Creative thinking enhancement through project-based learning in science: a meta-analytic review

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ABSTRACT

This research investigates the impact of project-based learning (PjBL) on enhancing students' creative thinking abilities through a comprehensive meta-analytic study. Creative thinking is recognized as an integral part of higher-order thinking skills (HOTS) required for success. Employing the preferred reporting items for systematic reviews and meta-analyses (PRISMA), studies published between 2014 and 2024 were identified and synthesized from the Scopus database. Data analysis, conducted with R, assessed the impact of PjBL using effect size (ES) measurements. The findings demonstrate that PjBL significantly improves creative thinking skills compared to traditional teaching methods. Moderator analysis revealed that variables such as educational level, subject area, and learning model influence the outcomes, with the highest impact observed in high school and inquiry-driven subjects like physics. Variations of PjBL, including technology-enhanced models, such as Google Classroom-based approaches, further amplified its effectiveness, particularly in virtual learning environments. This study highlights PjBL's adaptability and robust potential in fostering creativity and innovation across diverse educational contexts. The results provide practical implications for educators in designing tailored PjBL strategies to cultivate students' creative thinking, emphasizing the importance of interdisciplinary approaches and technological integration in modern education.

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1. INTRODUCTION

Higher-order thinking skills (HOTS) encompass various advanced cognitive capabilities, including creative thinking abilities [1]. In 21st-century education, creative thinking, along with critical thinking, communication, and collaboration, is recognized as one of the key competencies for success [2]. Creative thinking is distinguished by four essential attributes: the ability to generate numerous ideas, adapt to diverse perspectives, produce innovative concepts, and expand on ideas with detailed reasoning, all of which reflect the cognitive components of HOTS.

Fluency refers to the capacity to quickly produce a variety of ideas, formulate questions, and suggest solutions to challenges [3], [4]. Flexibility involves considering diverse perspectives and presenting multiple viewpoints. Originality is characterized by the generation of unique ideas and innovative approaches, while elaboration refers to refining and expanding on ideas to provide detailed reasoning and adapt concepts to new contexts [5]. Together, these skills enable students to produce broad, high-quality ideas and engage in imaginative, innovative thinking [6], [7].

Despite the importance of creative thinking, current levels among students remain low, particularly after the disruptions caused by the COVID-19 pandemic. Social and psychological challenges such as boredom, reduced school engagement, limited peer interaction, diminished motivation, and increased dependence on digital tools have significantly impacted students' cognitive development [8]. Addressing these challenges requires innovative pedagogical strategies that emphasize real-world connections and active engagement [9]. Among these strategies, project-based learning (PjBL) stands out as an effective approach.

PjBL is a student-focused method that engages learners in practical, real-world projects, encouraging them to apply their knowledge and abilities to solve problems in innovative ways [10]. By integrating creativity, critical thinking, and collaboration, PjBL not only improves learning outcomes but also fosters essential competencies needed to navigate the complexities of modern life [11], [12]. Across a range of disciplines, including biology, mathematics, and language learning, PjBL has consistently demonstrated its ability to enhance higher-order thinking skills, including creative thinking [13], [14].

PjBL is highly regarded for its ability to improve students' higher-order thinking abilities, particularly their creative thinking skills. Research has shown that PjBL fosters creativity by engaging students in project-based activities where they harness their knowledge and abilities to address challenges and develop innovative solutions [14]. This approach not only supports improved learning outcomes but also fosters essential competencies such as critical thinking, effective decision-making, and innovative problem-solving [15]. Across diverse educational contexts, including computer numerical control, rotational equilibrium, and Arabic language learning, PjBL consistently demonstrates positive impacts on students' creative thinking skills [13], [15], [16].

Integrating PjBL with other pedagogical frameworks further amplifies its impact. For instance, the Learning Cycle 7E and science, technology, engineering, arts, and mathematics (STEAM) approaches provide interdisciplinary learning experiences that foster creativity, collaboration, and innovation [17], [18]. These strategies help students develop a broader understanding by connecting concepts across subjects, enhancing both critical and creative thinking.

Digital tools and platforms also strengthen PjBL's effectiveness. For example, the use of dynamic math software and e-learning platforms improves both creativity and self-regulation abilities [19], [20]. Amid the COVID-19 pandemic, e-learning tools and flipped learning models emerged as valuable assets, allowing students to learn independently through multimedia resources. These digital adaptations created engaging environments that stimulated creativity and critical thinking [21], [22].

The literature highlights the significant positive influence of PjBL across various educational contexts and disciplines. Studies consistently report improvements in both critical and creative thinking skills [23]. Meta-analyses and empirical studies confirm that PjBL fosters creativity and innovation by engaging students in authentic tasks that require critical thinking, collaboration, and problem-solving [23]. However, research findings often show inconsistencies, which may arise from differences in study design, sample populations, and assessment methods. Some studies report strong correlations between PjBL and creative thinking, while others note more moderate or context-dependent effects. These variations underscore the importance of systematic analysis to better understand how specific factors influence PjBL outcomes.

The purpose of this research is to assess the effectiveness of the PjBL approach in promoting students' creative thinking abilities within the domain of science education. Utilizing a meta-analytic methodology, the study aims to present evidence on the connection between PjBL and creative thinking, while also identifying the contextual factors—such as educational level, sample size, and learning context—that influence its effectiveness. The novelty of this study lies in its focus on recent literature (2014–2024) and its analysis of how different PjBL variations and contextual factors specifically impact creative thinking in science education.

2. METHOD

This study investigates the implications of the PjBL model on developing students' creative thinking skills in science education through a systematic literature review (SLR) and meta-analysis. In order to ensure that this review followed the best practices for systematic reviews and meta-analyses, it was based on the preferred reporting items for systematic reviews and meta-analyses (PRISMA) recommendations [24]. Meta-analysis is a widely recognized method for synthesizing prior research and empirically validating theoretical frameworks across disciplines [25], [26]. The procedural framework for this study adhered to the comprehensive steps outlined by Hansen *et al*. [27], ranging from planning to the presentation of results.

The data collection process began with a systematic search of the Scopus database using four key phrases: i) "Project-based learning for creative thinking in science"; ii) "Project-based learning for creative thinking in chemistry"; iii) "Project-based learning for creative thinking in physics"; and iv) "Project-based learning for creative thinking in biology". Articles were used in the analysis if they met the following criteria: they were published between 2014 and 2024, indexed in Scopus, and written in English. Only journal articles were considered, excluding proceedings, books, or other publication formats. Articles were required to explicitly measure creative thinking skills and apply the PjBL model within experimental or quasi-experimental research designs. Data comprising pre- and post-treatment assessments or comparisons between control and experimental groups were also required of qualifying research, which included students from a range of educational backgrounds pursuing science-related disciplines including chemistry, biology, and physics.

The selection process for this study adhered to the PRISMA framework, encompassing four key stages: identification, screening, eligibility, and inclusion. During the identification phase, all pertinent articles were retrieved from the initial search results. In the screening phase, duplicates were removed, and titles and abstracts were assessed for preliminary relevance. The eligibility phase involved a detailed evaluation of the full text of articles that passed the screening stage, ensuring they met the inclusion and exclusion criteria. Finally, in the inclusion phase, articles that fulfilled all the inclusion requirements were incorporated into the final meta-analysis. A PRISMA flow diagram was used to illustrate this process in the study, as shown in Figure 1. Employing the PRISMA, 241 studies published between 2014 and 2024 were identified from the Scopus database, of which 12 met the inclusion criteria. These studies represent diverse international contexts, including Indonesia, Spain, Jordan, China, and the Philippines.

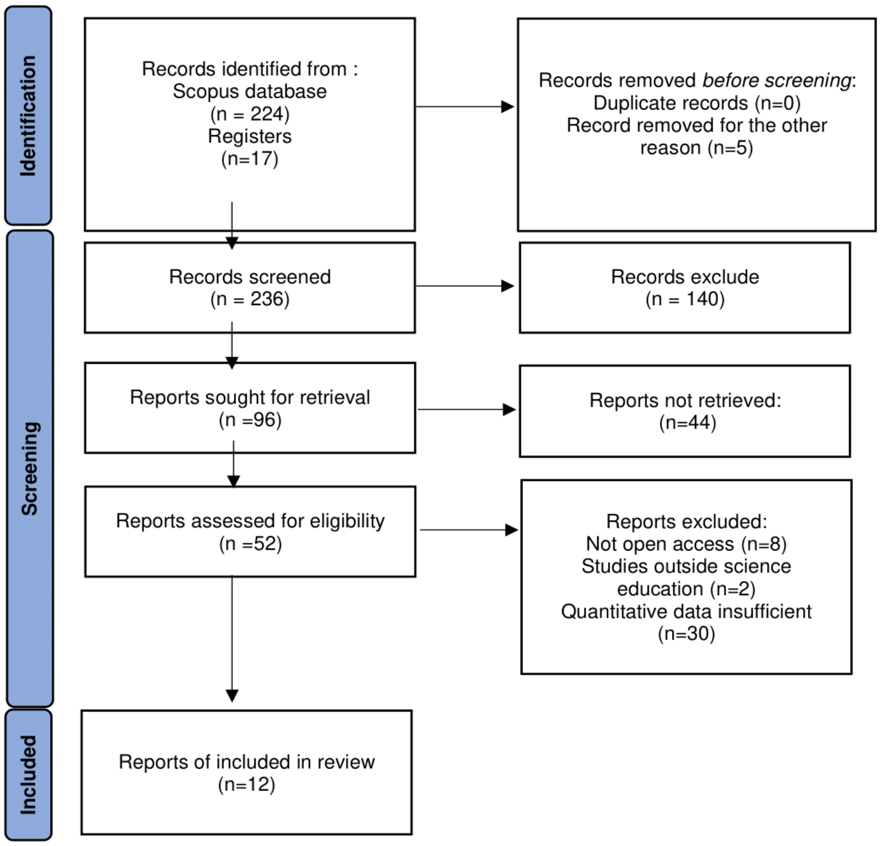

Figure 1. PRISMA flow diagram

The data analysis for this meta-analysis was performed using the R software. Effect sizes (ES) were determined to measure the influence of the PjBL model on students' creative thinking abilities. The data collected included ES values, standard deviations (SD), sample sizes (N), and moderator variables such as education level, assessment method, and study location. A random-effects model was utilized to manage variability across studies, and heterogeneity was evaluated using the I^2 statistic [28].

Funnel plots were used to evaluate publication bias and ensure the reliability of the meta-analysis findings [29]. Additionally, forest plots were created to depict the ES and confidence intervals (CIs) for each study. These plots provided a clear representation of the distribution and homogeneity of study results

[30], [31]. Heterogeneity analysis using the I^2 statistic determined the degree of variance across studies due to differences in methodologies, contexts, or sample characteristics [32].

Moderator analysis was performed to investigate factors that could influence the results, such as educational levels, assessment methods, or study locations. This analysis provided insights into the conditions under which the PjBL model is most effective. ES were interpreted using established interval criteria shown in Table 1, where a positive ES demonstrated that the experimental group applying the PjBL model outperformed the control group in creative thinking skills. These classifications provided an empirical basis for evaluating the overall effectiveness of the PjBL model.

Publication bias is a common issue in meta-analyses, arising when research with favorable or statistically significant outcomes are more often published compared to studies with negative or insignificant findings. The pooled effect estimates might be skewed due to this bias, as published studies might not be representative of all research on the subject [33]. To detect publication bias, funnel plots were generated using R software [34]. These plots display the ES of individual studies (e.g., standardized mean difference (SMD)) on the horizontal axis and the standard error on the vertical axis. In an ideal scenario, a symmetrical funnel plot indicates that studies with both significant and non-significant results are adequately represented, while asymmetry suggests potential publication bias. This analysis also used trim-and-fill techniques to estimate and adjust for potential missing studies, enhancing the reliability and accuracy of the meta-analysis findings [29], [35].

Table 1. Interval ES

ES	Value
ES<0.19	No effect
0.20≤ES≤0.49	Small effect
0.50≤ES≤0.79	Medium effect
ES>0.80	Large effect

3. RESULTS AND DISCUSSION

3.1. Effectiveness of PjBL in improving creative thinking skills

The reviewed studies, as seen in Table 2, demonstrate the role of PjBL in advancing creative thinking skills across different educational levels and disciplines. PjBL, which involves extended projects with real-world applications, consistently outperformed or matched problem-based learning (PBL), which focuses on structured problem-solving, in fostering creative skills [36]. Variations of PjBL, such as the scientific reasoning-based project (SRBP) model, were effective in improving creative thinking components like flexibility, elaboration, fluency, and originality [37]. Similarly, the integration of STEAM into PjBL significantly enhanced creativity by promoting interdisciplinary learning at the primary school level [38], [39]. Another variant, problem-oriented project-based learning (POPBL), proved effective in encouraging critical and creative thinking through active teacher-student interactions [40]. During the COVID-19 pandemic, online adaptations like the project collaborative model assisted by Google Classroom (PjCM-GC) maintained or even enhanced creative thinking skills, highlighting its viability as an alternative instructional approach [41]. Collectively, these findings underline PjBL's adaptability and potential to foster creativity through real-life challenges, hybrid strategies, and digital tools across diverse educational contexts.

Forest plots are widely used in meta-analyses to visually summarize and compare the results of multiple studies. In these plots, each study is represented by a horizontal line that shows its CI, with a dot or box in the center indicating the estimated ES. The width of the horizontal line reflects the uncertainty of the estimate, while the pooled ES is displayed at the bottom of the plot as a diamond or other shape, with its width representing the CI of the combined estimate [42].

The forest plot for this analysis, as shown in Figure 2, illustrates the ES of individual studies and evaluates the overall impact of the PjBL model on enhancing students' creative thinking skills. The analysis used a random effects model to account for heterogeneity across studies. Based on Figure 2, the I^2 heterogeneity value of 92% indicates that most of the variability between studies is due to real differences between studies, rather than random error. The τ^2 value of 1.1409 indicates that there is substantial variation among the studies analyzed. A p-value of less than 0.01 indicates that this heterogeneity is statistically significant. This significant heterogeneity indicates that the results of the twelve studies differ significantly. These variations may stem from differences in study designs, population characteristics, measurement techniques, or other influencing factors. Although the overall results of the intervention were favorable, the high variance suggests that the effectiveness of the PjBL model may differ significantly depending on the context and application [31], [42].

The pooled ES was 1.18, with a 95% CI of 0.68 to 1.68, showing a significant positive impact of the PjBL model on students' creative thinking skills [43]. However, the analysis of individual studies reveals considerable variability in outcomes. For instance, study R8a had an SMD of -0.16 (95% CI [-0.71; 0.40]) and study R11a had an SMD of 0.03 (95% CI [-0.61; 0.67]), both of which indicate no significant effect. Similarly, study R1a, with an SMD of 0.35 (95% CI [-0.16; 0.86]), also showed no significant effect. Conversely, studies R10 and R2 demonstrated significant positive effects, with SMDs of 0.51 (95% CI [0.04; 0.99]) and 0.58 (95% CI [0.30; 0.86]), respectively. Notably, study R12b reported the highest SMD at 4.74 (95% CI [4.03; 5.44]), indicating a very large and significant effect.

Table 2. Recapitulation of scientific articles reviewed

Code	Ref.	Location	Aim of study	Method	Level of education/ discipline	Results
R1a-b	[36]	Indonesia	Evaluate PBL and PjBL-based chemistry lessons with the aim of comparing the results for students who were trained to think critically and creatively.	Quantitative	Senior high school/chemistry	No significant difference in outcomes between PBL and PjBL. Both models foster critical and creative skills at similar stages, such as project design.
R2	[44]	Spain	Explore transversal skills training through hybrid activities combining PjBL and jigsaw techniques.	Mix method	College/biology	Hybrid activities improve creativity, teamwork, and oral communication, which are often absent in traditional teaching methods.
R3a-b	[37]	(a) Indonesia; (b) Jordan	Enhance creative thinking skills using the SRBP model in the context of elementary school teacher education.	Mixed method	College/science	Significant improvement in creative thinking (flexibility, elaboration, fluency, originality) using the SRBP model.
R4	[45]	Philippines	Investigate PjBL's impact on critical thinking among primary students.	Quantitative	Primary school/science	PjBL significantly improves critical thinking and highlights the need for integrating project-based strategies into textbook content.
R5	[38]	China	Examine PjBL-based STEAM's effectiveness on creativity development in primary school students.	Quantitative	Primary school/science	STEAM-PjBL increases creativity significantly over six weeks while maintaining comparable science knowledge.
R6	[39]	China	Explore how PjBL-STEAM impacts elementary students' creativity.	Quantitative	Primary school/science	PjBL-STEAM positively influences students' creativity, demonstrating the value of integrated project-based models.
R7a-b	[46]	Indonesia	Investigate blended PjBL on drawing learning outcomes and creative thinking skills.	Quantitative	College/physics	Interaction exists between PjBL and creative thinking ability, yielding higher outcomes for students with greater creativity.
R8a-b	[47]	Indonesia	Assess PjBL's impact versus direct instruction on middle school students' creative thinking.	Quantitative	Junior high school/science	PjBL significantly enhances creative thinking in areas like temperature and expansion compared to direct instruction.
R9	[48]	Indonesia	Test a local culture-based creative physics problem-solving model.	Quantitative	Senior high school/physics	Effectively enhancing innovative thinking and ability to solve issues in physics is the Cripics-Qu model.
R10	[40]	Indonesia	Assess the influence of the POPBL model on the development of innovative and analytical abilities.	Quantitative	Senior high school/biology	POPBL is effective for fostering critical and creative thinking through active teacher-student interaction.
R11a-b	[49]	Indonesia	Evaluate e-learning-based PjBL's impact during COVID-19 on creative thinking.	Quantitative	Senior high school/biology	E-learning PjBL improves post-test creative thinking, especially originality and elaboration, compared to non-PjBL approaches.
R12a-c	[41]	Indonesia	Assess the effectiveness of PjBL using Google Classroom (PjCM-GC).	Quantitative	Senior high school/physics	PjCM-GC significantly improves creative thinking skills and offers a viable alternative for addressing creative thinking issues.

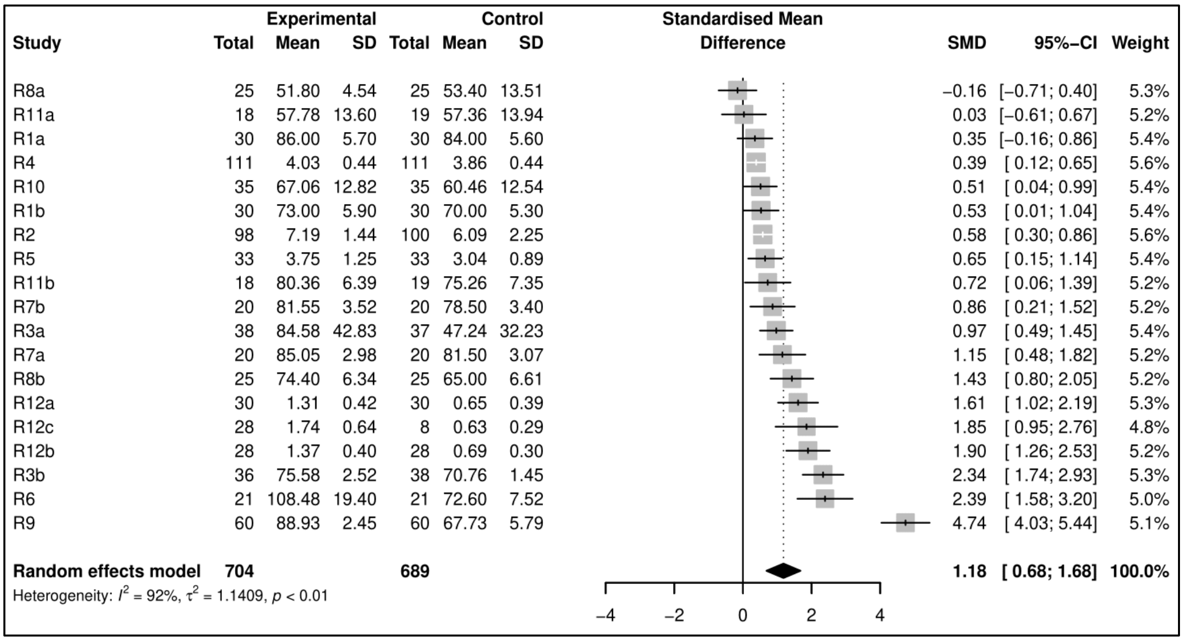

Figure 2. Forest plot of the effect of PjBL on students' creative thinking skills

The relative contribution of each study to the pooled ES was weighted based on sample size and result variability. Studies such as R10, R1b, and R2 had the largest weights (5.4% to 5.6%), while studies R12c, R7b, and R9 contributed less, with weights ranging from 4.8% to 5.2%. These weights influence the overall estimate, ensuring that larger and more reliable studies have a greater impact on the final pooled result.

Overall, the forest plot confirms that the PjBL model is generally effective in improving creative thinking skills across diverse contexts. However, there were significant variations among the study results, reflecting differences in the contexts, methods, and populations analyzed. By using the forest plot, researchers can gain a comprehensive picture of the effectiveness of the PjBL model in various contexts and populations, as well as identify areas where research results may be more or less consistent [43].

3.2. Moderator analysis

The analysis demonstrated in Figure 3 used a random effects model and revealed moderately high heterogeneity (I^2=86%, τ^2=0.6379, p<0.01), suggesting that the observed differences across studies were influenced by significant moderator variables rather than random variation alone. Moderator analysis examines variables that impact the relationship between independent and dependent variables in a meta-analysis. Moderators influence the direction or strength of this relationship, providing insights into the heterogeneity observed in study outcomes [43]. In this research, moderator analysis was utilized to investigate factors affecting the effectiveness of PjBL models in improving creative thinking skills [50].

The analysis revealed that the research method significantly impacted outcomes. Quantitative methods yielded an SMD of 1.17 (95% CI [0.59; 1.74]), while mixed methods produced an SMD of 1.27 (95% CI [0.24; 2.30]). Both methods demonstrated a significant positive effect of PjBL on creative thinking skills, highlighting the robustness of this instructional model across methodological approaches.

The effectiveness of PjBL varied across academic levels. High school students experienced the greatest benefit, with an SMD of 1.35 (95% CI [0.41; 2.28]). College-level studies followed with an SMD of 1.02 (95% CI [0.47; 1.56]). Results for primary and junior high school students were more variable, with SMDs of 1.49 (95% CI [-0.22; 3.20]) and 0.63 (95% CI [-0.92; 2.18]), respectively. These findings suggest that PjBL is particularly impactful at higher academic levels, though its effectiveness may depend on contextual factors at lower levels.

The subject matter also influenced outcomes, with physics showing the most significant effect (SMD=2.02, 95% CI [0.90; 3.13]). This was followed by science (SMD=1.11, 95% CI [0.41; 1.82]), biology (SMD=0.52, 95% CI [0.30; 0.74]), and chemistry (SMD=0.44, 95% CI [0.08; 0.80]). These differences highlight the importance of tailoring PjBL approaches to specific disciplines to maximize their impact on creative thinking skills. Sample size also affected the results, with smaller studies yielding an SMD of 1.20

(95% CI [0.75; 1.66]) and larger studies producing an SMD of 1.16 (95% CI [0.20; 2.11]). Both categories demonstrated significant effects, though smaller samples exhibited slightly higher variability in outcomes.

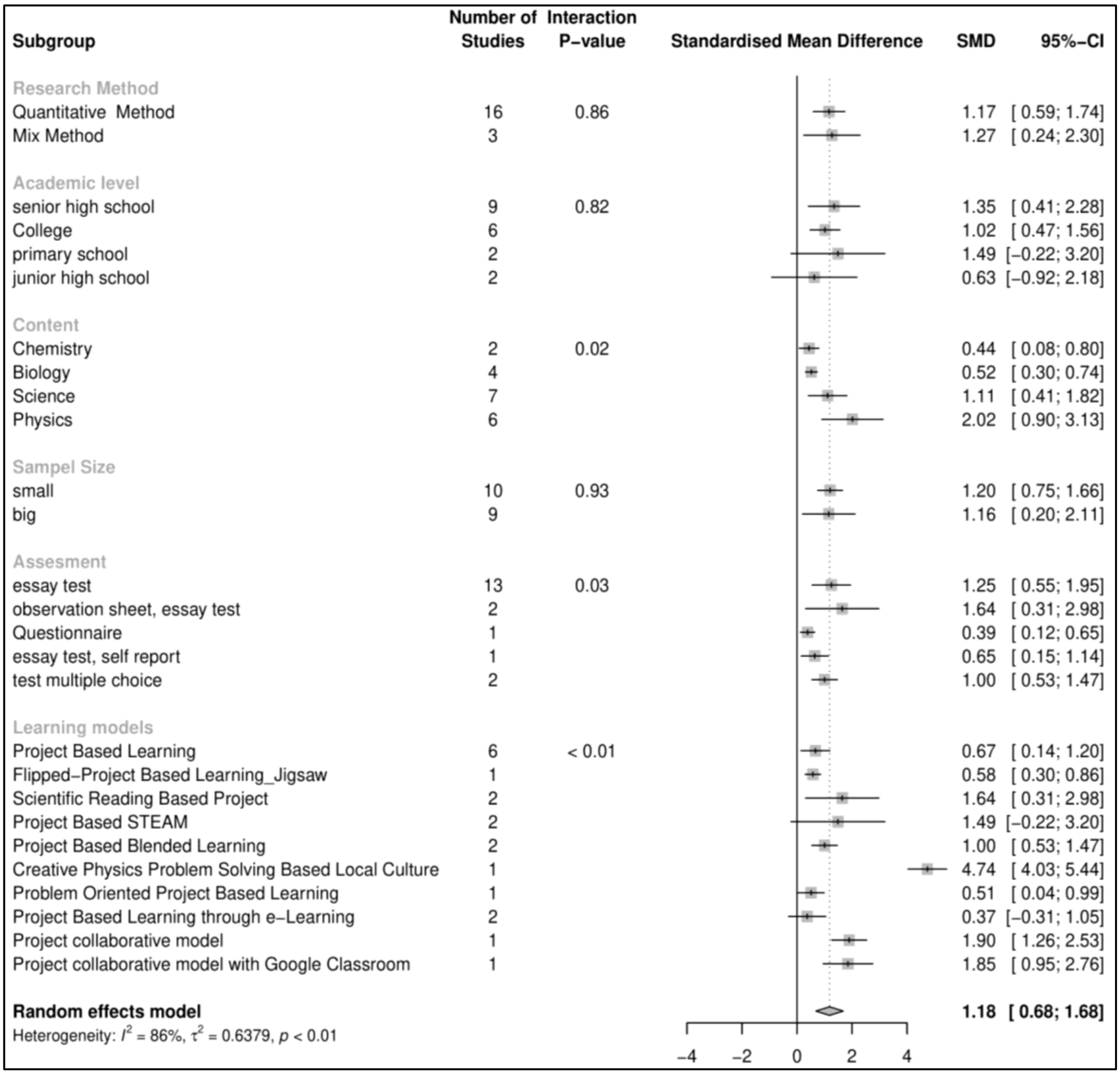

Figure 3. Moderator analysis of PjBL

Assessment types contributed to variations in outcomes. Essay-based assessments yielded an SMD of 1.25 (95% CI [0.55; 1.95]). When combined with observation sheets, the effect was greater (SMD=1.64, 95% CI [0.31; 2.98]). Conversely, studies using questionnaires reported a smaller effect (SMD=0.39, 95% CI [0.12; 0.65]). These findings suggest that assessment formats emphasizing qualitative and observational elements may better capture the impact of PjBL on creative thinking skills.

Variations in PjBL implementation revealed notable differences. The project-based blended learning model showed the most significant effect (SMD=4.74, 95% CI [4.03; 5.44]), followed by PjBL integrated with e-learning (SMD=1.90, 95% CI [1.26; 2.53]). The general PjBL model showed a smaller but still positive effect (SMD=0.67, 95% CI [0.14; 1.20]). These results highlight the potential for hybrid and technology-enhanced adaptations of PjBL to further enhance its impact. This moderator analysis suggests that the effectiveness of PjBL models in improving creative thinking skills is strongly influenced by various factors such as research method, academic level, learning content, sample size, type of assessment, and learning model used. These mixed results emphasize the importance of considering context and specific variables in the application and research of PjBL models.

3.3. Publication bias

The funnel plot in Figure 4 represents the outcomes of individual studies included in the meta-analysis. Each dot corresponds to a study, with the horizontal axis showing the ES (e.g., SMD) and the vertical axis representing the standard error. Ideally, in the absence of publication bias, the data points would be symmetrically distributed around the center line, which represents the pooled effect estimate. However, the plot shows asymmetry, with a noticeable clustering of points on one side, suggesting potential publication bias.

Studies with smaller standard errors (indicating larger sample sizes) tend to cluster near the pooled effect estimate at the lower part of the funnel plot, whereas those with larger standard errors (indicating smaller sample sizes) are more widely scattered toward the top of the plot [35]. The asymmetry observed indicates a higher likelihood of publication for studies with significant or favorable results, while those with non-significant or negative outcomes may be underrepresented. This pattern highlights the possibility of selective reporting, which could lead to an overestimation of the pooled ES in the meta-analysis.

To address this issue, statistical methods such as trim and fill can be applied. These methods estimate the number of potentially missing studies and incorporate them into the analysis to balance the distribution. Correcting for publication bias ensures a more accurate and credible representation of the true ES. Funnel plots, combined with statistical corrections, play a critical role in identifying and mitigating biases, thereby enhancing the reliability and validity of meta-analytic results [29].

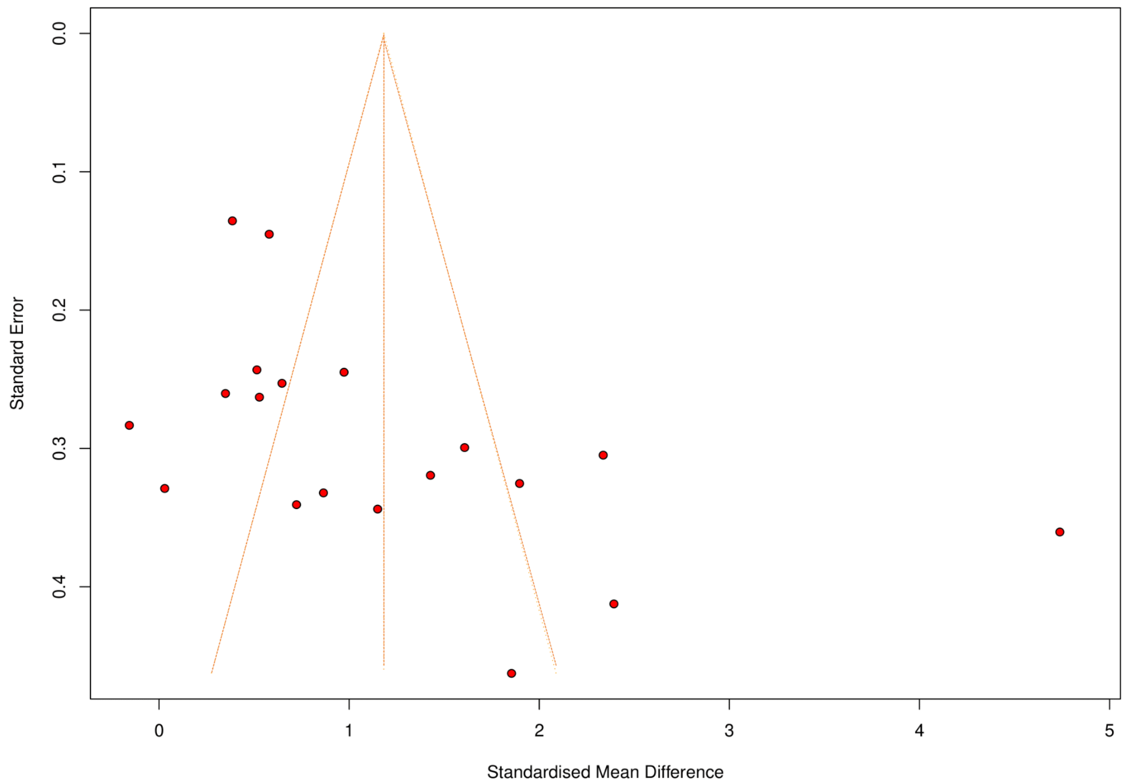

Figure 4. Funnel plot of analyzed studies of PjBL's impact on creative thinking skills

4. CONCLUSION

This study underscores the significant role of PjBL in enhancing students' creative thinking skills across diverse educational levels and disciplines. PjBL has been shown to foster creative thinking dimensions such as flexibility, fluency, elaboration, and originality, often outperforming or equaling other instructional approaches like PBL. Variants of PjBL, including the SRBP model and STEAM-integrated approaches, have demonstrated effectiveness in both higher education and primary school contexts, while digital adaptations such as PjCM-GC proved highly effective in virtual learning environments during the COVID-19 pandemic. These results highlight the versatility and adaptability of PjBL in addressing real-world challenges and integrating modern pedagogical strategies.

Furthermore, the study reveals that the effectiveness of PjBL is influenced by contextual and methodological factors such as education level, subject matter, assessment types, and learning models. The strongest impacts were observed in high school and college settings, particularly in practical, inquiry-driven subjects like physics and science. Moderator analysis also emphasizes the importance of tailored implementations to maximize the potential of PjBL. Despite some observed heterogeneity, the overall positive outcomes affirm PjBL as a reliable and adaptable instructional approach for fostering creative thinking skills in students. These findings confirming the correlation between PjBL and creative thinking skill development and demonstrating how its effects vary based on educational and contextual factors.

The implications of these findings are twofold. First, educators should consider adopting PjBL as a core instructional strategy to enhance creative thinking skills, leveraging its adaptability for both in-person and virtual learning environments. Tailored implementations, including interdisciplinary and technology-enhanced approaches, are recommended to align PjBL with the specific needs of students and subject areas. Second, researchers are encouraged to explore the interplay between contextual factors and PjBL effectiveness further. Future studies should focus on refining PjBL models to address the observed variability and ensure optimal outcomes across diverse educational settings. By doing so, PjBL can continue to serve as a transformative approach for preparing students to meet the demands of a rapidly evolving world.

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C : **C**onceptualization
M : **M**ethodology
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I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Authors state no conflict of interest.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article.

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