



The Effect of Project-Based Learning on Critical Thinking Skills in Elementary Science: A Meta-Analytic

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Abstract: In an effort to achieve the development of students' critical thinking skills in elementary school science learning, various innovative learning models can be used, one of which is the Project Based Learning (PjBL) model. The PjBL model is a learning method that can improve critical thinking skills through problem solving. This type of research is a quantitative meta-analysis study. The meta-analysis study aims to determine how big the effect of the PjBL model is on students' critical thinking skills in elementary school science learning? The collection of articles using the publish or perish application with the keywords project based learning model, critical thinking, elementary school science learning as many as 200 articles and 12 theses. Articles that meet the inclusion criteria are analyzed by calculating the effect size of each journal and thesis. The average effect size analysis of 0.59 is in the moderate category. The PjBL model has an effect on elementary school students' critical thinking skills with $r_{RE} = 0.59$ in the moderate category. This shows that the application of the PjBL model has an effect on students' critical thinking skills in elementary school science learning. PjBL-based science learning allows students to apply and develop theories, skills, and techniques to solve problems. PjBL enriches students' learning experiences and knowledge, providing more meaningful education in innovative learning.

INTRODUCTION

Critical thinking ability is one of the important skills that today's students must master. Critical thinking skills as life skills so that students are able to survive and adapt to future situations and are sensitive to the surrounding environment (Afandi et al., 2019; Bellaera et al., 2021). In line with Latif (2019) that it is difficult for individuals to compete in the global world unless they have sufficient critical thinking. Critical thinking skills are clear and rational thinking, including involvement in reflective and independent thinking (Mohammadi et al., 2022; O'Reilly et al., 2022). Apart from that, Giacomazzi (2022); Wale and Bishaw (2020) state that critical thinking is the ability to make decisions through the stages of observation, analysis and problem solving. Critical thinking is classified as a complex thinking process or generally a higher level thinking process (Bunt & Gouws, 2020; Spector & Ma, 2019). This ability includes the ability to analyze, evaluate and solve problems logically and systematically. In learning,

developing critical thinking skills is one of the main focuses to create a generation that is able to adapt to future changes and challenges. The application of critical thinking skills in the learning process can be done by asking open questions that stimulate critical thinking and student discussion. This can encourage students to explore complex ideas and develop reasoned arguments. In addition, Yazidi, (2023) developing students' critical thinking skills in the learning process can be done with simple experiments that require students to make hypotheses, observe results and evaluate their predictions.

Natural Science learning in elementary school has a strategic role in developing critical thinking skills because of its emphasis on exploration, experimentation and scientific discovery. In an effort to achieve this goal, various innovative learning models can be used, one of which is the Project Based Learning (PjBL) model. The PjBL model is a learner-centered learning approach that provides opportunities to study challenging problems, engage in ongoing inquiry, find answers to authentic questions, help select projects, reflect on processes, critique and revise work, and create products and public views (Grossman et al., 2019). PjBL learning is a learning method that can improve critical thinking skills through completing a series of complex tasks containing situations and practical life problems (Chiu, 2020; Issa, 2021). By engaging students in real-world projects, PjBL fosters active learning and deep understanding. Where, students can organize learning activities and group discussions through the process of searching for information, designing projects and presenting the results of completed projects (Chen, et al., 2019; Almulla, 2020). The PjBL model involves students to actively construct knowledge that is not transmitted directly by the teacher (Guo et al., 2020; Rio et al., 2022). Therefore, the complexity of the project should be aligned with the developmental stage of the students, allowing them to tackle challenges that are appropriately challenging yet achievable (Ashari & DongJin, 2024).

The PjBL model has been proven to significantly increase student learning independence in a variety of educational settings. Studies have shown that implementing the PjBL model, such as through herbarium projects or digital science teaching materials, can effectively increase student independence in learning (Haryani, 2023; Purnomo, 2022). By involving students in hands-on projects and collaborative activities, PjBL encourages autonomy, critical thinking skills, and active participation in the learning process. Additionally, integrating technology tools such as Canva, Google Classroom, and Zoom into PjBL further increases student creativity and independent learning, ultimately leading to a deeper understanding of the subject matter and improved overall learning outcomes (Ricka, 2023; Haryani, 2023). These findings underscore the importance of utilizing innovative teaching approaches such as PjBL to encourage student independence and the development of students' critical thinking skills. Teachers have an important role in the implementation of PjBL, where teachers encourage independent learning by students. Teachers act as facilitators, mentors and motivators, guiding students through real-world projects that enhance critical thinking and collaboration skills. To optimise this role, teachers can use strategies such as open-ended questions and experiments. However, in implementing PjBL teachers face challenges of time, curriculum alignment, and limited resources (Damayanti, 2023).

Consistently the results of research that have been conducted show positive results when applying the PjBL model in various educational contexts. Research conducted by Sumarna and Rushiana (2023), Nofiarida (2023), all highlights increasing students' critical thinking abilities through implementing the PjBL model. These studies show that PjBL not only improves critical thinking skills but also fosters students' independence, creativity and problem-solving abilities. Apart from that, the results of research conducted by Barak (2021) show that the PjBL model has a positive effect on students' critical and innovative thinking abilities. Ruslan (2021) stated that the PjBL model was successful in supporting the improvement of students' critical and social thinking skills. The successful application of the PjBL model in improving students' critical thinking skills is influenced by several factors (1) teacher competence in designing projects and facilitating learning effectively, (2) student motivation and independence in the learning process, (3) real problem-based project design with a clear structure (4) support for facilities and a conducive learning environment, and (5) an assessment system that focuses on the critical thinking process (Rio et al., 2022). The synergy between these factors will create meaningful learning for the development of students' higher order thinking skills. Based on studies that have been conducted, the PjBL model has shown significant effectiveness in improving elementary school students' critical thinking skills.

By involving students in real-life problem-solving scenarios and encouraging active participation in the learning process, PjBL has proven to be a valuable approach for developing critical thinking skills in elementary school students. In addition, Mochammad Amirudin (2023) emphasized that the characteristics of PjBL are in line with students' needs to think critically and creatively in applying the concepts learned, which ultimately leads to improved learning outcomes. Therefore, by looking at various research results that have implemented PjBL, it is necessary to study how effective innovative learning models are in improving students' critical thinking abilities. Meta-analysis was carried out to look at the quantitative research findings of several studies that have been conducted on students' critical thinking abilities. By knowing the influence of PjBL in improving critical thinking skills, it is hoped that it will be useful for practitioners in the field of education to consider implementing project-based learning models in their learning. With meta-analysis, this research seeks to answer the research question "How is the influence of project-based learning in supporting primary school students' critical thinking abilities in science learning?"

METHOD

This type of research is quantitative meta-analysis research. Metaanalysis is used to combine, review, and summarize the findings of two or more studies. By using metaanalysis, various questions can be investigated based on data collected from previous research publications (Asrizal, 2023). Meta-analysis is a systematic research method that combines the results of multiple empirical studies to produce a comprehensive and objective synthesis. This technique allows researchers to identify patterns, consistencies, or disparities in the literature, while increasing statistical power

by combining larger samples. By using a quantitative approach, meta-analysis can provide more precise estimates of effects and evaluate the influence of moderator variables. In academic contexts, meta-analysis is recognized as the gold standard for literature reviews because of its ability to minimize bias and produce more valid conclusions. Its applications span a wide range of disciplines, from medicine to psychology to the social sciences, making it an invaluable tool in evidence-based decision making. The meta-analysis steps can be seen in Figure 1.

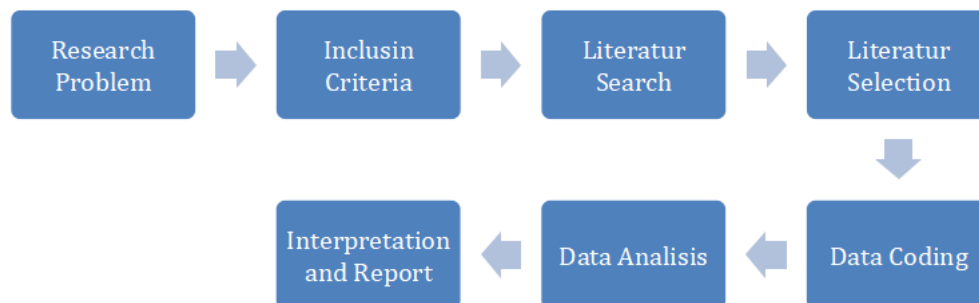


Figure 1. Meta-analysis steps (Modified by Retnawati, 2018)

This research method uses the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) (Page & Moher, 2017). Collecting articles using the publish or perish application with the keywords project based learning model, critical thinking, elementary school science learning. The use of PoP applications plays an important role in providing practical and efficient value, because through this application, various article choices will be directly provided that have been adjusted to the search characteristics. Article searches carried out since March 2024 resulted in 200 scientific articles and 12 theses. Next, articles were selected to be reviewed by determining the inclusion and exclusion criteria, in Table 1. There were 15 articles that met the inclusion criteria to be used as samples.

Table 1. Inclusion and Exclusion Criteria established in the study

Exclusion Criteria	1.	Types of Development Research and PTK
	2.	Abstract is incomplete
	3.	Research subjects at junior and senior high school levels
Inclusion Criteria	1.	Articles published in 2020 – 2024
	2.	Research topics in elementary science
	3.	PjBL model type
	4.	Experimental – Quasi Experimental Method
	5.	Critical thinking abilities of elementary school students

The instrument used in this research was an observation sheet. Observation is a method of systematically collecting data through observing and recording symptoms that appear in the research object, in this case a sample article (Sari, 2024). The observation sheet used in the research is in the form of a check list, which contains information from the articles being analyzed regarding year of publication, subject, subjects, pretest and posttest scores, number of samples. in the study used. This observation sheet is used to determine the achievement of each component that the researcher wants to carry out a

meta-analysis regarding the influence of the PjBL model on critical thinking abilities in elementary school science.

The data analysis technique used is calculating the effect value size of each study. Effect size is a measure of the quantity of a research result to determine the correlation or difference between research variables. Effect size statistics produce statistical standardization of research findings so that the resulting numerical values can be interpreted consistently across all variables and measures involved (Riopel et al., 2020 ; Hillmayr et al., 2020) . The effect size calculation technique in each study was carried out to see the influence of the PjBL model on elementary school students' science critical thinking abilities. The way to find the effect size used in this research uses Cohen's theory (Retnawati, 2018). Furthermore, the criteria for effect size values in this meta-analysis can be seen in Table 2.

Table 2. Effect Size Value Category

Effect Size	Categories
$0.00 \leq ES \leq 0.20$	Small
$0.20 \leq ES \leq 0.80$	Medium
$ES \geq 0.80$	Large

Additionally, an important thing to consider when conducting a meta-analysis is checking for study bias (Smith et al., 2023 ; Schmid et al., 2023) . In research to check study bias using funnel plots and the Rosenthal Fail Safe N test (Juandi et al., 2022 ; Diah et al., 2022) .

RESULT AND DISCUSSION

This meta-analysis method research aims to determine the effect of implementing the PjBL model on students' critical thinking abilities in elementary school science learning. This research analyzes the effect (Effect Size) resulting from the PjBL model. Effect size shows the influence between two variables, namely the independent variable and the dependent variable. The independent variable examined in this study was the Project-Based Learning (PjBL) model, an instructional approach centered on student-driven inquiry, collaboration, and real-world problem-solving. Meanwhile, the dependent variable was students' critical thinking abilities in science learning at the elementary school level, measured through validated assessments evaluating skills such as analysis, inference, evaluation, and decision-making. By focusing on this relationship, the study aimed to empirically assess the impact of PjBL on fostering higher-order cognitive skills in young learners, contributing to the growing body of research on innovative pedagogical strategies in STEM education. By examining this causal relationship, the study sought to empirically evaluate the efficacy of Project-Based Learning (PjBL) in enhancing higher-order cognitive skills such as analysis, synthesis, and evaluative reasoning among elementary school students. Grounded in constructivist learning theory, this investigation not only quantified the effects of PjBL on critical thinking but also explored contextual factors influencing its implementation in science classrooms. The findings contribute to the expanding literature on active learning methodologies in STEM education, offering evidence-based recommendations for curriculum design and

instructional practices tailored to young learners' developmental needs. Furthermore, this research addresses a critical gap in understanding how student-centered pedagogies can systematically cultivate 21st-century skills in early science education, thereby informing policy and teacher training initiatives. The findings are expected to provide evidence-based insights for educators and curriculum developers seeking to enhance scientific literacy and critical thinking in early education.. This research analyzes 15 articles that have been published in nationally accredited journals. This article was obtained with the help of publish or perish which was published from 2020-2024. The articles obtained were analyzed using JASP. Based on the inclusion criteria of the 15 articles that were analyzed, the effect size and standard error for each study were obtained which can be seen in Table 3.

Table 3. Effect Sizes and Standard Errors from 15 Studies

No	Study Name	Year	Effect Size	Standard Error
1	study 1	2024	0.5	0.24
2	study 2	2024	1.36	0.2
3	study 3	2024	0.48	0.24
4	study 4	2023	0.4	0.21
5	study 5	2023	0.36	0.29
6	study 6	2023	1.1	0.24
7	study 7	2023	0.28	0.19
8	study 8	2023	0.85	0.21
9	study 9	2023	0.44	0.2
10	study 10	2023	0.57	0.21
11	study 11	2023	0.49	0.24
12	study 12	2022	0.25	0.24
13	study 13	2020	0.54	0.17
14	study 14	2020	0.28	0.24
15	study 15	2020	0.88	0.24
Average			0.59	0.22

From table 3 it can be seen that the effect size value of the 15 articles analyzed ranged from 1.38 to 5.64 with an average effect size of 2.83/ The average standard error was 0.22 with a standard error ranging from 0.17 to 0.29. Based on Cohen's effect size category, there are four studies in the large category (27%) and eleven studies in the medium category (73%). After that, heterogeneity was carried out and the estimation model used to calculate the average effect size of the 15 articles was determined. The results of the heterogeneity test and determination of the estimation model using the random fixed model can be seen in table 4 .

Table 4. Heterogeneous Random and Fixed Model Results

	Q	Df	P
Omnibus test of Model Coefficients	48,019	1	< .001
Test of Residual Heterogeneity	31,295	14	0.005

Table 4 explains the results of the heterogeneity test, obtained a Q value of 31.295 which is greater than the value of 48.019 and a p value <0.001. These findings conclude that the analyzed effect sizes are heterogeneously distributed. The random effects model was effective for analyzing the average effect size of the 15 articles

included in the meta-analysis. The next step was to examine the publication bias of the 15 articles included in the meta-analysis. Checking publication bias in meta-analysis with funnel plots and Rosenthal Fail Safe N (Bernard et al., 2014 ; Suryono et al., 2023 ; Li & Wang, 2023 ; Juandi et al., 2021) . The results of the study bias can be seen in Figure 2.

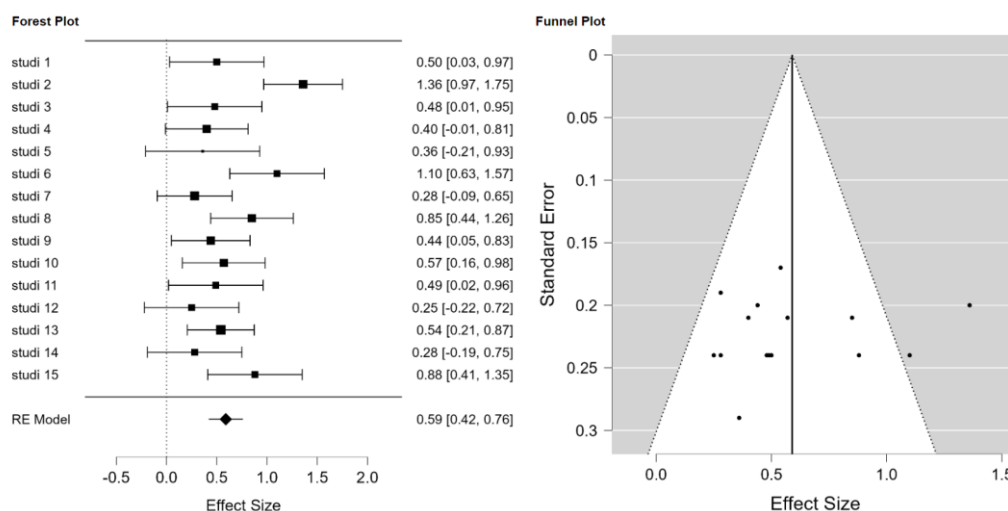


Figure 2. Funnel Plot Standard Error

Based on the funnel plot analysis in Figure 2, it shows that the data distribution in the funnel plot is symmetrical. To confirm this, a Rosenthal test was carried out as shown in Table 5. The table shows that there is no data that needs to be trimmed, which means the data distribution in the funnel plot is symmetrical (Li & Wang, 2023 ; Juandi et al., 2021).

Table 5. Rosenthal Fail Safe N

	Fail-safe N	Target Significance	Observed Significance
Rosenthal	581,000	0.050	< .001

Table 5 shows the results of the Rosenthal fail safe N test of 581,000 with a sig value. 0.050 and $p < 0.001$. The Rosenthal fail safe value is compared with the value $k = 15$ or $k = 5k + 10 = 85$, so the Rosenthal fail safe value $N > 5k + 10$ means that in the analysis of the 15 articles included in the meta analysis data no publication bias was found. Next, calculate the average effect size value to test the hypothesis. The results of the mean effect size test can be seen in Table 6.

Table 6. The results of the mean effect size test

	Estimate	Standard Error	z	P	95% Confidence Interval	
					Lower	Upper
intercept	0.590	0.085	6,930	< .001	0.423	0.757

Based on table 6, it is known that the effect size value with the random effect model was obtained ($r_{RE} = 0.590$; $SE = 0.085$; $z = 6.930$; $p < 0.001$). This shows that the application of the project based learning (PjBL) model has a significant effect on students' critical thinking abilities in elementary school science learning. At the 95% confidence level with a lower limit value of 0.423 and an upper limit of 0.757. The influence of the PjBL model on students' critical thinking abilities in elementary school

science learning is included in the medium category ($r_{RE} = 0.590$). Therefore, the application of the project based learning (PjBL) model influences students' critical thinking abilities in elementary school science learning.

This meta-analysis was carried out to see the influence of the PjBL model on students' critical thinking skills in elementary school science learning obtained from 15 articles in the database for the last 3 years. Based on the results of the analysis, the average effect size obtained was 0.59, which is in the medium category. This shows that the PjBL model has an influence on students' critical thinking abilities in elementary school science learning. This is in line with the results of Pratiwi's (2020) research that the project-based learning model affects students' critical thinking abilities. Damailia's (2023) research results state that the PjBL model improves students' critical thinking skills and makes students more active, involves students in problem solving, increases collaboration and develops students' communication skills.

The PjBL model has been proven to significantly improve elementary school students' critical thinking skills in various subjects (Nadiyah, 2023). The research results show that implementing PJBL leads to increased critical thinking skills, such as problem solving, analyzing and evaluating situations to make the right decisions. This model not only improves students' critical thinking but also encourages independence and creativity in the learning process, fostering a deeper understanding of concepts and real-life applications (Ricka, 2023; Haryani, 2023). Through the implementation of PJBL, students are involved in hands-on activities, which stimulate cognitive processes and enable them to explore various solutions to complex problems, which ultimately leads to improved critical thinking skills and improved student learning outcomes.

In applying the PjBL model to measure students' critical thinking abilities, teachers can use Ennis' critical thinking indicators. The critical thinking indicators that Ennis has set are abbreviated as FRISCO (Focus, Reason, Inference, Situation, Clarity, and Overview), where Focus is the student's ability to understand the problems presented by the teacher; Reasoning: students' ability to give reasons based on relevant facts in making conclusions; Concluding (inference) students' ability to choose the right reasons to make conclusions; Condition of students' abilities when using information according to the problem. Identified five systematic indicators in critical thinking, namely analytical skills, the main goal of which is to understand a concept. Synthesizing skills, skills in combining parts into a new structure. Skills to recognize and solve problems, these skills require students to understand reading critically so that after the reading activity is finished students are able to grasp the main ideas of the reading. Conclusion skills and evaluation skills (Perdana et al., 2020).

The characteristics of students' critical thinking abilities according to Beyer consist of, (1) students have an open attitude; (2) critical thinking must have a criterion or benchmark; (3) critical thinking skills including recognition, searching for information and making assessments; (4) consideration; (5) students will view an event from various points of view, and (6) procedures for applying critical thinking include formulating problems, determining decisions to be taken (Hasanuddin, 2017). Students' critical thinking abilities are developed through learning activities at school so that students can

reflect on their own thinking and can apply previous knowledge with newly acquired knowledge. Based on the opinion above, students' critical thinking abilities have several indicators, namely (1) students have the ability to analyze a given problem; (2) students are able to combine things into new arrangements; (3) students are able to recognize and solve the problems they face; (4) students are able to conclude a problem they are facing, and (5) students are able to evaluate a problem.

CONCLUSION

This research provides clear and precise information that the PjBL Model influences elementary school students' critical thinking abilities in science learning. Science learning is learning that can develop critical, logical and creative thinking skills. This meta analysis was carried out to see the effect of using the PjBL model on elementary students' critical thinking abilities in science learning obtained from 15 articles in the database for the last 3 years. Based on the results of the analysis, the average effect size obtained was 0.59, which is in the medium category. This shows that the PjBL model can improve students' critical thinking skills in elementary school science learning. Science learning in elementary schools provides a meaningful learning experience because in developing potential, students are given direct experience with nature in a systematic manner. Project-based learning is designed to be used on complex problems that require students to investigate and understand them. Considering that each student has a different learning style, project-based learning provides students with the opportunity to explore content (material) using various methods that are meaningful to them, and carry out experiments collaboratively.

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