

Integrating Problem-Based Learning and Flipped Classroom Models: Evaluating Their Impact on Mathematical Problem-Solving Skills

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ABSTRACT

Integrating Problem-Based Learning (PBL) with the Flipped Classroom (FC) model has gained attention as a strategy to enhance students' mathematical problem-solving skills (MPSS). While multiple studies have examined this approach, their findings show considerable variation. A meta-analysis was conducted using Comprehensive Meta-Analysis (CMA) software to synthesize findings from previous studies. A random-effects model was applied to account for variability among studies. The pooled effect size was $g = 1.06$ with a p -value < 0.01 , indicating a strong and statistically significant positive impact of the PBL-FC model on MPSS. Moderator analysis showed that the effectiveness varied significantly by media platform used ($Q_b = 21.98, p = 0.01$) and type of publication ($Q_b = 7.94, p = 0.01$). However, no significant differences were found regarding educational level ($Q_b = 7.45, p = 0.06$), experimental group size ($Q_b = 0.29, p = 0.62$), or publication year ($Q_b = 0.21, p = 0.64$). The forest plot indicated consistent positive effects across most studies, although variations in effect sizes suggest heterogeneity due to differences in methodology, populations, or contexts. This meta-analysis confirms that the PBL-FC model significantly improves students' MPSS. Differences in media platform and publication type should be considered in future implementations. These findings provide a foundation for best practices and further research into enhancing critical thinking through PBL-FC integration.

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1. INTRODUCTION

Up to the present, the development of students' mathematical problem-solving skills (MPSS) has frequently been supported by the integration of Problem-Based Learning with the Flipped Classroom approach, commonly referred to as the PBL-FC. This instructional strategy has attracted substantial attention from researchers around the world due to its potential to enhance active learning and critical thinking in mathematics education. A growing body of empirical evidence supports the effectiveness of this model, with numerous studies reporting that the PBL-FC approach has a significant and positive impact on students' MPSS. The combination of student-centered problem exploration and the flexibility of pre-class content delivery allows learners to engage more deeply with mathematical concepts. As a result, this model has been widely recognized as a promising method for promoting HOTS and improving academic achievements in diverse educational settings (Albalawi, 2018; Mulyanto et al., 2018; Petrillo, 2016; Zeineddine, 2018).

Although various studies have reported that the PBL-FC significantly enhances students' mathematical problem-solving skills (MPSS), other research has produced varying results, suggesting that its impact may not always be consistent across different contexts (Clark, 2015; Crawford, 2017; Jackson, 2019; Overmyer, 2015). These inconsistencies may be attributed to various factors, such as differences in instructional design, technological tools used, student demographics, or implementation fidelity. As such, while the PBL-FC is widely regarded as a beneficial approach to mathematics instruction, the variation in outcomes highlights the need for further investigation.

Understanding the conditions under which the PBL-FC is most effective can help educators refine its application and maximize its potential to improve students' problem-solving abilities. This calls for comprehensive analyses that examine not only the overall effectiveness but also the moderating variables that may influence its success in diverse educational environments. These results show various inconsistent research results. Conversely, educational policymakers, particularly mathematics educators, require reliable evidence regarding effective strategies for implementing the PBL-FC.

Variations in research findings can be caused by variations in implementation methods, learning contexts, or different student characteristics in each lesson. Davies (2000) says that an individual study is subject to specific constraints, including limitations involving time limitations, sample characteristics, and contextual conditions, which can explain differences in research results. Therefore, contradictions between research discoveries can be understood as a reflection of the diversity of conditions in the field. To address this issue, undertaking a meta-analytic study is deemed essential as an approach that can unify insights gathered from different empirical works (Borenstein et al., 2009; Hunter, J. E. & Schmidt, 2004; Lidyasari et al., 2023).

Meta-analysis refers to a statistical methodology within quantitative research that combines and analyzes data from numerous independent studies to assess the magnitude of associations among variables, employing metrics like effect size to quantify the overall impact (Borenstein et al., 2009). Through the aggregation of findings from a variety of independent studies, meta-analysis provides a thorough and reliable evaluation of how the PBL-FC affects students' mathematical problem-solving skills (MPSS). This method not only allows researchers to draw broader conclusions by increasing the statistical power of the data but also helps identify patterns and inconsistencies across different educational settings. By examining a diverse set of research outcomes, meta-analysis can provide meaningful perspectives on the overall efficacy of the PBL-FC, positioning it as a powerful resource for guiding evidence-informed instructional strategies and educational policy-making.

Several prior meta-analytic investigations examining the impact of the PBL-FC on students' mathematical problem-solving skills (MPSS) still exhibit certain limitations. In order to enhance the credibility and robustness of such studies, it is crucial to conduct thorough assessments of publication bias and perform sensitivity analyses. These procedures are essential for ensuring the validity and reliability of the meta-analytic findings, as they help identify potential distortions and evaluate the stability of the results across various analytical conditions (Borenstein et al., 2009). However, several existing meta-analytic studies have not yet included publication bias and sensitivity analyses, which

are essential for ensuring the reliability and validity of the findings. Without these components, the accuracy and generalizability of the conclusions may be compromised (Nurtamam et al., 2023).

Moreover, the magnitude of the overall effect is often overestimated and may not accurately represent the true impact. To better understand the variability in meta-analytic findings, examining moderator variables is essential. However, several meta-analyses investigating the influence of the PBL-FC have not explored potential moderators such as the platform used, education level, experimental group size and type, year of publication, and type of publication. These factors could contribute to the heterogeneity of effect sizes but have been overlooked. Therefore, the present study seeks to synthesize, estimate, and critically assess the overall effect of the PBL-FC on students' MPSS.

The findings of this meta-analysis are anticipated to offer more accurate and practical guidance for educational policymakers, particularly mathematics educators, in applying effective strategies for mathematics instruction. By examining moderator variables that may influence the effectiveness of the PBL-FC mathematical problem-solving skills (MPSS), this study aims to deliver a more comprehensive understanding of the key factors that should be considered when designing and implementing the PBL-FC approach to optimize student outcomes. Consequently, this research not only contributes valuable theoretical insights into the relation between the model of PBL-FC and MPSS, but also offers meaningful practical implications for educators and instructional designers.

2. METHODS

2.1 Design Research

This study used a design of meta-analysis to examine the effect model of PBL-FC on students' MPSS in mathematics learning. Meta-analysis is a research methodology that systematically integrates and synthesizes the results of several quantitative studies in a particular research subject (Paul & Barari, 2022). The aim is to ensure consistency of effect correlations across different investigations (Brüggemann & Rajguru, 2022) and comprehensive decision-making can be supported by adequate meta-analysis techniques (Jager et al., 2022).

This methodological approach was selected to consolidate the outcomes of previous studies, allowing for a more holistic and in-depth representation of the effects of the PBL-FC. By systematically combining results from a range of independent investigations, this design facilitates a broader interpretation of the model's influence across diverse educational contexts. It not only enhances the accuracy of the conclusions drawn but also provides a clearer understanding of how consistently the PBL-FC contributes to the development of students' mathematical problem-solving skills. Ultimately, this approach strengthens the empirical foundation for recommending the model's implementation in varied learning environments.

2.2 Inclusion Criteria

The selection criteria for this study were established to ensure the inclusion of relevant and methodologically sound research. Eligible studies met the following requirements: they were published between 2016 and 2023 and involved learners at different educational stages who participated in mathematics learning facilitated by the PBL-FC. Additionally, the studies had to utilize experimental, quasi-experimental, or observational research designs that included a clearly identified control group for comparison. Only studies that explicitly reported outcomes related to students' mathematical problem-solving skills (MPSS) as a result of the PBL-FC intervention were considered. To maintain consistency in interpretation and facilitate accurate analysis, only publications written in English were included. Furthermore, the studies needed to provide sufficient statistical data—such as means, standard deviations, and sample sizes—necessary for calculating effect sizes. These criteria were designed to ensure the reliability and validity of the meta-analysis findings by incorporating studies with both rigorous design and relevant outcomes.

2.3 Data Collection and Coding

Data for this study were gathered from research articles that satisfied the predefined inclusion criteria through a systematic search of academic databases and internationally recognized scholarly journals. The search strategy employed a combination of relevant keywords, such as “integration of PBL and FC” and “mathematical problem-solving skills,” to locate pertinent studies. In addition to database searches, supplementary literature exploration was conducted to identify potentially valuable sources that may not be indexed in traditional databases, thereby ensuring a more comprehensive data collection process.

From an initial set of 189 studies, a total of 31 primary studies were deemed eligible for inclusion, having met all established selection standards. The process of identifying and selecting studies was carried out in four structured stages: identification, screening, evaluation of eligibility, and final inclusion. This multi-step approach was designed to ensure the quality and relevance of the selected studies for the purposes of meta-analysis. A visual representation of the literature selection process is provided in Figure 1, offering a clear overview of how the final sample was derived.

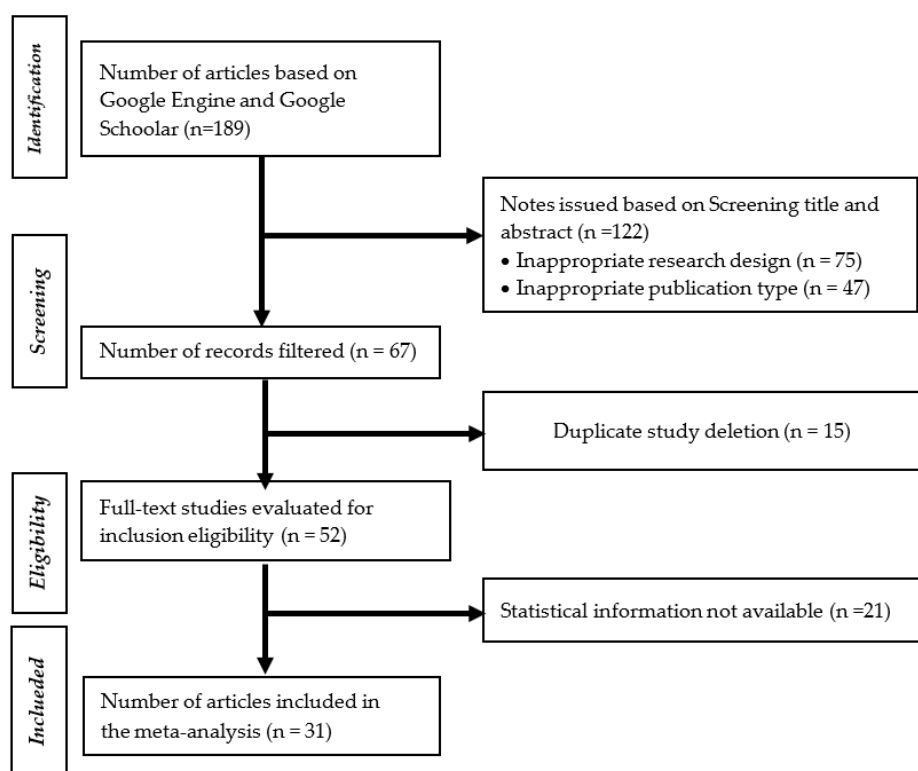


Figure 1. Screening process the literature uses PRISMA

In addition, the identification of key characteristics within the selected literature was carried out through a systematic coding procedure. To enhance reliability and minimize potential bias, the coding process was independently performed by two raters. This approach ensured a more objective interpretation of the data. The coded information encompassed several relevant variables, including the level of education targeted, the size of the experimental groups, the classification of experimental group types, and the specific digital platforms employed in implementing the PBL-FC. A comprehensive summary of the coding results is presented in Table 1, offering a clear depiction of the data used in the analysis and supporting the integrity of the meta-analytic findings.

Table 1. Coding of Studies Meeting Inclusion Criteria

Content Classification	Moderating Factor	Occurrence Rate (%)
Level of Education	Primary Education (PE)	2 (4.76%)
	Junior High School (JHS)	13 (30.95%)
	Senior High School (SHS)	19 (45.24%)
	College	8 (19.05%)
Size of the Experimental Group	≤ 30	14 (33.33%)
	> 30	28 (66.67%)
Platforms	Edmodo	1 (2.38%)
	google classroom	7 (16.67%)
	Khan Academy	4 (9.52%)
	Moodle	6 (14.29%)
	QQ Learning	1 (2.38%)
	WhatsApp	15 (35.71%)
	Information not provided	8 (19.05%)
Year of Publication	2016-2019	17 (40.48%)
	2020-2023	25 (59.52%)
Type of Publication	Journal	39 (92.86%)
	Proceedings	3 (7.14%)

2.4 Data Analysis

The data were processed and examined using the Comprehensive Meta-Analysis (CMA) software, which enabled a systematic and rigorous statistical evaluation of the selected studies. The meta-analytic procedure followed a structured series of steps to ensure accurate and meaningful synthesis of the research findings.

The initial phase of the analysis involved calculating the effect size for each individual study to determine the impact of the PBL-FC on students' mathematical problem-solving skills (MPSS). This process enabled the outcomes of various studies—each with differing methodologies, sample sizes, and assessment tools—to be standardized and compared on a common scale. Converting diverse findings into a uniform metric facilitated a more coherent synthesis of results, laying the foundation for a valid and meaningful meta-analytic interpretation.

Following this, a pooled or overall effect size was computed to evaluate the aggregate influence of the PBL-FC across all eligible studies. This was accompanied by an assessment of publication bias, which aimed to confirm the trustworthiness and generalizability of the results by determining whether unpublished or selectively reported studies might skew the findings. In the final phase, a moderator analysis was conducted to explore the role of contextual and methodological factors—such as the learning platform utilized, the structure of the experimental design, or the education level of the participants—that could potentially shape the magnitude or direction of the model's effect. Collectively, this multi-step analytical strategy offered a comprehensive and nuanced understanding of both the overall effectiveness and variability of the PBL-FC approach in improving MPSS.

The effect size interpretation process in this study refers to the classification proposed by Cohen et al. (2018). The effect size classifications used for interpretation of the results are detailed in Table 2.

Table 2. Classification of effect size (g)

Level	Interval
Ignored	$0.00 < g \leq 0.19$
Small	$0.19 < g \leq 0.49$
Medium	$0.49 < g \leq 0.79$
Large	$0.79 < g \leq 1.29$
Very Large	$g > 1.29$

3. FINDINGS AND DISCUSSION

3.1 Main Analysis

The process of computing the effect sizes for each individual study was carried out utilizing Comprehensive Meta-Analysis (CMA) software, Version 3. This specialized statistical tool facilitated accurate and consistent calculation of the effect sizes, which served as the foundation for evaluating the influence of the PBL-FC model on students' mathematical problem-solving skills. The use of CMA ensured methodological rigor and precision in quantifying the strength of the relationship across a diverse range of included studies.

To visually represent these results, Figure 1 provides a consolidated overview of the effect sizes derived from each primary study. This figure helps to illustrate the variation in outcomes and allows for a clearer understanding of the individual and collective contributions of the analyzed studies. Through this comprehensive presentation, readers can easily observe the distribution, magnitude, and direction of the effects, which is essential for interpreting the overall impact of the PBL-FC model in a meta-analytic context.

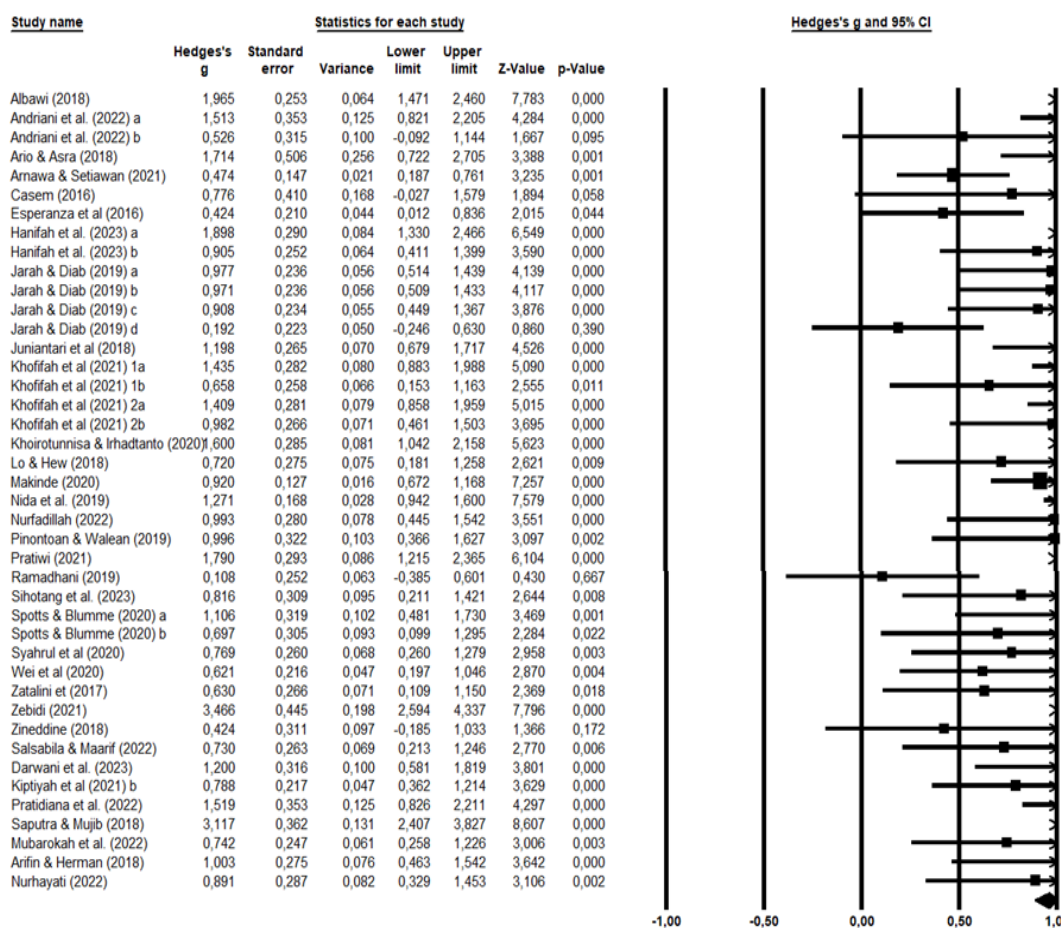


Figure 2. Forest Plot

In the forest plot, the central vertical axis serves as a visual marker for the overall or combined effect size, which is synthesized from all the individual studies included in the meta-analysis. This line reflects the average magnitude of the effect under investigation, offering a summary measure that represents the general trend across diverse research findings.

Each plotted dot on the graph corresponds to the calculated effect size of a specific study, indicating its individual contribution to the overall analysis. Extending horizontally from these dots

are lines that depict the 95% confidence intervals (CI), illustrating the range within which the true effect size is likely to fall. These intervals provide insight into the precision and reliability of each study's findings. When interpreted together, these graphical elements allow for an in-depth understanding of both the central tendency and variability present across the research body.

When the confidence interval of a study intersects the central line, it implies that the effect is not statistically significant. Conversely, if the interval doesn't cross the line, the effect is considered statistically significant. The horizontal line's length is directly related to the study's sample size, with longer lines typically signifying larger sample populations. Furthermore, the size of each dot reflects the statistical weight that the corresponding study contributes to the overall analysis—larger dots represent studies with a more substantial influence on the pooled effect size. This visualization not only communicates the distribution and reliability of individual study outcomes but also illustrates the degree of consistency and overall impact measured across the body of research.

The forest plot presented above displays the meta-analysis findings from 42 studies, with effect sizes reported using Hedges' g . Hedges's g values indicate the standardized difference between intervention and control groups, with positive values indicating a positive effect of the intervention being analyzed. Most of the Hedges's g values were on the positive side of the zero line, indicating that the majority of interventions had a favorable impact. The highest value of 1.965 was recorded in the Albawi (2018) study, indicating a very strong effect, while the lowest value of 0.174 in the Casem (2016) study indicated a minimal effect.

The accuracy of each study's estimate is measured through the 95% confidence interval (CI) visualized as a horizontal line around the Hedges's g point. Studies with CI lines that do not cross zero have statistically significant results, such as Albawi (2018) and many other studies. In contrast, some studies have CIs that cross the zero line, signaling that the effect is not significant. The variation in CI width among studies reflects the different levels of uncertainty in each study's results, with narrower CIs indicating more definitive results. The majority of studies had a p -value < 0.05 , indicating that the observed effect did not occur by chance.

Overall, this forest plot shows that the analyzed interventions had significant positive effects in most studies. However, the variation in effect sizes and significance levels between studies suggests heterogeneity, which may be due to differences in methodology, population or study conditions. This suggests the importance of additional analyses to explore the factors influencing these differences and ensure generalizability of the meta-analysis results.

If classified according to the scheme Cohen et al. (2018), the range of effect sizes observed among the included studies varied considerably: eleven demonstrated very large effects, sixteen showed large effects, ten reported moderate effects, three indicated small effects, and two revealed minimal or negligible effects. This variation underscores the inconsistency in how the PBL-FC influences students' mathematical problem-solving skills (MPSS) across different contexts and study conditions. Given this level of diversity, calculating a pooled or overall effect size becomes crucial in order to arrive at a more accurate and generalizable conclusion regarding the model's effectiveness. Table 4 presents a detailed summary of the heterogeneity analysis, alongside the estimated effect sizes derived using both random-effects and fixed-effects models. This dual-model estimation allows for a deeper understanding of the robustness and variability of the findings, enhancing the reliability of the meta-analytic interpretation.

Table 3. Overview of the Pooled Effect Size Estimations

Model	N	g	P	Df	Heterogeneity		
					Q	p	I ²
Random-Effect	42	1.06	< 0.01	41			
Fixed-Effect	42	0.97	< 0.01	41	180.210	< 0.05	78.25%

The selection of an appropriate model for estimating the overall effect size was informed by the outcomes of the heterogeneity assessment. As presented in Table 3, the statistical test yielded a p-value less than 0.05, which indicates a significant degree of variability among the included studies. This degree of heterogeneity suggests that the effect sizes differ due to factors beyond chance alone. Therefore, a random-effects model was deemed the most appropriate analytical framework, as it acknowledges and accommodates the assumption that the true effect size may not be identical across all studies. This model is particularly useful in educational research, where variations in context, population, and implementation strategies are common.

Using the random-effects model, the aggregate effect size was computed and found to be $g = 1.06$ with a statistical significance of $p < 0.01$. According to widely accepted guidelines for interpreting effect sizes, this value falls within the category of a large effect. This result highlights the substantial and statistically meaningful impact of the PBL-FC on enhancing students' mathematical problem-solving skills (MPSS). The strength of this effect across studies with differing methodologies and contexts reinforces the robustness of the PBL-FC as an instructional approach. It further underscores the potential for this model to serve as a valuable and adaptable framework for mathematics instruction in various educational environments.

Heterogeneity affects the reliability of conclusions in meta-analyses as it indicates the presence of apparent variation in effect sizes between studies, which could be due to differences in methodology, population or intervention context. In addition, in a random effects model, heterogeneity affects the weighting of studies, where studies with high variability receive less weight, which may alter the overall results. It can be concluded that implementing the PBL-FC has a beneficial impact on students' mathematical problem-solving skills (MPSS). This result aligns with previous meta-analyses, which have similarly reported that the use of the PBL-FC significantly enhances student learning outcomes (Wei et al., 2020; Yakar, 2021). The alignment of these findings reinforces the validity and reliability of recommending the PBL-FC as an effective instructional approach for enhancing students' mathematical problem-solving skills (MPSS).

PBL-FC opens the door to improve students' MPSS innovatively and effectively. By presenting learning materials outside the classroom through videos or self-paced materials, students are given more control over their learning process. Students are able to engage with and comprehend the material at their own pace, which facilitates a more thorough grasp of the concepts. This individualized learning process supports the development of HOTS, particularly in mastering content and achieving conceptual clarity (Limniou et al., 2018). Engaging in open discussions and collaborative activities during class time, which is used more effectively, can enhance students' mathematical communication and encourage the application of both cognitive and metacognitive strategies (Batubara et al., 2022; Ha et al., 2019; Izzah et al., 2024).

In addition, the PBL-FC provides sufficient time for students to explore mathematics and conduct investigations outside the classroom, so that they are better prepared when discussing in class (Jdaitawi, 2020). The integration of the Problem-Based Learning combined with Flipped Classroom (PBL-FC) model transforms students from passive recipients of information into active participants in their own learning journey. This approach positions learners at the center of the instructional process, encouraging them to engage deeply with content through exploration, inquiry, and collaborative dialogue. Rather than merely absorbing facts, students are prompted to apply their knowledge to solve problems, participate in meaningful discussions, and critically examine mathematical concepts through hands-on investigation and peer interaction.

Such a learning model not only fosters the development of students' mathematical problem-solving skills (MPSS), but also cultivates a classroom environment that is engaging, interactive, and closely aligned with real-world applications. Through this dynamic framework, students build the cognitive and metacognitive competencies necessary to navigate complex mathematical tasks. The relevance of the learning experiences to practical situations enhances student motivation and prepares

them to tackle authentic mathematical challenges beyond the classroom, making the PBL-FC a powerful tool for both academic and lifelong success.

3.2 Moderator Variable Analysis

To gain a deeper understanding of the conditions under which the PBL-FC yields the most significant benefits, a moderator variable analysis was conducted. This analysis aimed to identify specific factors that might influence the effectiveness of the model in enhancing students' mathematical problem-solving skills (MPSS). By examining variations in outcomes across different study characteristics, such as educational level, platform used, publication type, experimental group size, and other contextual variables, the analysis sought to uncover patterns that could explain the heterogeneity observed in the overall findings. Understanding these moderators is crucial for educators and policymakers, as it enables the development of more targeted instructional strategies and the adaptation of the PBL-FC approach to suit diverse learning environments. The results of this detailed moderator analysis, which highlight both significant and non-significant influencing factors, are systematically summarized in Table 5, providing valuable insights for further research and practical implementation in educational settings.

Table 4. Results of Moderator Variable Analysis

Moderator Variable	N	g	Standard Error	P	Heterogeneity			
					Q	Df	Qb	P
Level of Education								
PS	2	0.87	0.18	< 0.01	0.52			
JHS	13	1.12	0.06	< 0.01	58.14	3	7.45	0.06
SHS	19	0.82	0.07	< 0.01	51.81			
College	8	0.98	0.08	< 0.01	62.28			
Experiment Group Capacity								
≤ 30	14	0.98	0.03	< 0.01	91.06	1	0.29	0.62
> 30	28	0.88	0.63	< 0.01	88.92			
Platforms								
Khan Academy	4	0.74	0.11	< 0.01	8.48			
QQ Learning	1	0.64	0.21	< 0.01	0.00			
Google Classroom	7	0.71	0.08	< 0.01	23.73			
Edmodo	1	1.21	0.25	< 0.01	0.00	6	21.98	0.00
Moodle	6	1.06	0.10	< 0.01	17.45			
WhatsApp	15	1.12	0.05	< 0.01	30.04			
Not Report	8	1.03	0.10	< 0.01	78.52			
Year of Publication								
2016-2019	17	0.94	0.06	< 0.01	93.05	1	0.21	0.64
2020-2023	25	0.97	0.05	< 0.01	86.96			
Publication Type								
Journal	39	0.92	0.04	< 0.01	165.51	1	7.94	0.01
Proceedings	3	1.30	0.13	< 0.01	6.75			

3.3 Education Level Factor

The moderator analysis based on educational level demonstrated that the PBL-FC produced statistically significant improvements in students' mathematical problem-solving skills (MPSS) across all educational stages. Specifically, the effect sizes were $g = 0.87$ ($p = 0.00$) for elementary school, $g = 1.12$ ($p = 0.00$) for junior high, $g = 0.82$ ($p = 0.00$) for senior high school, and $g = 0.98$ ($p = 0.00$) at the university level. Despite these significant outcomes within each group, the results of the heterogeneity test $Q_b = 7.45$ ($p = 0.06$) indicated that the differences in average effect sizes among the educational levels were not statistically significant. Therefore, it can be inferred that educational level doesn't act as a significant

moderating factor in the effectiveness of the PBL-FC on enhancing students' MPSS. In other words, the effectiveness of the PBL-FC approach appears to be stable and consistent regardless of whether it is implemented in primary, secondary, or higher education settings. These findings are consistent with previous research, which also reported no significant moderating effect of educational level on the efficacy of the PBL-FC (Kar et al., 2018; Vitta & Al-Hoorie, 2023; Wei et al., 2020). An important implication of these findings is that the PBL-FC can be considered as an effective strategy to improve students' MPSS at various educational levels, including primary school, junior high school, senior high school, and university.

At the primary school level, *problem-based learning* (PBL) helps students understand mathematical concepts by exploring problems that are relevant to everyday life, so as to train critical and analytical thinking skills early on (Birgili, 2015; Wahdaniyah et al., 2023). The Flipped Classroom model, on the other hand, offers students the flexibility to study foundational concepts independently at home, utilizing digital resources such as video lectures, interactive modules, or other online learning materials. This self-paced learning outside the classroom allows students to gain a preliminary understanding of the subject matter before attending class. As a result, valuable in-class time can be repurposed for engaging in higher-order learning tasks, such as collaborative discussions, group-based problem-solving, and hands-on activities that deepen conceptual understanding.

By shifting the delivery of basic content outside the classroom and emphasizing active learning during face-to-face sessions, the Flipped Classroom approach promotes a more student-centered learning environment that supports critical thinking and meaningful interaction (Aidoo et al., 2022; Anggito et al., 2023; Kurino et al., 2024). Integrating these two instructional approaches—Problem-Based Learning and the Flipped Classroom—fosters a dynamic and engaging learning atmosphere that enhances both student participation and enjoyment. This blended model not only promotes a more interactive classroom experience but also actively supports the cultivation of essential problem-solving abilities, particularly for students at the elementary level. By allowing learners to explore fundamental concepts independently through digital media and then apply their understanding collaboratively through real-world challenges and guided inquiry during class time, this approach encourages deeper cognitive processing. Ultimately, the synergy between these methods helps nurture critical thinking, creativity, and autonomy in young learners, laying a strong foundation for lifelong learning and academic success.

Within the context of junior high school education, the use of problem-based learning (PBL) approach challenges students to solve problems that are relevant to real-life contexts (Lim, 2023; Rahman et al., 2023), so as to encourage active participation and hone critical thinking skills (Issa & Khataibeh, 2021; Nurmadiya et al., 2017). Conversely, the Flipped Classroom approach empowers students to engage with fundamental theories independently prior to class sessions by utilizing digital learning resources such as videos, e-books, or interactive content. This self-directed pre-class preparation enables students to enter the classroom with a foundational understanding of the material. Consequently, classroom time can be strategically used for collaborative discussions, clarification of complex ideas, and the practical application of concepts through problem-solving activities.

This shift in instructional focus not only enhances student engagement and active participation but also promotes higher-order thinking skills. By fostering an environment where learners are both prepared and encouraged to apply their knowledge in meaningful ways, the Flipped Classroom model contributes to a more student-centered and effective learning experience (Ali et al., 2024; Rayees, 2018). The integration of these two instructional approaches allows junior high school students to gain a deeper and more comprehensive understanding of mathematical concepts. Through this combined model, students not only grasp abstract theories more effectively but are also encouraged to apply their knowledge to real-life contexts and everyday problem-solving scenarios. This approach bridges the gap between theoretical learning and practical application, making mathematics more meaningful and relevant to students' lives. As a result, learners are more likely to develop critical thinking skills and a stronger sense of confidence in using mathematics beyond the classroom.

At the high school level, Problem-Based Learning (PBL) engages students in addressing real-world, meaningful problems, encouraging them to take an active role in their learning. This approach promotes deeper intellectual engagement by requiring learners to explore complex issues, evaluate possible solutions, and justify their reasoning. As students work through these authentic challenges, they naturally enhance their critical thinking, analytical reasoning, and creative problem-solving abilities. By confronting situations that mirror real-life scenarios, PBL not only reinforces academic content but also equips students with essential skills needed for future academic pursuits and real-world decision-making. This learner-centered method fosters independence, collaboration, and reflective thinking—key competencies for success in higher education and beyond (Birgili, 2015; Widiastuti et al., 2023; Zakaria et al., 2023).

Flipped Classroom, being a tool that utilizes digital technology, allows students to understand basic material independently before class, so that face-to-face time can be focused on discussion, strengthening concepts, and solving more complex problems (Nugraheni et al., 2022; Putro et al., 2024). The high school level is an important stage because it begins to demand various efforts to solve problems that are more complex and complicated than the previous level. The combination of these two methods provides a more in-depth learning experience and improves students' ability to overcome real-world math challenges.

3.4 Experimental Group Capacity Factor

The moderator analysis concerning experimental group size revealed that the application of the PBL-FC significantly improved students' mathematical problem-solving skills (MPSS) in both smaller classes (≤ 30 students; $g = 0.98$; $p = 0.00$) and larger classes (> 30 students; $g = 0.88$; $p = 0.00$). The heterogeneity test indicated no statistical significant difference in the average effect sizes between these two group sizes ($Q_b = 0.29$; $p = 0.62$). This suggests that class size doesn't serve as a moderating factor influencing the impact of the PBL-FC on students' MPSS. In essence, the effectiveness of the PBL-FC approach appears consistent regardless of whether it is implemented in smaller or larger classroom settings. Although a slight variation in effect sizes was observed, the statistical analysis confirmed that this difference was not meaningful.

These findings align with earlier studies which also found that class size doesn't significant influence the success of implementing a flipped classroom combined with problem-based learning in enhancing mathematics learning outcomes (Purnomo et al., 2022). The results suggest that educators are able to implement the PBL-FC successfully in classrooms of varying sizes without being concerned about major disparities in its effectiveness on students' mathematical problem-solving skills (MPSS). This indicates that class size doesn't significantly influence how well the PBL-FC approach functions, making it a reliable instructional strategy regardless of the number of students involved.

This level of adaptability offers substantial advantages for mathematics instruction, as it enables teachers to apply the model in a wide range of educational settings—from small-group environments to larger classes—without sacrificing learning quality. As a result, the PBL-FC supports instructional flexibility by allowing educators to tailor their teaching strategies to fit various classroom dynamics, including differences in student numbers, learning needs, and available technological resources. This adaptability not only enhances the effectiveness of instruction but also empowers teachers to create more engaging and personalized learning experiences. Moreover, the model encourages the broader implementation of active, student-centered learning approaches by promoting collaboration, critical thinking, and independent inquiry, making it highly suitable for fostering 21st-century skills in diverse educational settings.

This result is consistent with previous research findings suggesting that class size doesn't play a critical role in determining the instructional success of combining problem-based learning with the flipped classroom approach. These earlier studies have shown that whether implemented in smaller or larger classes, the integration of these two pedagogical models consistently supports improvements in students' mathematical performance. Furthermore, the implication of this finding is that educators can

adopt the PBL-FC across various classroom sizes without compromising its effectiveness. It highlights the model's adaptability and scalability, reinforcing its value as a flexible instructional strategy suitable for diverse educational contexts. This provides educators and institutions with greater confidence in implementing innovative teaching methods, even in classrooms with varying student capacities (Muniri & Choirudin, 2022; Sappaile et al., 2020).

The study revealed that, despite different class sizes, both large and small, the integration of *problem-based learning* in a flipped classroom approach continues to exert a beneficial influence on students' math skills. In a *flipped classroom*, students can learn independently based on problems, especially those around the environment, to deepen their understanding and problem-solving skills (Peny et al., 2022; Rachman et al., 2020). This approach allows every student, regardless of class size, to interact more personally with the material. Even in large classes, the use of technology such as GeoGebra can enrich students' learning experience without being tied to the physical size of the class as learning becomes more individualized and technology-based.

3.5 Media Platform Factor

The moderator analysis concerning the media platforms utilized in the implementation of the PBL-FC indicates that incorporating specific digital platforms significantly enhances students' mathematical problem-solving skills (MPSS). Notable effect sizes were observed with Edmodo with $g = 1.21$ ($p = 0.00$), Google Classroom with $g = 0.71$ ($p = 0.00$), Khan Academy with $g = 0.74$ ($p = 0.00$), Moodle with $g = 1.06$ ($p = 0.00$), QQ Learning with $g = 0.64$ ($p = 0.00$), and WhatsApp with $g = 1.12$ ($p = 0.00$). The heterogeneity analysis revealed a statistically significant variation in average effect sizes among these platforms ($Q_b = 21.98$; $p = 0.00$), suggesting that the choice of media platform plays a crucial role in influencing the effectiveness of the PBL-FC on students' MPSS. This conclusion is in line with prior studies, which also demonstrated that the effectiveness of PBL-FC implementation may vary depending on the technological platform used (Purnomo et al., 2022; Puspitasari et al., 2022).

Although notable differences were observed among the various media platform groups analyzed, the findings of this study consistently demonstrate that the PBL-FC produces a significant positive impact across all platforms investigated. Whether delivered through Khan Academy, Edmodo, Google Classroom, QQ Learning, Moodle, or WhatsApp, the PBL-FC remains effective in enhancing students' mathematical problem-solving skills. This consistency suggests that the instructional benefits of the model are not limited by the specific digital platform used, highlighting its adaptability and broad applicability in diverse technological environments. Consequently, educators can confidently implement the PBL-FC approach using the digital tools most accessible and appropriate for their teaching contexts, without compromising its effectiveness.

WhatsApp has a more significant impact than other platforms in teaching problem-based learning and flipped classroom (PBL-FC) models on students' mathematical problem-solving skills (MPSS), driven by various important aspects that can increase student engagement, accessibility, and collaboration. WhatsApp, as the most common instant messaging program, is evolving into the most familiar and easy-to-use communication medium for many users, especially in areas with less than optimal technical infrastructure (Mustar & Nashihuddin, 2020; Yudianto & Murtiyasa, 2021). The app allows students to access pre-existing learning resources, evaluate learning outcomes using PBL-FC, and engage in informal discussions regarding questions or difficulties with teachers and/or classmates via text messages, voice notes, and video recordings.

In addition, WhatsApp also allows for asynchronous and synchronous learning. It can support students' development to quickly obtain educational resources and engage in real-time discussions as needed (Handayani et al., 2022; Hendri, 2022; Melfawani et al., 2022). With a high level of engagement in group discussions, students are more involved in learning as well as working together to understand various knowledge related to mathematical concepts taught through PBL-FC. The ease of downloading files and media also enhances learning effectiveness by allowing students to receive feedback silently from their teachers. Therefore, WhatsApp offers flexibility and hands-on learning, making it more

effective than other platforms in the context of teaching with problem-based learning and flipped classroom (PBL-FC).

These findings provide evidence that the PBL-FC can be effectively implemented using various media platforms. Every media platform offers distinct features and functions that contribute to the success of mathematics instruction. Gaining a comprehensive understanding of these unique characteristics enables educators to make informed choices when integrating the PBL-FC into their teaching practices. The variety of platforms gives students the freedom to access information based on their individual needs, both inside and outside of class time.

This implementation encourages more systematic and technology-based learning assessment, thus improving students' overall knowledge (Børte et al., 2023; Elmahdi et al., 2018; Johnson et al., 2016; Trianjung et al., 2024). The good news is that combining problem-based learning with the flipped classroom model through various media platforms can promote a more stimulating and meaningful educational experience for student learning. This data shows that PBL-FC can be effectively used across different media channels. Each media platform has different roles and attributes that facilitate effective mathematics learning (Engelbrecht & Borba, 2024; Hillmayr et al., 2020). A comprehensive understanding of these qualities allows educators to make informed choices when adopting PBL-FC.

Moreover, this study assessed the potential presence of publication bias among the selected studies. To address this, we employed the Fail-Safe N (FSN) method as a statistical tool to evaluate the robustness of the meta-analytic findings. The FSN technique estimates how many additional studies with null or non-significant results would be necessary to reduce the observed combined effect size to a level that is no longer statistically significant. In essence, a high FSN value indicates that the current findings are stable and not easily overturned by unpublished or missing studies. This approach adds credibility to the conclusions drawn from the meta-analysis by ensuring that the observed effect is not merely the result of selective publication. The detailed results of the FSN analysis are presented in Table 6, providing further evidence of the reliability of the findings.

Table 5. Results of Publication Bias Tests

P	0.00
Alpha	0.05
z for Alpha	1.96
N	42
P > number of missing studies	6888

Considering the established significance level ($\alpha = 0.05$) and the resulting p-value being well below 0.001, the analysis indicates that the aggregated effect size maintains its statistical significance even when accounting for the possibility of unpublished research. This outcome highlights the reliability and consistency of the meta-analytic findings, suggesting that they are not unduly influenced by selective publication or missing data. It strengthens the claim that the observed effect is not an artifact of biased reporting practices but rather a genuine representation of the intervention's impact.

Furthermore, the resilience of the results against potential publication bias enhances the overall scientific integrity of the study. Even if future investigations or previously unreleased studies with non-significant outcomes were added to the dataset, they would likely not diminish the strength of the current conclusions. This reinforces the trustworthiness of the meta-analysis and supports its contribution to the evidence base in educational research, particularly concerning the efficacy of the PBL-FC in enhancing students' mathematical problem-solving skills.

4. CONCLUSION

Based on a meta-analysis of 31 primary studies, this research concludes that the integration of Problem-Based Learning and the Flipped Classroom (PBL-FC) model has a significant and positive

effect on students' mathematical problem-solving skills (MPSS). Moderator analyses revealed that the effectiveness of this model varied significantly depending on the media platform used, the type of experimental group, and the nature of the publication, while no significant differences were found regarding educational level, class size, or publication year. These findings highlight the adaptability and broad applicability of the PBL-FC model across diverse educational contexts. However, the study is limited by its reliance solely on peer-reviewed journal articles and a relatively small sample size of 31 studies, which may affect the generalizability of the conclusions. To address these limitations, future research should expand the scope of literature to include theses, dissertations, and non-journal publications, and examine additional moderators such as intervention duration, instructional content, and sampling methods. Moreover, longitudinal studies are recommended to explore the model's long-term effects on critical thinking, learning independence, communication, collaboration, motivation, and student engagement. Given its interactive and student-centered nature, the PBL-FC approach holds strong potential as a comprehensive strategy to enhance various cognitive and affective dimensions of mathematics learning.

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