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Meta-Analysis: The Impact of PjBL on Students' Creative Thinking Skills in Physics Education

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Abstract

Education needs to enhance creative thinking skills, which are crucial in the era of the Fourth Industrial Revolution. However, traditional teacher-centered learning strategies have proven ineffective in fostering these skills, especially in challenging subjects like physics. The use of Project-Based Learning (PjBL) has been shown to improve students' creative thinking skills in physics education. This study aims to explore the impact of PjBL on students' creative thinking skills across various indicators in physics education by synthesizing findings from related research. The study employs a meta-analysis method, collecting empirical data using Google Scholar through Harzing's Publish or Perish 8 and Mendeley reference management software. The search yielded 28 articles from 2014-2024, with 13 articles meeting the inclusion criteria and providing sufficient data to calculate effect size. The results show an effect size of 1.03 (high). The effect size interpretation indicates that PjBL has an 84% impact on students' creative thinking skills. Additionally, 19 research articles observed creative thinking indicators influenced by PjBL, with elaboration being the highest and flexibility the lowest. It is concluded that the application of the PjBL model significantly affects students' creative thinking skills in physics education.

Keywords: Project-based learning; Creative thinking; Physics education; Meta-analysis.

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INTRODUCTION

The integration of 21st-century skills into the learning process is crucial for meeting the demands of the current Industry 4.0 era (Abdul et al., 2023). The reality of the Industry 4.0 revolution presents vast employment opportunities, making human labor more efficient, faster, and yielding satisfying results (Mardhiyah et al., 2021). Consequently, individuals must adapt quickly, innovate, think critically, collaborate, and solve complex problems (Redhana, 2019). Education plays a significant role in preparing quality human resources by integrating 21st-century skills into the learning process (Dewi, 2019; Redhana, 2019). These skills encompass the 4Cs: creative thinking, collaboration, critical thinking, and communication skills (Sari & Trisnawati, 2019).

Countries such as Ireland, Finland, Korea, New Brunswick (Canada), and Belgium have integrated 21st-century skills into their national curricula. Schools from elementary to secondary levels in these countries are required to prepare students with high-quality 21st-century skills. Ireland prioritizes communication and problem-solving skills across all subjects, while Finland's national core curriculum includes cross-curricular skills such as media and communication skills, environmental responsibility, citizenship and entrepreneurship, cultural identity and internationalism, and technology. Korea's curriculum includes seven core skills: creativity, problem-solving, self-management, citizenship, basic literacy, future job preparation, and multicultural sensitivity. New Brunswick, Canada, has initiated the "21st Century Schools" program aimed at creating innovative learning environments (Ananiadou & Claro, 2009).

The 21st-century learning emphasizes four principles: learner-centeredness, real-life collaborative relationships, context, and purpose (Hidayah & Nuroso, 2022). Moreover, students must develop competencies in creativity and innovation, meaning they should be able to create and update existing concepts (Kono et al., 2016). Teachers are thus required to integrate 21st-century skills into learning activities. In this context, students engage in individual or group practical activities while teachers act as facilitators (Widodo & Wardani, 2020). A learner-centered approach meets students' needs, including skills and knowledge acquisition (Amir, 2016).

With advancements in technology and science, creative thinking skills are essential for addressing challenges, requiring individuals to master creative thinking (Ulfa et al., 2019). Creative thinking skills involve solving real-life problems by generating new and unique solutions (Sumarni et al., 2019; Marliani, 2015). These skills comprise four indicators: flexibility, originality, elaboration, and fluency (Nurlaela & Aris, 2021).

Creative thinking skills can be nurtured in physics education (Fisher, 1995). They are crucial for helping students understand complex and abstract physics concepts through innovative and unique approaches (Armandita et al., 2017; Nurfadilah & Siswanto, 2020). By thinking creatively, students can solve difficult physics problems and contribute to scientific and technological advancements. Therefore, physics education should encourage creative thinking using relevant and interactive learning tools and technologies that align with current developments (Fakhri, 2023).

Currently, students' creative thinking skills tend to be low (Chasanah et al., 2016). This is supported by the Global Creativity Index (GCI) survey by Martin Prosperity, which ranks Indonesia low at 115 out of 139 countries in technology, talent, and tolerance (Florida et al., 2015). This may be influenced by the unsuitable learning strategies used in Indonesia (Yuliani et al., 2017). The learning process is still very passive and teacher-centered, resulting in teachers being more active than students (Ningsih et al., 2023). Students receive material passively from teachers without engaging in activities that involve their creativity, such as practical work (Sinta et al., 2022).

Observations by Maulani et al. (2021) and Munandar et al. (2018) at high schools confirm that teaching and learning activities are still teacher-centered. As a result, students participate less, and learning outcomes are unsatisfactory due to their inability to analyze material, such as physics content. These findings suggest that teacher-centered learning is not conducive to enhancing students' creative thinking skills and may even reduce their interest in learning due to lack of engagement (Hidayah & Nuroso, 2022).

Moreover, according to Witdiya et al. (2023), students find it difficult to understand physics material, perceiving it as too complex and not relatable. They also struggle with real-life problem-solving, often focusing on a single issue without considering alternative solutions, indicating a convergent thinking tendency

(Risnaini et al., 2016). This issue affects students' interest in physics and leads to lower learning outcomes (Sinta et al., 2022).

Based on the issues outlined, a student-centered learning model is needed. Student-centered learning aims to improve teaching quality, thereby enhancing students' learning potential and curiosity (Febriyana & Winarti, 2021). According to Firmansyah & Jiwandono (2022), student-centered learning has advantages in improving learning outcomes. Project-based learning, a proposed student-centered approach, has received positive responses from students and teachers in physics education (Fatmawati et al., 2023). Combining project-based learning with educational media influences students' creative thinking skills (Nasir, 2018).

Project-based learning, also known as PjBL, involves engaging students in scientific activities during the learning process (Nasir et al., 2019). In practice, PjBL employs a contextual learning approach through innovative and complex activities, encouraging students to produce designs, prototypes, or tangible products (Anas & Murti, 2016). PjBL guides students to address real-world problems by involving them in group project completion (Putri & Zulyusri, 2022).

Research on the impact of PjBL in physics education has been extensively discussed in previous studies. Studies by Wahyudi (2021), Mulyadi (2015), Oktadifani et al. (2016), and Datu et al. (2020) indicate that student learning outcomes improve after implementing PjBL. Research by Roziqin et al. (2018), Prameswari & Wahyudi (2019), and Oktadifani et al. (2016) shows that PjBL enhances science process skills in physics. Additionally, studies by Roziqin et al. (2018) and Permata et al. (2018) demonstrate that PjBL increases students' interest in learning physics. Furthermore, research by Monika et al. (2018) and Sasmita & Hartoyo (2020) suggests that PjBL improves students' understanding of physics concepts. However, Sasmita & Hartoyo (2020) used a STEM approach in PjBL implementation. The impact of PjBL with a STEM approach was also studied by Kanza et al. (2020), who found that this learning model increased student engagement in physics education.

Contrarily, a study by Kristanti et al. (2016) found no significant difference in student learning outcomes between the experimental class using PjBL and the control class using direct instruction in physics learning. Research on PjBL's effect on creative thinking skills by Mawarni & Sani (2020) and Firdaus et al. (2022) revealed that students' skills improved with PjBL, as indicated by their enthusiasm and increased interaction with teachers during the learning process.

These previous studies suggest that PjBL is effective in physics education, enhancing various skills, engagement, interest, and learning outcomes. However, inconsistencies exist in the research findings. Thus, a comprehensive review focusing on a single dependent variable, creative thinking skills, is necessary. This involves analyzing extensive information using statistical methods to determine PjBL's impact on creative thinking skills in physics education. Therefore, a meta-analysis technique, which provides a comprehensive effect size, is required.

Previous meta-analyses on PjBL's impact on creative thinking skills in physics education by Sutria et al. (2023), Hidayah & Nuroso (2022), and Ananda et al. (2021) focused solely on high school level and subject matter with potential to enhance creative thinking skills. However, these studies showed inconsistencies. Hidayah & Nuroso (2022) found that electromagnetic induction is the most effective physics material for enhancing creative thinking with PjBL, whereas Ananda et al. (2021) and Sutria et al. (2023) found that sound waves are more effective.

Objective of Study

This meta-analysis aimed to address these inconsistencies that previously described by expanding the sample to include both secondary and tertiary education levels, and examining the overall effects of PjBL on creative thinking skills and its indicators in physics education. Therefore, this study aims to achieve the following objectives:

1. Determine the overall impact of PjBL on students' creative thinking skills in physics education.
2. Assess the impact of PjBL on the indicators of creative thinking skills in physics education.

The results of this meta-analysis are expected to provide consistent insights and a comprehensive overview of the overall research findings. Additionally, this study aims to serve as a reference for future research.

METHODS

This study is based on a quantitative approach using meta-analysis. Meta-analysis is a type of quantitative research that utilizes numerical data and statistical methods from various studies to organize and explore information in-depth, achieving optimal comprehensiveness (Chandra, 2011). It combines results from multiple studies, which can then be statistically analyzed (Santosa & Yulianti, 2020). Meta-analysis leverages the effect size from several studies for comparison and analysis (Fahrezi et al., 2020). Thus, meta-analysis is employed in this study to provide a comprehensive overview of the effectiveness of PjBL on students' creative thinking skills in physics education by synthesizing data from various studies.

The research steps using the meta-analysis method follow the three stages proposed by Paloloang et al. (2020).

1. Determine inclusion criteria for the research objects to be studied.
2. Explain the stages of empirical data collection and research variables.
3. Describe the data analysis stages.

Inclusion criteria are essential for obtaining relevant studies to achieve the research objectives. The relevant studies must meet the following criteria.

1. Publication year of the research articles between 2014 and 2024.
2. Articles from journal publications, proceedings, and national sources.
3. Articles demonstrating the impact of PjBL on students' creative thinking skills in physics education.
4. Research methods include experimental, pre-experimental, quasi-experimental, and classroom action research.
5. Studies involving at least one experimental group and one control group, with results that can be compared and one group receiving the intervention incrementally.
6. Articles containing necessary effect size and statistical data, such as mean, chi-square, standard deviation, sample size, and t-test results.

Empirical data collection was conducted using the Google Scholar database via Harzing's Publish or Perish 8 and Mendeley reference management software. Data collection aimed to obtain relevant journal articles and proceedings using keywords such as "PjBL," "Creative Thinking," and "Physics Education." This process yielded 28 journal articles and proceedings published between 2014 and 2024. The obtained data were then screened based on the inclusion criteria. Articles not meeting the inclusion criteria were excluded, leaving those that fit the criteria for meta-analysis calculation to determine the overall effect size of PjBL on students' creative thinking skills in physics education.

A coding sheet for data collection was necessary to translate the information easily. The required data included a coding sheet encompassing relevant article information, such as the researchers' names and publication years (within 2014-2024), research model, means (pretest and posttest) or n (sample size ≥ 30), standard deviation (SD) or t-values, and formulas. This coding was performed to obtain the effect size (ES), showing the magnitude of the effects from comparing several studies with different samples. The effect size was calculated using mathematical equations tailored to the statistical data obtained, as shown in Table 1, to estimate the influence of independent and dependent variables (Shorten & Shorten, 2013).

Tabel 1. Mathematical equation of effect size (ES)

Data Statistics	Mathematical Equation of ES	Formula (Fr)
Mean and SD for each group (posttest only)	$ES = \frac{\bar{x}_{experiment} - \bar{x}_{control}}{SD_{control}}$	Fr-1
Mean and SD for each group (pretest and posttest)	$ES = \frac{(\bar{x}_{post} - \bar{x}_{pre})experiment - (\bar{x}_{post} - \bar{x}_{pre})control}{\left(\frac{SD_{pre\,control} + SD_{pre\,experiment} + SD_{post\,control}}{3}\right)}$	Fr-2
Mean and SD for a single group	$ES = \frac{\bar{x}_{post} - \bar{x}_{pre}}{SD_{pre}}$	Fr-3
t value	$ES = t\sqrt{\frac{1}{n_{exp}} + \frac{1}{n_{control}}}$	Fr-4
Chi-square	$ES = \frac{2r}{\sqrt{1 - r^2}}; r = \sqrt{\frac{x^2}{n}}$	Fr-5

Once the effect size (ES) is obtained, it can be interpreted according to the effect size interpretations proposed by Cohen (1988) as shown in Table 2.

Table 2. Cohen's effect size interpretations

No	Effect Size (ES)	Interpretation
1	ES ≥ 0.8	High
2	0.2 ≤ ES < 0.8	Moderate
3	0 ≤ ES < 0.2	Low

Once the average effect size is obtained, the influence of the independent variable on the dependent variable can be interpreted according to Table 3 (Coe, 2002).

Table 3. Interpretation of the effect size (ES)

Effect Size (ES)	Influence (%)
0.0	50
0.1	54
0.2	58
0.3	62
0.4	66
0.5	69
0.6	73
0.7	76
0.8	79
0.9	82
1.0	84
1.2	88
1.4	92
1.6	95
1.8	96
2.0	98
2.5	99
3.0	99.9

RESULTS AND DISCUSSION

The data collection phase resulted in 28 scientific journal articles featuring the keywords "PjBL," "Creative Thinking," and "Physics Education," presented in Table 4.

Table 4. Summary of research articles on PjBL and creative thinking skills in physics education

No	Author(s)	Research Method	Indicator Percentage
1	(Risnaini et al., 2016)	Nonequivalent Control Group Design	-
2	(Fajrina et al., 2018)	Posttest Only Control Group Design	1. Fluency = 88.28% 2. Flexibility = 70.31% 3. Originality = 78.91% 4. Elaboration = 70.31%
3	(Umamah & Andi, 2019)	Nonequivalent Pretest-Posttest Design	1. Fluency = 82.58% 2. Elaboration = 76.14% 3. Flexibility = 74.62% 4. Originality = 64.20%
4	(Sinta et al., 2022)	Nonequivalent Control Group Design	1. Elaboration = 92% 2. Originality = 88% 3. Flexibility = 86% 4. Fluency = 71%
5	(Andi et al., 2018)	Nonequivalent Control Group Design	-
6	(Firdaus et al., 2022)	Posttest-only Control Group Design	1. Elaboration = 100% 2. Fluency = 83% 3. Originality = 54% 4. Flexibility = 39%
7	(Mawarni & Sani, 2020)	Two Group Pretest-Posttest Design	1. Fluency = 82.24% 2. Originality = 75.45%

No	Author(s)	Research Method	Indicator Percentage
			3. Elaboration = 71.23% 4. Flexibility = 70.31%
8	(Safrina et al., 2022)	Pre-experiment Design Posttest Only	1. Originality = 480.5 2. Flexibility = 417.5 3. Fluency = 334
9	(Nurfa & Nana, 2020)	Nonequivalent Control Group Design	-
10	(Khoiri et al., 2016)	Pretest-Posttest Design	1. Elaboration 2. Originality 3. Flexibility 4. Fluency
11	(Mulhayatiah, 2014)	Quasi Experiment	1. Elaboration = 7.59 2. Flexibility = 7.55 3. Fluency = 7.43 4. Originality = 7.34
12	(Amalia et al., 2019)	One Group Pretest-Posttest Design	1. Originality = 95.59% 2. Fluency = 79.41% 3. Elaboration = 75% 4. Flexibility = 62.65%
13	(Khanifah & Saefan, 2016)	Quasi Experiment	-
14	(Putri et al., 2020)	One Group Pretest-Posttest Design	-
15	(Rohman & Husna, 2021)	Pre-Experiment One Group Pretest-Posttest Design	1. Fluency = 22.17% 2. Elaboration = 21.95% 3. Flexibility = 14.55%
16	(Dinantika et al., 2019)	Posttest Only Control Group Design	-
17	(Fajaruddin, 2022)	Classroom Action Research (CAR)	-
18	(Sari et al., 2018)	Mixed Methods with Embedded Experiment Model	1. Elaboration = 100% 2. Fluency = 89.06% 3. Originality = 81.25% 4. Flexibility = 53.12%
19	(Medriati et al., 2022)	Classroom Action Research (CAR)	-
20	(Erisa et al., 2021)	Classroom Action Research (CAR)	-
21	(Aini et al., 2018)	Posttest Only Control Design	1. Elaboration = 80 2. Flexibility = 69.53 3. Originality = 61.91 4. Fluency = 52.38
22	(Cahyani & Viyanti, 2023)	Nonequivalent Control Group Design	1. Originality = 69% 2. Flexibility = 61% 3. Elaboration = 50% 4. Fluency = 50%
23	(Rachmawati et al., 2018)	Pre-Experiment One Group Pretest-Posttest Design	1. Fluency 2. Flexibility 3. Originality
24	(Sahida, 2021)	Control Group Pretest-Posttest Design	1. Elaboration = 88.5% 2. Fluency = 85.5%

No	Author(s)	Research Method	Indicator Percentage
			3. Originality = 80% 4. Flexibility = 80%
25	(Utami et al., 2019)	Two Group Pretest-Posttest Design	1. Fluency = 77.64% 2. Elaboration = 71.32% 3. Flexibility = 69.15% 4. Originality = 68.65%
26	(Fauziah et al., 2018)	Pretest-Posttest Group Design	-
27	(Ningsih et al., 2023)	Pretest-Posttest Control Group Design	1. Originality 2. Flexibility 3. Elaboration 4. Fluency
28	(Abdullah et al., 2017)	Equivalent Pretest-Posttest Design	1. Elaboration = 70% 2. Originality = 70% 3. Fluency = 69% 4. Flexibility = 68%

Note: (-) indicates that creative thinking indicators were not observed.

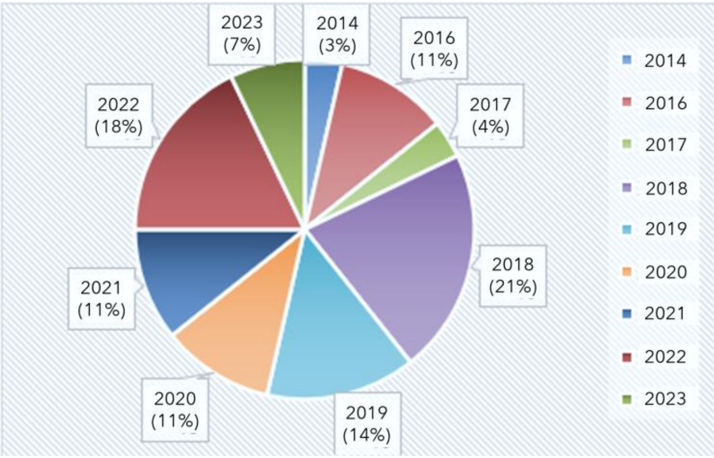

Figure 1. Distribution of studies by publication year

The collected studies cover publication years from 2014 to 2024. The distribution of research by publication year is illustrated in Figure 1. The pie chart in Figure 1 shows that the highest number of studies were published in three specific years: 2018 (21%), 2022 (18%), and 2019 (14%). This indicates a trend in research on PjBL and creative thinking skills in physics education peaking in 2018, with six articles published that year.

After the selection phase, the results were grouped as shown in Figure 2. A total of 13 relevant research articles (displaying statistical data) were identified for calculating the effect size based on the statistical data presented in each relevant journal article. Referring to Table 4, these relevant articles are listed as articles No. 1-13, now presented in Table 5. Meanwhile, 15 articles (No. 14-28) either lacked statistical data or presented insufficient data for meta-analysis. Furthermore, 19 articles observed creative thinking indicators, which are detailed in Table 6. Therefore, 9 articles did not report the percentage of creative thinking indicators affected by PjBL.

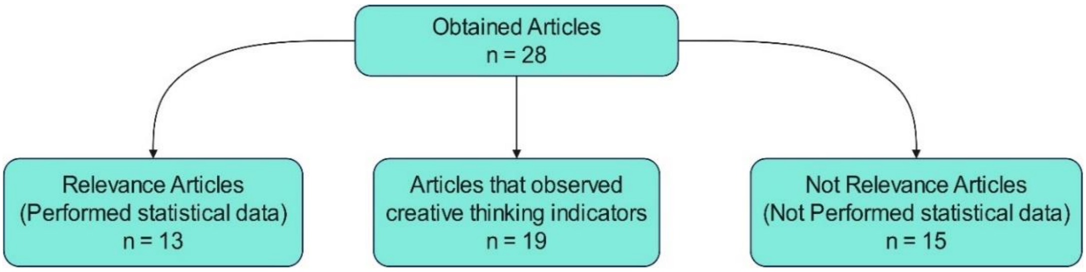

Figure 2. Mapping of collected research articles

Through the data collection phase, 28 research journal articles were obtained by adhering to the inclusion criteria. Subsequently, a selection phase was conducted to identify relevant articles that provided sufficient statistical data for calculating the effect size. These selected articles are detailed in Table 5. This organized mapping resulted in 13 relevant research journal articles that discussed the implementation of PjBL on students' creative thinking skills in physics education, all presenting complete statistical data as required for this study. The remaining 15 articles were deemed irrelevant because they either did not provide statistical data or the provided data was insufficient for meta-analysis, thus excluding them from further consideration. The effect size values for each of the 13 relevant research journal articles were calculated using the statistical data provided in each article, referencing one of the mathematical equations from Table 1. The results of these calculations were compiled in Table 5, along with the overall average effect size value. The representation of the effect size values in Table 5 is shown in Figure 3.

Table 5. Effect size calculation of PjBL impact on students' creative thinking skills in physics education

No	Author	$\bar{x}$/n	SD/t_{value}	Fr	ES	Interpretation
1	(Risnaini et al., 2016)	$\bar{x}_{exp} = 93$ $\bar{x}_{control} = 82$	$SD_{exp} = 8.56$ $SD_{control} = 13.68$	Fr-1	0.80	High
2	(Fajrina et al., 2018)	$\bar{x}_{exp} = 82.19$ $\bar{x}_{control} = 67.50$	$SD_{exp} = 10.78$ $SD_{control} = 10.47$	Fr-1	1.40	High
3	(Umamah & Andi, 2019)	$\bar{x}_{exp} = 75.2273$ $\bar{x}_{control} = 71.7045$	$SD_{exp} = 6.12$ $SD_{control} = 6.14$	Fr-1	0.57	Moderate
4	(Sinta et al., 2022)	$\bar{x}_{pre\ exp} = 34.05$ $\bar{x}_{post\ exp} = 73.84$ $\bar{x}_{pre\ control} = 31.67$ $\bar{x}_{post\ control} = 63.20$	$SD_{pre\ control} = 10.87$ $SD_{pre\ exp} = 4.21$ $SD_{post\ control} = 8.74$	Fr-2	1.0	High
5	(Andi et al., 2018)	$\bar{x}_{exp} = 90.5$ $\bar{x}_{control} = 82.33$	$SD_{control} = 7.626$	Fr-1	1.07	High
6	(Firdaus et al., 2022)	$\bar{x}_{exp} = 69.06$ $\bar{x}_{control} = 62.06$	$SD_{control} = 5.71$	Fr-1	1.23	High
7	(Mawarni & Sani, 2020)	$\bar{x}_{pre\ exp} = 36.96$ $\bar{x}_{post\ exp} = 74.46$ $\bar{x}_{pre\ control} = 36.61$ $\bar{x}_{post\ control} = 68.30$	$SD_{pre\ control} = 8.76$ $SD_{pre\ exp} = 10.07$ $SD_{post\ control} = 8.58$	Fr-2	0.66	Moderate
8	(Safrina et al., 2022)	$\bar{x}_{exp} = 88.31$ $\bar{x}_{control} = 85.86$	$SD_{control} = 3.81$	Fr-1	0.64	Moderate
9	(Nurfa & Nana, 2020)	$n_{exp} = 40$ $n_{control} = 36$	$T_{value} = 2.99$	Fr-4	0.69	Moderate

No	Author	$\bar{x}$/n	SD/t_{value}	Fr	ES	Interpretation
10	(Khoiri et al., 2016)	n_{exp} = 35 $n_{control}$ = 35	T_{value} = 1.82	Fr-4	0.43	Moderate
11	(Mulhayatiah, 2014)	$\bar{x}_{pre\ exp}$ = 8.34 $\bar{x}_{post\ exp}$ = 29.91 $\bar{x}_{pre\ control}$ = 7.71 $\bar{x}_{post\ control}$ = 24.76	$SD_{pre\ control}$ = 15.73 $SD_{pre\ exp}$ = 15.28 $SD_{post\ control}$ = 11.4	Fr-2	1.2	Moderate
12	(Amalia et al., 2019)	n_{exp} = 34 $n_{control}$ = 30	t_{hitung} = 12.33	Fr-4	3.09	High
13	(Khanifah & Saefan, 2016)	n_{exp} = 40 $n_{control}$ = 36	t_{hitung} = 2.99	Fr-4	0.68	Moderate
	Average				**1.03**	**High**

Based on the effect size graph in Figure 3, the interpretation of the effect size is high at 3.09 and medium at 0.43. No studies were found with a low effect size interpretation. Additionally, the overall average effect size calculation in Table 5 indicates that the application of PjBL significantly enhances students' creative thinking skills in physics education, with an effect size value of 1.03, interpreted as high (according to Table 2), and an influence percentage of 84% (according to Table 3).

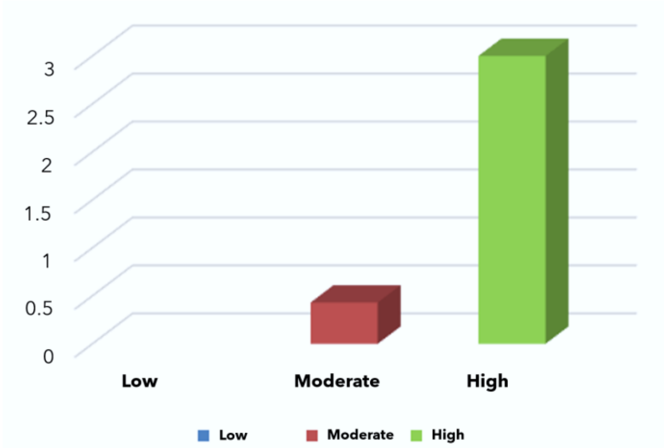

Figure 3. Interpretation of effect size of PjBL on students' creative thinking skills in physics education

Previous studies by Hidayah & Nuroso (2022) also showed a high interpretation, with an overall average effect size of 0.82 from 10 research articles. Another study by Sutria et al. (2023) revealed a high interpretation with an average effect size of 1.39 from 11 research articles. Similarly, Ananda et al. (2021) found that the impact of PjBL on creative thinking skills in physics education reached a high effect size interpretation, with an average value of 1.58.

Table 6. Highest and lowest indicators based on research articles presenting creative thinking indicators

No	Author(s)	Highest Indicator	Lowest Indicator
1	(Fajrina et al., 2018)	Fluency	Elaboration
2	(Umamah & Andi, 2019)	Fluency	Originality
3	(Sinta et al., 2022)	Elaboration	Fluency
4	(Firdaus et al., 2022)	Elaboration	Flexibility

No	Author(s)	Highest Indicator	Lowest Indicator
5	(Mawarni & Sani, 2020)	Fluency	Flexibility
6	(Safrina et al., 2022)	Originality	Fluency
7	(Khoiri et al., 2016)	Elaboration	Fluency
8	(Mulhayatiah, 2014)	Elaboration	Originality
9	(Amalia et al., 2019)	Originality	Flexibility
10	(Rohman & Husna, 2021)	Fluency	Flexibility
11	(Sari et al., 2018)	Elaboration	Flexibility
12	(Aini et al., 2018)	Elaboration	Fluency
13	(Cahyani & Viyanti, 2023)	Originality	Fluency
14	(Rachmawati et al., 2018)	Fluency	Originality
15	(Sahida, 2021)	Elaboration	Flexibility
16	(Utami et al., 2019)	Fluency	Originality
17	(Ningsih et al., 2023)	Originality	Fluency
18	(Fajrina et al., 2018)	Fluency	Elaboration
19	(Abdullah et al., 2017)	Elaboration	Flexibility

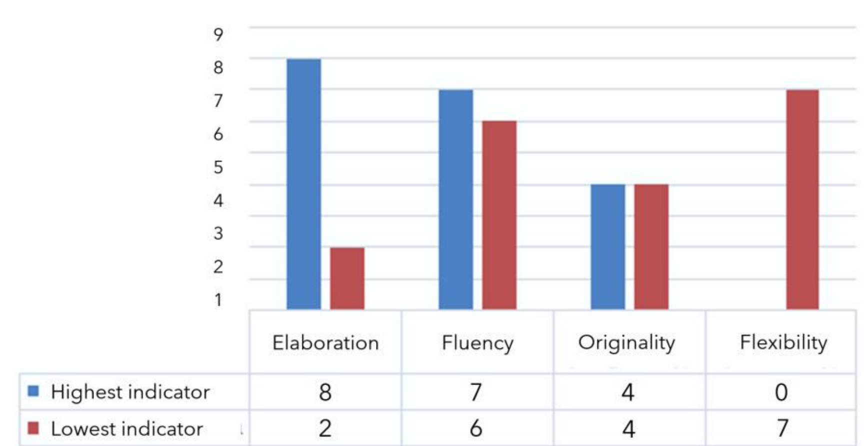

Figure 4. Highest and lowest creative thinking indicators

Based on Table 6, 19 research journal articles observed creative thinking indicators, represented in Figure 4, showing the highest and lowest creative thinking indicators influenced by PjBL. According to Figure 4, 8 research articles indicated that elaboration was the highest indicator influenced by PjBL. This suggests that students are more capable of detailing ideas when solving problems, as noted by Sari et al. (2018), who found that most students could elaborate on their ideas more thoroughly when answering questions. Additionally, Sinta et al. (2022) reported that students were able to create detailed plans for completing tasks during projects and discussions. Elaborative thinking is crucial as it encourages students to present their work in various ways for each group. Students with good elaboration skills can systematically, sequentially, and thoroughly address problems, providing detailed explanations.

Conversely, flexibility was the lowest indicator, as shown by 7 research articles. Firdaus et al. (2022) found that students struggled to provide diverse answers with complete reasoning during posttest assessments of creative thinking skills. Sari et al. (2016) supported this finding, noting that students were often confused and stuck on one problem, unable to find the best or most efficient solution.

CONCLUSION

The results of this meta-analysis indicate that the implementation of PjBL has a very high impact on students' creative thinking skills in physics education, with an effect size interpretation of 84% from an effect size value of 1.03 based on 13 relevant research journal articles out of a total of 28 articles that met the inclusion criteria. Additionally, among the 19 articles that observed creative thinking indicators, elaboration was identified as the highest indicator, while flexibility was the lowest. Therefore, the implementation of PjBL can significantly enhance students' creative thinking skills in physics education across various educational levels.

RECOMMENDATION

The meta-analysis results suggest that future research should focus more on enhancing the flexibility indicator, which has been identified as the lowest creative thinking skill indicator when applying the PjBL model in physics education. Future studies should investigate methods and approaches that have the potential to improve flexibility, such as integrating technology into PjBL, using brainstorming techniques, and mind mapping. Additionally, it is highly recommended to develop learning modules specifically designed to enhance flexibility and to provide training for teachers on these methods and approaches. Long-term studies are also needed to assess the impact of PjBL on students' flexibility in thinking over extended periods. Consequently, it is expected that the application of PjBL will become more effective in improving all indicators of students' creative thinking skills, particularly flexibility.

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