Project-Based Learning on Critical Thinking Skills in Science Learning: Meta-analysis

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Abstract **- The development of information technology and the environment constitutes one of the most difficult challenges facing the 20th century. Quality education plays a crucial and strategic role in building quality human resources. We need to teach critical thinking to today's students. Critical thinking skills can be improved if the project-based learning model is applied to science education. The research method used was a literature review of relevant articles for five years (2019-2023). The systematic literature review process involves three stages: article search, research article filtering and selection analysis. Using Cohen's formula, the researchers have estimated the effect size. In the light of this study, the practical application of the project based learning method, Project Based Learning, aims to improve critical thinking skills in science education. Twenty research articles show that critical thinking skills essential to science education can be improved using Project Based Learning instruction.**

Keywords **– PjBL, critical thinking, science, effect size, Meta-analysis.**

1. Introduction

The development of information technology and various environmental problems have given rise to challenges and complex life situations in the 21st century.

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To overcome these multiple challenges, qualified and competent human resources are needed. Quality education plays a crucial and strategic role in building quality human resources. In the 21st century, learning is the process of acquiring practices that develop a person's moral and intellectual character as well as various skills, such as the ability to know something, ability to create new things and solve problems [1].

Critical thinking and communication, collaboration, problem-solving and creativity are 21st-century skills [2]. This will be consistent with the independent curriculum developed by the Ministry of Education and Culture. In this concept, the learning process should be rooted on freedom of thought, which starts with the teacher and then moves to the students. Teachers have to be able to plan and implement a meaningful learning process and understand the concept of an independent curriculum. However, in reality, schooling can be more effective. In schools that have yet to improve the skills needed, learning has to understand the demands of the 21st-century curriculum and skills.

Critical thinking is a thinking process that attempts to identify a problem in order to find a solution and make decisions that are considered logical in solving the problem. Teachers can consciously choose learning materials for programs to encourage students' critical thinking [3]. Developing cognitive skills and storing information effectively requires critical thinking. The educational activities so far have only been in the form of lectures, discussions, and exercises, which are still based on teacher instructions (teacher-centered learning) [4]. Students need critical thinking skills in solving problems, studying problems through multiple interpretations, understanding problems in responding to situations, and expressing opinions about problems and solving problems [5].

Appropriate learning models, methods, and strategies are needed to improve these skills. One way to develop 21st-century skills is to use the PjBL model. Learn according to this model emphasizes student activities in product production as a form of application of research, analysis, creation, and presentation skills of concepts learned with experience [6].

Project-based learning is considered an excellent learning model for developing various basic skills that students have to have, such as decision-making, creativity, and problem-solving [7].

Students can conduct collaborative research with the PjBL education model. Students can solve real-world problems and create challenging projects by interacting with the environment. From conducting experiments to the planning stage, exchanging ideas, finding solutions, and determining complex results, everything becomes more accessible with the PjBL model. Students can meet independent course demands through project-based learning in the twenty-first century. This learning can enable students to explore their knowledge and participate directly in acquiring knowledge [8].

PjBL learning is a way of thinking that enhances students' thinking ability to a higher level. PjBL helps students actively participate in the learning process and helps them acquire the skills they need for the 21st century. In short, it is project-based learning that integrates knowledge and practice [9]. A project-based learning model can develop a more disciplined learning attitude and help students become more proactive and creative. Project-based learning also has great potential to create a more engaging and meaningful learning experience. In addition, project-based learning allows students to explore student-centered problem solutions and create real products through projects [10].

Departing from the problems above, this research will present a study on analyzing student's critical thinking skills in a PjBL model. Teachers can use these learning outcomes as a guide to assess the impact of Project-based Learning (PjBL) on students' critical thinking skills. The results of this study help to strengthen student's critical thinking skills and improve the quality of education.

2. Methodology Section

The approach to writing this scientific article was to conduct a systematic literature review using international literature search engines of digital platforms (especially Google Scholar). Systematic Literature Review is a term used to refer to a research method by reviewing and evaluating research in a structured manner and classifying it according to specific topics by focusing on the results found in previous research. The purpose of a Systematic Literature Review is to identify, research, evaluate, and interpret all existing research based on topics related to the research.

The PRISMA method is an activity carried out using a literature review and meta-analysis approach to facilitate structural revision of the research objective roadmap [11].

Meta-analysis in literature reviews is used to analyze domestic and foreign scientific articles and dissertations with data from selected digital media using the Google Scholar platform to obtain previous research, quantifying a variable using analytical statistics to calculate effect sizes to obtain accurate data.

The systematic literature review process involves three stages: article search, research article filtering and selection analysis. The first step was to search for scientific articles with the word "Design-based critical thinking skills in science" and 9430 scientific articles were registered in 2019-2023. The application used to search for these keywords is Google Scholar or Google Scholar platform article search results from ±100 articles. The second stage is filtering and selecting scientific articles. By filtering articles according to inclusion and exclusion criteria, more specific articles have been selected.

The general characteristics of research subjects in the target population that can be used for research are inclusion criteria. Exclusion criteria eliminate subjects who meet the research inclusion criteria for various reasons. It is seen in Table 1 below.

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
1. National/International Scientific Articles on PjBL Model for Enhancing Critical Thinking Skills in Science Subjects	1. Scientific articles that cannot be accessed in full
2. Scientific articles use complete experimental research with average values and standard deviations from the experimental and control classes.	2. Scientific articles do not use experimental methods.

A sample of 100 scientific articles was filtered to find journals relevant to the problem formulation and met the inclusion and exclusion criteria. In the end, 80 articles were deleted because they needed to meet the purpose of writing this article. Therefore, 18 complete scientific articles were obtained. A total of 18 papers were analyzed and summarized according to the research purpose

3. Results

Data were analyzed and studied using the formula proposed by Glass (1981). We use the following effect size (ES) criteria:

- ES ≤ 0.15 negligible effect
- $0.15 < ES \leq 0.40$ small effect
- $0.40 < ES \leq 0.75$ medium effect
- $0.75 < ES \leq 1.10$ high effect
- $1.10 < ES \leq 1.45$ very high effect
- $1.45 <$ ES high influence

The research results were obtained by analyzing 18 scientific articles research articles published in the country and abroad using the Google Scholar platform to obtain effect size values, as presented in Table 2.

Table 2. Compilation of 18 Articles Project-Based Learning Models to Improve Critical Thinking Skills in Science Subjects

Journal Code	Author's Name and Year	Scale	Subject	Instrument	N	ES	Description
A1	[12]	International	Momentum and impulse	Description test	48	1.15	very high
A2	[13]	National	Momentum and impulse	Multiple choice test	62	1.91	high influence
A3	[14]	National	Optical Tools	Description test	32	2.09	high influence
A4	[15]	International	Ecosystem	Description test	58	0.69	medium
A5	[16]	International	Static Fluid	Work method	32	0.99	high
A6	[17]	International	Biotechnology	Multiple choice test	25	1.48	high influence
A7	[18]	International	Temperature and Heat	Description test	35	1.42	very high
A8	[19]	National	Optical Tools	Description test	179	2.09	high influence
A9	[20]	International	Dynamic electricity	Multiple choice test with reasons	31	2.26	high influence
A10	[21]	International	Temperature and Heat	Description test	30	3.33	high influence
A11	[22]	International	Climate change	Description test	72	0.97	high
A12	[23]	National	Magnetism	Work method	74	0.098	negligible
A13	[24]	National	-	Description test	26	2.64	high influence
A14	[25]	National	Physics	Work method	64	0.52	medium
A15	[26]	National	Physics	Description test	-	6.13	high influence
A16	[27]	National	University Science	Description test	-	1.36	very high
A17	[28]	National	Elementary Science	Description test	33	0.36	small
A18	[29]	International	Static Fluid	Description test	52	1.13	very high

The impact of the project-based learning model on students' critical thinking skills in science education, as indicated in the previous table, is established by 18 studies with various effect size values. Seven studies had effect sizes between 1.48 and 6.13 in the high influence category, four studies had effect sizes between 1.13 and 1.42 in the very high category. Two studies in the high category had effect sizes between 0.97 and 0.99. Two studies had effect sizes ranging from 0.52 to 0.69 in the medium category. One study had an effect size of 0.36 in the small category, and 1 study had an effect size of .098 in the negligible category.

The data analysis showed that the project-based learning model of science teaching affected improving student's critical thinking skills.

The analysis continues by examining the impact of PjBL models on the educational level. An average effect size was calculated for the 18 existing journals and grouped by educational levels of education, elementary school to university. The summary results are shown in Table 3 below.

Table 3. Effectiveness of Project-Based Learning Model Based on Education Level

Educational Level	Article Code	ES	Average ES	Description
Elementary school	A17	0.36	0.36	small
Junior high school	A6	1.48	2.13	high influence
	A9	2.26		
	A13	2.64		
Senior high school	A1	1.15	1.48	high influence
	A2	1.91		
	A3	2.09		
	A4	0.69		
	A5	0.99		
	A7	1.42		
	A8	2.09		
	A10	3.33		
	A11	0.97		
	A14	0.52		
	A18	1.13		
Vocational school	A14	0.098	0.098	negligible
Undergraduate	A15	6.13	3.75	high influence
	A16	1.36		

In Table 3, based on the subject analysis of PjBL's pedagogical effects at all levels of education, we find that it can be seen that it is divided into four levels: elementary school, junior high school, senior high school/vocational school, and undergraduate level. It consists of 1 subject in elementary school with a sub-category score of 0.36. At the level of junior high school, there are three subjects with an average score of 2.13, making it the most influential category. There are 13 subjects at the high school level with an average score of 1.48, which falls into the highest category. At the vocational school level, it consists of 1 article and an effect size of 0.098 is obtained with a negligible category. At the undergraduate level, there were two articles, and the average score was 3.75 which placed it in the most effective category. Understanding the impact on subjects of the PjBL model will be another analysis. Table 4 below gives a summary of the data analysis results.

Table 4. The influence of the PjBL model on subjects

Subject	Article code	ES	Average ES	Description
Momentum and impulse	A1	1.15	1.15	very high
Work and Energy	A2	1.91	1.91	high influence
Optical Tools	A3	2.09	2.09	high influence
	A8	2.09		
Ecosystem	A4	0.69	0.69	medium
Static Fluid	A5	0.99	1.06	high
	A18	1.13		
Biotechnology	A6	1.48	1.48	high influence
Temperature and Heat	A7	1.42	2.4	high influence
	A10	3.33		
Magnetism	A12	0.098	0.098	negligible
Elementary Science	A17	0.36	0.36	small
University Science	A16	1.36	1.36	very high
Magnetism	A12	0.098	0.098	negligible

The project-based learning (PjBL) model has a moderate impact on ecosystem content by topic. High effect sizes were found in static fluid materials and climate change. Very high effect sizes were found in momentum and impulse material and University Science. There is a high influence on work and energy materials, optical devices, biotechnology, temperature and heat. Meanwhile, elementary science material has a small effect size, and magnetism material has a negligible effect size.

The last thing to do is to see the impact of the Project Based Learning (PjBL) model on the assessment tools used. The results of the data analysis can be found in Table 5 below.

Table 5. Effectiveness of project-based learning model based on assessment tools

Instruments	Article code	ES	Average ES	Description
Description test	A1	1.15	1.95	high influence
	A3	2.09		
	A4	0.69		
	A7	1.42		
	A8	2.09		
	A10	3.33		
	A11	0.97		
	A13	2.64		
	A15	6.13		
	A16	1.36		
	A17	0.36		
	A18	1.13		
Multiple choice test	A2	1.91	1.7	high influence
	A6	1.48		
Multiple choice test with reasons	A9	2.26	2.26	high influence
Work method	A5	0.99	0.54	medium
	A12	0.098		
	A14	0.52		

A project-based learning (PjBL) model meta-analysis of the assessment tools used shows that interpretation tests have a significant effect on description and multiple-choice tests. Sizes range from 1.7 to 2.26. However, the performance assessment tool only achieved an average score of 0.54 in the medium category.

4. Discussion

The impact size is an important factor to be taken into consideration when conducting the analysis. The effect size indicates how much impact intervention will have on the relationship between two variables. The impact size can be used to provide information from the abstract findings of a journal's analysis. The effect size for each study can be determined to arrive at a general average of the effects. Using Cohen's formula, the researchers have estimated the effect size.

The relationships between variables considered in this study are the impact of the project-based learning model on improving critical thinking skills, the impact of the project-based learning model on educational achievement, and the relationship between project-based learning variables and topics. Materials and the relationship between project-based learning models and assessment tools are used. Therefore, the study has shown that learning through projects can help students to improve their analytical thinking skills in science education.

The purpose of this study is to describe several research findings that relate to the effects of Project Based Learning on students' ability to critically think in educational science. The study found that the project-based learning (PjBL) model has a mostly positive impact on student's critical thinking abilities. Of the 18 studies that showed high and medium effect sizes, only two showed low ones. According to the research results on educational level differences in the implementation of project-based learning models, the implementation of PjBL is very important for middle school, high school, and bachelor's level students. However, research shows that elementary and vocational school students have low effect size values.

Based on observations in elementary schools, the current learning process generally still relies on conventional models, such as lectures and assignments. So, the learning process is monotonous, and students are less able to explore their existing abilities and need to be used to thinking critically. This shows that teachers' lack of role in providing innovative learning experiences results in student's low critical thinking abilities [30].

The vocational school level also has a low effect size value. This is because vocational school students are only focused on hard skills to become professional workers and anticipate future needs and challenges that are aligned with the development of the needs of the business/industry world, developments in the world of work, and developments in science and technology [31].

We want our vocational school students to have general science skills and higher-order thinking skills, as well as hard skills. General science skills are essential skills that all students can develop through science education. These skills include direct observation, indirect observation, awareness of magnitude scales, fluency in using symbolic language, thinking in a sound logical framework, making logical inferences, understanding the laws of cause and effect, making mathematical models and building functional abstract concepts.

Regarding subject matter, project-based learning has the highest positive impact on temperature and heat material but has a low impact on magnetism material. This is because the concepts of magnetism are abstract, such as the concept of a magnetic field. Understanding the concept of a low magnetic field will impact further materials related to magnetic fields, such as electromagnetic induction, electromagnetic waves and others. The concept of magnetic fields also provides students with knowledge because there are many applications of magnetic fields in everyday life, such as fans, electrical measuring instruments, electric motors and so on. When implementing a project-based learning model, we need learning media to support the learning process [32].

Meanwhile, from the aspect of assessment instruments, Project-based learning has a higher effect size when students are given tests in multiple-choice and multiple-choice explanations. Meanwhile, the evaluation tool as performance has a medium effect size. The description test enables students to express themselves creatively so that they can analyze, identify, and connect problems with the knowledge they have and then be able to conclude a problem with the right reasons. With these abilities, students can improve their critical thinking abilities.

5. Conclusion

Three results emerged from the data analysis. The first is that introducing PjBL at middle school and graduate education levels is most effective in improving critical thinking skills compared to other education levels. Second, applying PjBL to temperature and heat material has the highest effect compared to other science materials in improving critical thinking skills.

The third implementation of PjBL is more effective in developing critical thinking skills using assessment tools such as descriptive and multiple-choice tests.

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