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INNOVATING PROBLEM-SOLVING APPROACHES WITH PROBLEM-BASED LEARNING: A META-ANALYSIS STUDY

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Abstract

Education in the 21st century has undergone substantial transformations, marked by a shift from teacher-centered learning approaches to a student-focused paradigm. This evolution necessitates a transformation in learning dynamics that emphasizes active engagement and student participation. One innovative pedagogical approach that has garnered significant attention for its potential to enhance problem-solving skills is Problem-Based Learning (PBL). This meta-analysis provides insights into the effectiveness of PBL implementation on students' problem-solving abilities. The combined results from effect size measurements using a random effects model indicate that the application of the PBL model yields an effect size of 0.649 from 14 analyzed articles, categorizing its impact as moderate. Thus, the implementation of the PBL model can significantly contribute to the enhancement of students' problem-solving skills.

Keywords: Innovating, Meta-Analysis, Problem-Based Learning, Problem-Solving.

INTRODUCTION

The 21st century has witnessed substantial transformations in the field of education. This evolution encompasses a shift from teacher-centered learning approaches to student-focused methodologies, transitioning from one-way instructional models to interactive engagements, moving from isolated learning to interconnected environments, evolving from transitional to active interaction approaches, shifting from abstract methods to dialogic processes, from individual learning to teamwork, from factual thinking to critical analysis, and from mere information delivery to a process of knowledge transformation [1]. These changes necessitate a transformation in learning dynamics, emphasizing active student engagement and participation.

Student progress is highly dependent on mastering 21st-century skills, including critical thinking, problem-solving, communication, and collaboration [2]. Problem-solving is a fundamental skill necessary for achieving success in various aspects of life, including academics, the workplace, and everyday challenges. In today's rapidly evolving world, where complexity abounds and new problems continually arise, the ability to effectively address and resolve issues is more crucial than ever. However, traditional educational approaches often struggle to equip learners with the problem-solving skills demanded by modern society [3] [4].

One innovative pedagogical approach that has garnered significant attention for its potential to enhance problem-solving abilities is Problem-Based Learning (PBL). Research studies have consistently demonstrated the positive impact of PBL on students' problem-solving skills across various disciplines, including science, mathematics, and physics [5] [6] [7].

By integrating aspects of science, technology, engineering, and mathematics (STEM), PBL encourages students to engage in real-world problem-solving scenarios, leading to improved critical thinking and analytical skills. Studies have shown that implementing the PBL model in educational settings can significantly enhance students' problem-solving proficiency [8].

Although numerous studies have explored the effectiveness of PBL in various educational contexts, a comprehensive synthesis of existing research is needed to provide a clearer understanding of its impact on problem-solving skills. One research method that can synthesize diverse research findings on a relevant theme through a quantitative approach is meta-analysis.

Meta-analysis is a research method that comprehensively synthesizes various primary studies using a quantitative approach to summarize, estimate, and evaluate information on a unified basis regarding the strength of mean effects, correlations, and associations between variables, utilizing effect size as its measurement unit [9] [10] [11]. Meta-analysis offers several advantages, such as increased transparency, detection and reduction of bias, improved estimation of population parameters, the ability to assess outcomes across various domains, providing strong evidence for significant rejections, and offering a rigorous methodology in the synthesis process. These advantages contribute to the higher quality of meta-analysis research.

The main objective of this meta-analysis is to assess the overall effectiveness of PBL in innovating problem-solving approaches across various educational environments and disciplines. By synthesizing findings from numerous studies, we aim to elucidate the extent to which PBL facilitates the development and enhancement of problem-solving skills among learners.

Through this meta-analytic study, the authors provide valuable insights to educators, policymakers, and stakeholders regarding the potential of PBL as a transformative approach to problem-solving education. By delineating the strengths, limitations, and best practices associated with PBL implementation and facilitating progress in pedagogical strategies that empower learners to become proficient problem solvers in a rapidly changing world.

METHODOLOGY

The methodology employed in this research is meta-analysis, which constitutes a quantitative analysis utilizing information from multiple prior studies to deduce findings in a holistic manner. Meta-analysis amalgamates the outcomes of individual research endeavors to achieve statistically robust conclusions. It represents a statistical scrutiny of a series of individual analyses grounded on research to consolidate findings [12]. In the context of this study, meta-analysis utilizes secondary data derived from post-test scores for experimental and control groups from a study on Problem-Based Learning.

The aim of meta-analysis in this research is to assess various levels of understanding of publication outcomes. Furthermore, meta-analysis also serves as a process of categorizing subjects, themes, or research fields based on specific criteria and evaluating their outcomes quantitatively.

Meta-analysis involves a series of steps, commencing with delineating the subject, designing the overall study, identifying research samples, collecting data, and analyzing data [13].

This meta-analytical process unfolds as follows: Firstly, the problem under investigation is explicated and defined, with a focus on implementing the Problem-Based Learning model specifically to enhance problem-solving abilities.

Secondly, data are sought based on the research topic, i.e., articles published in online journals via Google Scholar, Scopus, and the Publish or Perish application. Thirdly, the gathered articles are analyzed to ascertain their relevance to the research questions.

The subsequent step entails evaluating the Cohen's Effect Size values of the compiled articles. This computation aims to categorize the values according to the predefined classification table. This classification is utilized to assess the effectiveness of implementing the blended learning model on learning achievement improvement. Below is the table illustrating the classification of Cohen's Effect Size based on Rosenthal & Rubin. [14].

Table 1: Cohen's Effect Size Classification

Effect Size	Category
0 ≤ES≤ 0,2	Low Effect
0,2 ≤ ES≤ 0,8	Medium Effect
ES ≥ 0,8	High Effect

An additional crucial analysis in meta-analytical research is publication bias testing. This examination is imperative to mitigate the inclination towards studies published by journals with significant results, which could lead to effect sizes larger than actual. [15]. Publication bias testing is performed by examining the funnel plot; if the combined effect size is symmetrically distributed, then there is no bias in the analyzed articles.

Based on the FSN value obtained from the formula N/(5k-10) > 1 (where k is the number of studies involved), it can be inferred that the analyzed studies are not susceptible to publication bias, thus ensuring the reliability of their interpretations.

Moreover, the correlation trim and fill test with the funnel plot are employed to identify the number of studies inducing publication bias and to assess interpretations of exaggerated effect sizes. Each meta-analytical study entails effect size analysis, determination of combined effect size, effect size assessment for each moderator variable, and publication bias testing using the OpenMee Software.

RESULTS

Results of Literature Review

From various databases such as Google Scholar, Semantic Scholar, ERIC, Science Direct, IOP Science, and Atlantis Press, we identified 210 primary studies. However, there were 90 primary studies with similar titles, hence we excluded them from the screening process. Through abstract screening, we identified 20 primary studies as irrelevant, leaving only 110 primary studies eligible for the feasibility stage.

Considering the inclusion criteria, we found that 50 primary studies did not fully report statistical data, while 36 primary studies did not involve conventional learning/class control as the comparison group. Therefore, only 14 main studies met the inclusion criteria and successfully passed the research selection stage to be involved in this study process. The effect size of each article is presented in the following table:

Table 2: Results of Data Selection

Article code	Eksperimen			Control			National
	N	Mean	standard deviation	N	Mean	standard deviation	
article 1 [16]	26	8,962	1,886	26	7,846	2,327	Indonesia
article 2 [17]	30	33,3	390,8	30	49,6	179,5	Indonesia
article 3 [18]	37	88,22	3,645	37	76,38	7,147	Indonesia
article 4 [19]	39	57,64	10,34	39	54,36	9,76	Indonesia
article 5 [20]	94	10,93	1,95	94	7,4	2,31	Malaysia
article 6 [21]	30	84.17	9.921	30	74.00	10.780	Indonesia
article 7 [22]	183	2.69	23	183	2.66	28	south korea
article 8 [23]	28	82.56	7.890	27	73.28	7.755	Indonesia
article 9 [24]	60	7.14	2.065	60	6.19	1.786	Indonesia
article 10 [24]	60	5.84	1.881	60	4.46	2.219	Indonesia
article 11 [25]	34	78.35	11.96	34	58.76	11.84	Indonesia
article 12 [26]	26	74.96	5.103	25	79.36	6.304	Indonesia
article 13 [27]	34	3.38	0.49	34	2.78	0.64	south korea
article 14 [28]	30	28.4	4.11	30	25.03	1.99	Saudi Arabia

Publication Bias Analysis

The funnel plot displays the distribution of effect sizes from 14 primary studies included in this meta-analysis. The distribution of these effect sizes is illustrated in Figure 1

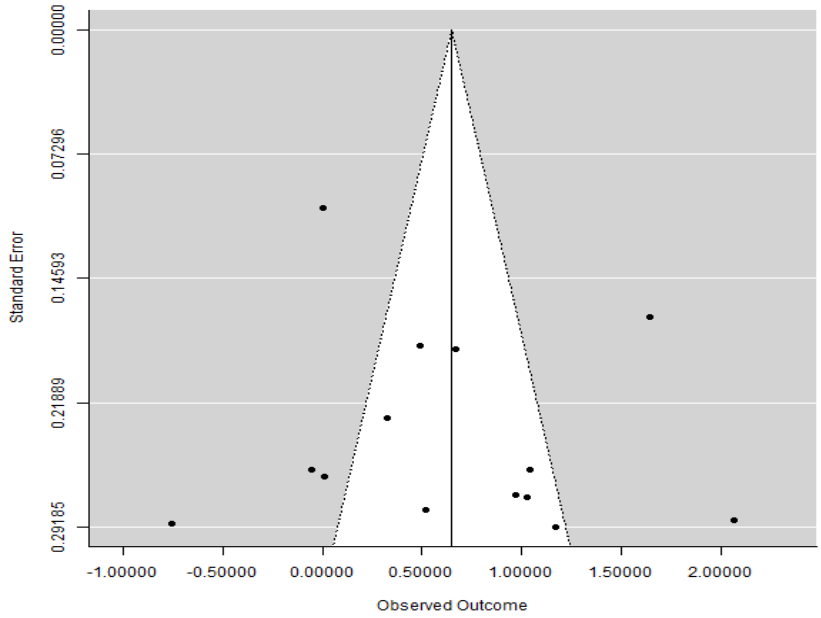

Figure 1: Diagram Funnel Plot

The results of the analysis, as depicted in Figure 1, indicate that the distribution of effect size data from the 14 primary studies analyzed in this meta-analysis exhibits a symmetrical nature. This symmetrical phenomenon strongly suggests a minimal risk of publication bias within the observed effect size data. In other words, the presence of symmetry in the data distribution indicates that studies with both large and small effect sizes have an equal chance of being published, without a tendency to select or publish only statistically significant results. This lends additional confidence to the integrity of the data utilized in this meta-analysis, thereby enhancing the validity of the findings obtained.

Total Effect Size from Each Primary Study

Table 3: Overall Effect Size

No	Article code	Hedge's	*Effect Size Category*
1	article 1	0.519	Medium Effect
2	article 2	-0.053	Which can be ignored
3	article 3	2.065	High Effect
4	article 4	0.323	Medium Effect
5	article 5	1.645	High Effect
6	article 6	0.969	High Effect
7	article 7	0.001	Low Effect
8	article 8	1.169	High Effect
9	article 9	0.489	Medium Effect
10	article 10	0.667	Medium Effect
11	article 11	0.010	Low Effect
12	article 12	-0.757	Which can be ignored
13	article 13	1.041	High Effect
14	article 14	1.030	High Effect
Average effect size		**0,649**	**Medium Effect**

Based on the available data, there is variation in the categories of effects generated by the analyzed articles. Specifically, two articles were categorized as having negligible effects, two articles with low effects, six articles with moderate effects, and four articles with very high effects. Analysis using the fixed effects model indicates that the implementation of Problem-Based Learning (PBL) model influences the improvement of problem-solving skills with an effect size value of 0.649, falling into the moderate effect category. This finding provides empirical evidence that the PBL model has a significant positive impact on problem-solving abilities, although the strength of the effect varies among the analyzed studies. Further analysis may be necessary to understand the factors influencing the variability in the observed effects.

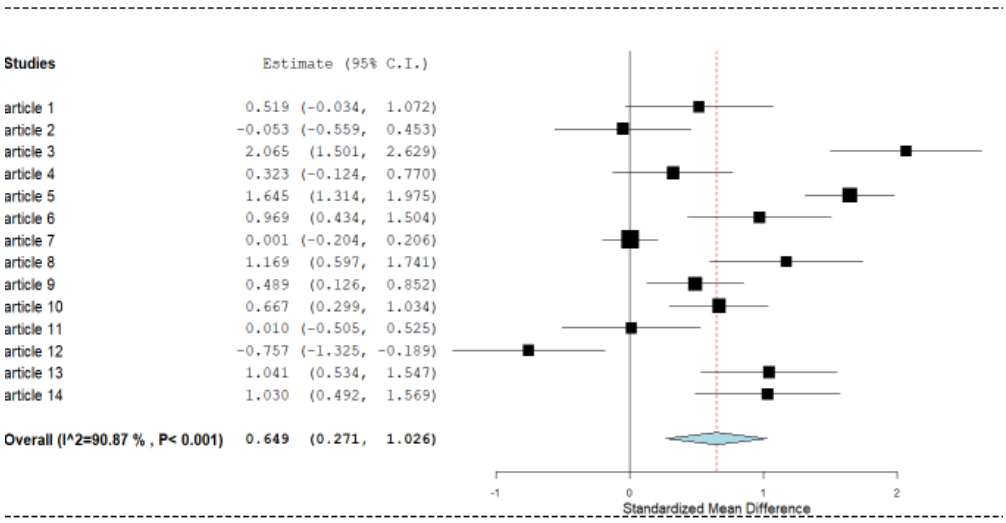

Figure 2: Cumulativ Forest Plot

The primary analysis indicates significant results regarding the impact of using PBL on students' problem-solving abilities (gRE = 0.649; 95% CI [1.026]; p < 0.001). The summary effect size value is 0.649; according to Cohen's classification, this value falls into the category of Moderate Effect. Thus, it can be concluded that the implementation of PBL has a sufficiently significant impact on students' problem-solving abilities.

PBL (Problem-Based Learning) has been proven effective in stimulating students' problem-solving abilities. This finding underscores the importance of problem-based learning approaches in enhancing students' problem-solving skills, which are crucial skills for solving everyday life problems and future careers.

The heterogeneity analysis in Table 4 reveals that the p-value of the Cochran's Q statistic is less than 0.05. This finding indicates that the effect size data significantly differ from one another. Additionally, the analysis suggests that the random-effects model is significantly superior to the fixed-effects model. Consequently, the meta-analysis process in this study employs the random-effects model.

Table 4: The Result of Heterogeneity

Model	Estimate	Lower bound	Upper bound	Std. error	p-Value
Random-Effects Model	0.649	0.271	1.026	0.649	< 0.001
Heterogeneity		tau^2	Q(df=13)	Het. p-Value	I^2
		0.459	142.352	< 0.001	90.868

The hypothesis analysis confirms that the implementation of Problem-Based Learning (PBL) has a significant impact on students' problem-solving abilities [29]. A meta-analysis study conducted by Musna et al. [30], which synthesized data from 13 primary studies, along with consistent findings from other research, demonstrates a significant improvement in problem-solving abilities through PBL compared to conventional or control learning [27] [31]. This reinforces that PBL consistently yields a significant positive impact on students' problem-solving abilities. The adoption of PBL as a learning approach offers several advantages in developing and enhancing students' competencies in learning. With an emphasis on real-world problem-solving, PBL encourages students to actively engage in identifying and solving problems, as well as collaborating with their peers. Furthermore, by providing direct experience in dealing with complex problems, PBL assists students in acquiring critical, analytical, and problem-solving skills crucial for success in the real world.

These findings provide a strong basis for educational policies to consider PBL as one of the effective learning options in enhancing students' problem-solving abilities. In efforts to improve the quality of education, problem-based learning approaches such as PBL can serve as valuable tools in preparing students to tackle future challenges.

DISCUSSION

This study aims to evaluate the impact of PBL on students' problem-solving abilities. The analysis results indicate that PBL has a significant influence in enhancing problem-solving abilities. Estimation methods were selected based on heterogeneity tests to ensure consistency in measurement.

The results demonstrate significant differences in the effects of PBL across studies, thus the most appropriate estimation model is the random effect size. Using this model, we found that out of the 14 analyzed articles, PBL has a moderate effect with an effect size value of 0.649. This indicates that PBL consistently enhances students' problem-solving abilities.

Another analysis found significant results regarding the influence of Problem-Based Learning (PBL) on students' problem-solving abilities (gRE = 0.649; 95% CI [1.026]; p

< 0.001). This summary effect value of 0.649 indicates that the use of PBL has a meaningful impact on enhancing students' problem-solving abilities.

According to Cohen's classification, this effect size value falls into the category of Moderate Effect, indicating that PBL can make a significant contribution to improving students' abilities in dealing with problems.

The heterogeneity analysis indicates that the p-value of Cochran's Q statistic is less than 0.05, indicating a significant difference between the effect size data. This finding suggests significant variation in the results of studies included in this meta-analysis. Furthermore, the findings also demonstrate that the random-effects model significantly outperforms the fixed-effects model in explaining the variation among studies. Therefore, in this meta-analysis process, the random-effects model is used to account for the variation among the studies included in the analysis. By employing the random-effects model, we can accommodate significant variation among studies that may be caused by unknown or unmeasured factors.

The overall moderator analysis results indicate that the implementation of problem-based learning models in several countries can enhance problem-solving abilities. This finding provides strong empirical evidence that the Problem-Based Learning (PBL) model has a significant positive impact on problem-solving abilities. However, it is important to note that the strength of the effect may vary among the analyzed studies, as indicated by the previous heterogeneity analysis. Therefore, further analysis steps may be necessary to understand the factors influencing the variability in the observed effects.

Further analysis could include investigating contextual factors such as the implementation methods of PBL, characteristics of students and teachers, learning environment, and other factors that may affect the effectiveness of PBL in improving students' problem-solving abilities. Through a deeper understanding of these factors, we can identify more effective strategies in implementing the PBL model to achieve optimal outcomes in problem-solving learning.

CONCLUSION

Based on the results the meta-analysis conducted reveals that Problem-Based Learning (PBL) models significantly enhance students' problem-solving abilities. The combined effect size, utilizing a random effects model, indicates an effect size of 0.649, categorizing the impact as moderate. This finding underscores the significant contribution of PBL in improving students' problem-solving skills. The meta-analysis supports the implementation of PBL as an effective pedagogical approach, contributing substantially to the development of essential skills among students.

Future research should continue to explore the nuances of PBL implementation across various educational settings and its long-term effects on student learning outcomes. Consequently, further studies are encouraged to conduct more in-depth analyses of these factors to gain a comprehensive understanding of the effectiveness of PBL in diverse educational contexts. Such future research is anticipated to provide a more detailed and profound contribution to our understanding of the application of PBL in enhancing students' problem-solving abilities.

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