4	University	Critical Thinking	Google Scholar	1.02
KT 5	University	Critical Thinking	ERIC	1.16
KT 6	Secondary School	Critical Thinking	ERIC	0.43
KT 7	University	Scientific	ERIC	0.57
KT 8	University	Scientific	Google Scholar	0.91
KT 9	Secondary School	Scientific	Taylor of Francis	1.20
KT 10	University	Scientific	Taylor of Francis	1.91
KT 11	Secondary School	Scientific	Google Scholar	1.44
KT 12	Secondary School	Sciencetific	Google Scholar	0.29
KT 13	Elementary	Critical Thinking	ScienceDirect	0.75
KT 14	University	Critical Thinking	ScienceDirect	0.89
KT 15	Elementary	Critical Thinking	ERIC	1.38
KT 16	Secondary School	Critical Thinking	ERIC	1.04
KT 17	Secondary School	Scientific	ERIC	0.59

Based on Table 2, the effect size value of the 17 studies ranged from 0.29 to 1.91. The 17 effect sizes, 6 studies ad medium criteria effect sizes and 11 studies had high criteria effect size values. Based on the results of the data test based on JASP outputs, the following results were obtained:

Heterogeneity Test

Furthermore, analyze the heterogeneity test of the ten analyzed studies which can be seen in Table 3.

Table 3. Resiadual Heteroneity test

Q_c	df	P
61.481	16	< 0.001

Based on Table 3. The results of the heterogeneity test analysis showed that 10 researchers had a heterogeneous distribution (Q_e = 61.48; P < 0.001). With this, random effect size is effective to estimate the average effect size of the 10 studies analyzed. The results of the analysis showed that blended problem-based learning had an effect on strengthening character values in students.

Hypothesis Test

Next, calculate the p-value to test the hypothesis through the random effect model. The results of the summary effect model analysis with the random effect model can be seen in Table 4.

Tabel 4. Pooled Effect Size Test

Estimate	Standard error	t	df	P
0.885	0.107	8.26	16	< 0.001

Table 4. The results of the analysis of the average value of effect size with the random effect model showed that there was a positive influence between the blended project-based learning model on strengthening character values in Islamic religious education students (t = 8.26; p< 0.001).

Publication Bias

Checking publication bias through funnel plot analysis and Rosenthal fail safe N (FSN) test (Badawi et al., 2023; Tamur et al., 2020). The results of checking publication bias with funnel plot can be seen in Figure 1. The analysis of the funnel plot is not yet known whether it is symmetrical or asymmetrical, so it is necessary to conduct a Egger's test. The results of the Egger's test calculation can be seen in Table 5.

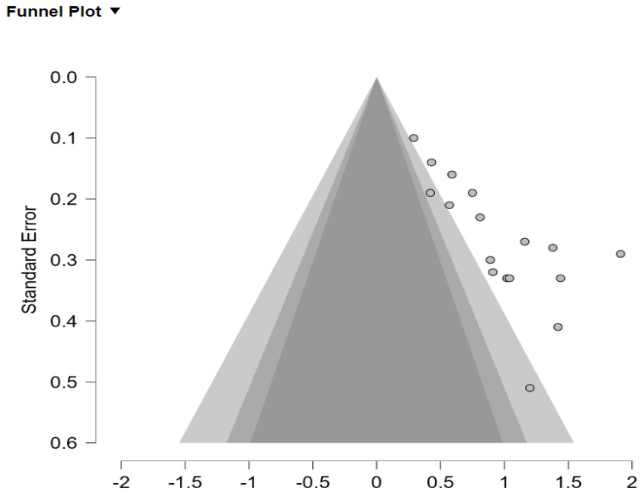

Figure 1. Funnel Plot

Tabel 5. Egger's Test

	z	p
Sei	1.42	0.15

Based on Table 5, the Z value is 1.019 and the p-value is 0.152 more than the sig value. 0.05 means that there is no publication bias in this study. Next, the forest plot analysis can be seen in Figure 2.

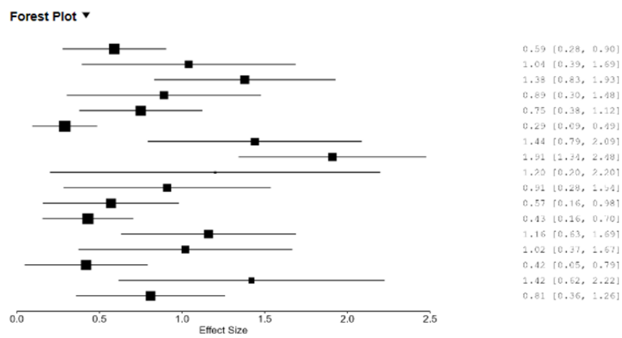

Figure 2. Forest Plot

Based on the forest plot analysis, it can be observed that the analyzed articles have values that vary between 0.29 to 1.91 with a summary effect size value of 0.885. This finding explains that influence of the deep learning-based PjBL model on students' scientific and critical thinking skills in learning The effect size category is higher than conventional models. The calculation of the combined effect size yields a Hedges' g value of around 0.88 which is classified as a high category according to criteria (Ponti et al., 2024). These results indicate that a project-based learning model with a deep learning approach is able to go beyond conventional learning in honing students' scientific and critical thinking skills that are essential to meet the challenges of the 21st century. The improvement of scientific thinking skills can be explained through the characteristics of DL–PjBL which emphasize the process of investigation, deep reflection, and cross-concept connections.

Project activities involving hypothesis formulation, data collection and analysis, and evaluation of results allow students to practice the scientific method in real life (McMillan et al., 2022; Rönnebeck et al., 2016). The study of Aswan et al. (2024); Situmorang et al. (2022), supports these findings with evidence that the integration of deep learning in PjBL significantly improves the ability to formulate research questions and interpret data. In the realm of critical thinking, DL–PjBL provides a collaborative learning environment that encourages discussion, argumentation, and complex problem-solving (Eskiyurt & Özkan, 2024). This process fosters metacognitive and evaluative abilities that are essential for making evidence-based decisions (Guamanga et al., 2025; Shekh-Abed, 2024). The results of the meta-analysis showed that students involved in DL–PjBL had better skills in assessing arguments and making conclusions than the group that participated in lecture-based learning, in line with previous findings by (Putri et al., 2025), on the advantages of project-based learning on critical thinking skills (Suteja & Setiawan, 2022; Zhang & Ma, 2023).

These findings have strong practical implications for educators in Indonesia (Aswan et al., 2024; Ichsan et al., 2023). The integration of deep learning in PjBL not only encourages deeper conceptual understanding, but also supports the development of 21st-century skills such as collaboration, communication, and problem-solving (Peters-burton & Stehle, 2019; Thornhill-Miller et al., 2023). Teachers are advised to design challenging projects, provide space for reflection, and make effective use of digital technology so that students can internalize concepts and apply them in real-world contexts (Hillmayr et al., 2020; Yaseen et al., 2025; Zulkifli et al., 2022).

Conclusion

From the results of this study, it can be concluded that the summary effect size value is $d = 0.88$; $t = 8.26$; $p < 0.005$ high effect size category. These findings explain the significant influence of the deep learning-based PjBL model on students' scientific and critical thinking skills in learning.i The deep learning approach in PjBL is able to encourage deep conceptual understanding, reflection, and knowledge transfer to a real context. These results reinforce previous findings on the excellence of PjBL in developing high-level thinking skills and support a 21st-century skills framework that demands the ability to think critically and scientifically on a sustainable basis. In practical terms, these findings recommend the implementation of DL–PjBL more broadly at various levels of Indonesian education with project designs that emphasize reflection, collaboration, and complex problem-solving. Teachers and education policymakers are advised to integrate deep learning strategies in the curriculum and provide adequate infrastructure support so that the learning process can take place optimally. Follow-up research needs to be conducted with a wider geographical scope and longitudinal design to strengthen the evidence of causality and explore moderator variables such as teacher competence, duration of intervention, and utilization of digital technology.

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Conceptualization; methodology; formal analysis; investigation; resources; M. E. N.; writing—preparation of original draft, T.; writing—reviewing and editing; visualization; supervision; project administration; obtaining funding. D. All authors have read and approved the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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