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Effectiveness of Technology-Integrated Problem-Based Learning (TIPBL) on Students' Mathematics Performance: A Meta-Analysis

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Abstract

This meta-analysis investigates the effectiveness of Technology-Integrated Problem-Based Learning (TIPBL) in enhancing students' mathematics performance across secondary and tertiary education. Drawing on 10 empirical studies published from 2015 to 2024 and following PRISMA 2020 guidelines, this study synthesized quantitative data using Hedges' g under a random-effects model. The overall pooled effect size was large and statistically significant ($g = 2.85$, 95% CI [1.44, 4.26], $p < .001$), indicating substantial improvement in mathematics achievement among students exposed to TIPBL. The selected studies encompassed a wide range of mathematical domains, including geometry, calculus, and statistics, and featured diverse technological tools such as GeoGebra, mobile applications, dynamic web platforms, and animation-based media, combined with various PBL strategies like flipped, collaborative, and mobile-based learning. Despite considerable heterogeneity ($I^2 = 99.31\%$), the robustness of the findings was supported by a Fail-safe N of 1,846 and significant equivalence test results. However, signs of potential publication bias were detected through Egger's regression and funnel plot asymmetry. The results affirm the pedagogical promise of TIPBL in promoting active learning, conceptual understanding, and real-world problem-solving in mathematics education. The study recommends greater investment in teacher training, technological infrastructure, and curriculum design aligned with TIPBL principles, while also encouraging further research to explore moderating variables such as instructional design, student demographics, and intervention fidelity.

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Introduction

Technology integration in mathematics education has become a growing focus of research and practice, particularly as educators seek innovative ways to enhance students' learning experiences and outcomes. Numerous studies have reported that the use of technology, especially when combined with inquiry-based pedagogies such as problem-based learning (PBL), can lead to improvements in mathematical understanding, engagement, and achievement (Cheung & Slavin, 2013; Yoon et al., 2021). However, despite the growing body of research, there is limited quantitative synthesis of how effective Technology-Integrated Problem-Based Learning (TIPBL) is across diverse educational contexts, mathematical domains, and technological tools. The present study aimed to address this gap by conducting a meta-analysis to determine the overall effectiveness of TIPBL on students' mathematics performance. This meta-analysis synthesized findings from empirical studies published in recent years, evaluated the magnitude of the effect, and examined the topics, technologies, and instructional strategies used.

Problem-Based Learning is grounded in constructivist and sociocultural theories of learning, which emphasize the role of active inquiry, collaboration, and real-world problem-solving in the development of understanding (Piaget, 1970; Vygotsky, 1978). When students are encouraged to explore problems in context, they build not only procedural fluency but also conceptual depth. The integration of digital technologies, such as GeoGebra, mobile applications, learning management systems, and interactive simulations, can further enhance PBL by providing opportunities for dynamic visualization, immediate feedback, and self-paced exploration (Mayer, 2009; Heid & Blume, 2008). TIPBL thus represents a convergence of pedagogical and technological innovation aimed at fostering meaningful learning experiences in mathematics.

Although individual studies have shown promising results, differences in the implementation of PBL, the type of technologies used, the mathematical content targeted, and the learners involved have made it difficult to generalize findings. Some studies report large gains in achievement, while others show modest or mixed results. A meta-analytic approach offers a systematic way to evaluate the consistency and strength of the evidence across studies, while also identifying potential moderators that may explain variation in effectiveness (Borenstein et al., 2011).

To address this need, the current study conducted a meta-analysis to investigate the impact of TIPBL on students' mathematics performance. In addition to estimating the overall effect size, the study examined the mathematics concepts commonly addressed, the types of technology used, and the instructional strategies applied in TIPBL implementations. Specifically, this study sought to answer the following research questions:

1. What mathematics lessons or concepts incorporate technology-integrated problem-based learning strategies?
2. What types of technology and PBL strategies are used and found effective in improving mathematics performance?
3. How effective is TIPBL in enhancing students' mathematics performance?

Method

Research Design

This study employed a quantitative meta-analysis research design to examine the effectiveness of problem-based learning (PBL) with the integration of technology on students' mathematics performance. Meta-analysis is a systematic method of synthesizing quantitative results from multiple independent studies, using statistical techniques to calculate an overall or "absolute" effect (Amlung, 2023; Borenstein et al., 2011). Unlike merely pooling data to increase sample size, meta-analysis uses well-established procedures to address variations in sample size, study design, and treatment effects, while also evaluating the robustness of findings against the systematic review protocol (Amlung, 2023).

To ensure a thorough and transparent process, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Framework was followed in identifying, screening, and selecting relevant studies (Anghelescu, 2023). The systematic review component of the study critically synthesized findings from empirical studies addressing a clearly formulated research question (Higgins et al., 2019), focusing on the impact of PBL with technology integration on mathematics performance.

The meta-analysis followed five standard steps: (1) defining the research problem or hypothesis; (2) searching for relevant literature; (3) extracting and coding data; (4) applying statistical methods; and (5) presenting the results (Borenstein et al., 2009; Duvneck, 2015; Schmidt & Hunter, 2015). This approach allowed for a logical, transparent, and analytical synthesis of the quantitative findings from comparable studies (Cohen, 1988; Pigott & Polanin, 2020; Gough et al., 2017). Ultimately, the goal was to draw broad conclusions about the current state of research and suggest new directions for future studies (Cohen et al., 2007; Creswell, 2013).

Search Protocol

The identification of studies in this report was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol (Moher et al., 2009; Antonio, 2022). Prior to the search, inclusion and exclusion criteria were clearly established. The researcher employed a comprehensive strategy involving both manual and electronic searches to minimize potential bias and ensure the collection of relevant literature.

A series of searches was conducted using Harzing's Publish or Perish software (Harzing, 2007), along with five meta-search engines: Google Scholar, Crossref, Scopus, Semantic Scholar, and OpenAlex. The search was purposely delimited to studies published from 2015 to 2024.

Various keywords were strategically entered across search platforms. These included: "problem-based learning", "problem-based learning using technology", "PBL", "problem-based learning in mathematics", "effects", "effectiveness", "mathematics performance", "mathematics achievement", and "technology integration". The persistent use of the terms "problem-based learning" or "problem based learning" was emphasized until relevant studies were exhausted.

This rigorous search process enabled the researcher to gather a comprehensive and relevant pool of empirical studies aligned with the goals of the meta-analysis.

Inclusion and Exclusion Criteria

To ensure the applicability of this study's findings, the research focused exclusively on the studies connected to the effects of TIPBL to Students' Mathematics Performance in. A specific criterion is followed in selecting these articles, encompassing the following aspects:

1. The full copy of the article/thesis is available online;
2. Should be written in English language;
3. The study design was experimental or quasi-experimental aimed to evaluate the efficacy of TIPBL on students' mathematics performance as the outcome variable;
4. The study should be educational research focusing on Mathematics Education;
5. Should have evident inclusion or use of TIPBL;
6. Date of publication falling from 2015 to 2024;
7. The study should report quantitative measures of student mathematics performance with sufficient statistical information to enable analysis (e.g., sample size, pretest and post-test mean and standard deviation)
8. Conduct of study in Secondary and Tertiary Education.

Studies that did not meet the following criteria were excluded from the analysis. The researcher alone inspected the results from the different databases along the set parameters.

The literature search and selection process followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 protocol, as depicted in Figure 1. A total of 1,591 articles were initially retrieved from five databases: Google Scholar, Crossref, Scopus, Semantic Scholar, and OpenAlex, covering the publication years from 2015 to 2024.

Following the initial search, a duplicate removal tool was employed, which eliminated 93 duplicates. However, due to inconsistencies in formatting and metadata (e.g., variations in author names, titles, or numerical values), an additional 29 duplicates were identified and manually removed after cross-verification. This resulted in 1,469 unique records subjected to screening.

During the screening phase, 69 studies were removed for not being written in English, 176 for lacking the target population, 854 for not focusing on mathematics performance, and 296 for not incorporating technology integration. After this stage, 74 studies were sought for full-text retrieval. However, 9 reports could not be accessed or retrieved, leaving 65 full-text articles for eligibility assessment (see Figure 1).

Of the 65 full-text articles assessed, 55 were excluded for the following reasons: 36 due to insufficient quantitative

data (e.g., missing means, standard deviations, or sample sizes), and 19 because they were not quasi-experimental in design. After this rigorous screening process, 10 studies met all inclusion criteria and were included in the final meta-analysis. These studies are marked with an asterisk (*) in the reference list.

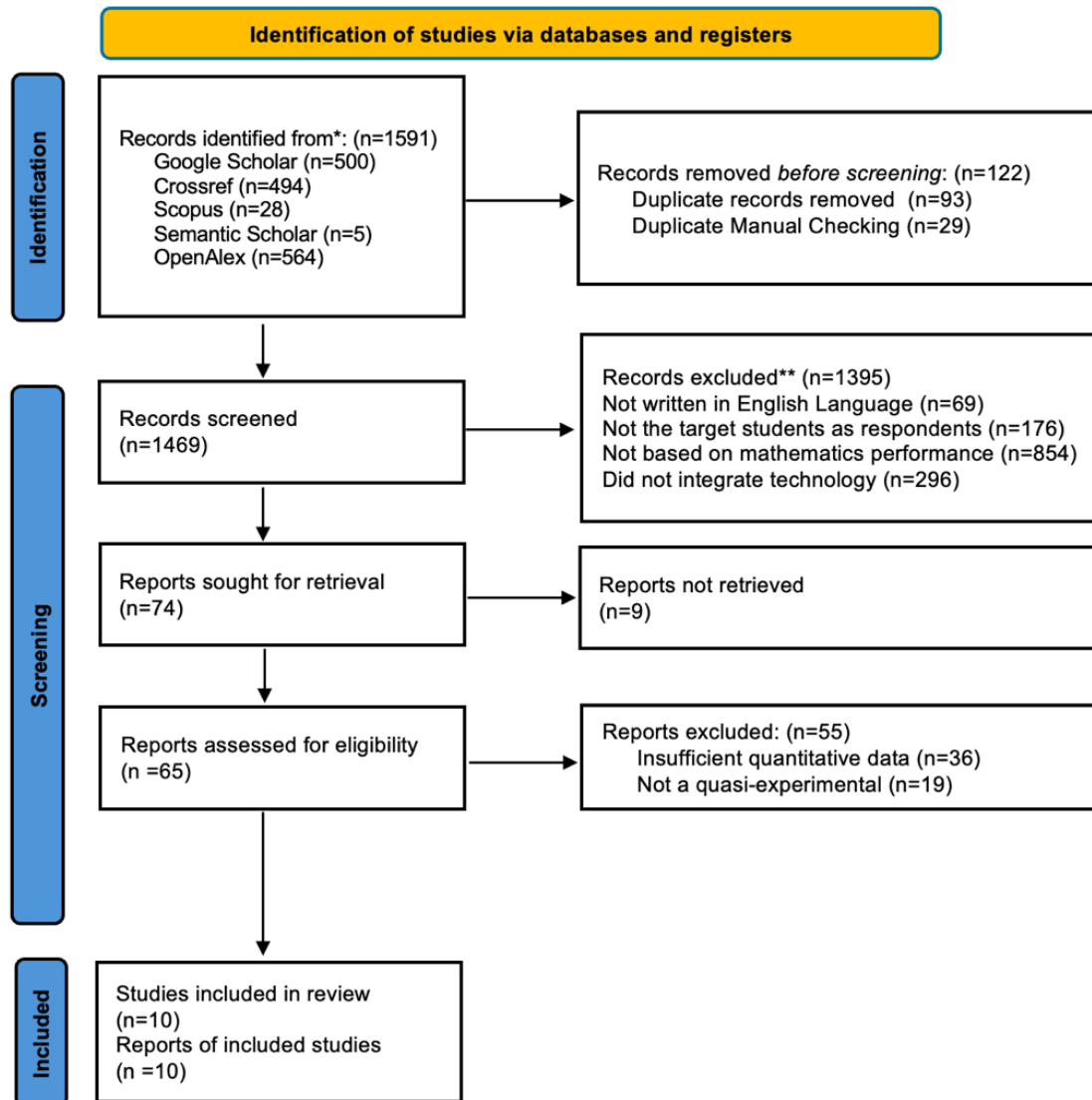


Figure 1. Flow Diagram of the Literature Search Using PRISMA Protocol

Coding Procedures

The ten (10) selected research articles were subjected to critical analysis, and relevant data were systematically coded and recorded by the researcher. Each study was reviewed to extract descriptive and statistical information based on a structured coding scheme. The coding included the following variables: (a) study identification (author's last name and year of publication); (b) database source; (c) country or location of the study; (d) the specific mathematics lesson or concept investigated; (e) the type of technology integrated; (f) the problem-based learning (PBL) strategy employed; and (g) outcome measure characteristics, including pre- and post-test means, standard deviations, and sample sizes. Additionally, relevant content and results of each study were noted. All extracted data were compiled and organized using Microsoft Excel for subsequent quantitative synthesis.

Effect Size Calculation

To assess the effectiveness of technology-integrated problem-based learning (TIPBL) on students' mathematics performance, the researcher computed effect sizes using Hedges' *g*. Effect sizes quantify the magnitude of change or difference, offering insight into the practical significance of an intervention (D'Angelo et al., 2014). Specifically, Hedges' *g* was calculated by dividing the mean difference between posttest and pretest scores by the pooled standard deviation, with a correction for small sample bias (Hedges & Olkin, 1985; Morris & DeShon, 2002).

Hedges' *g* was preferred over Cohen's *d* due to its superior accuracy in studies with small sample sizes (Glen, 2016; Hedges & Olkin, 1985, 2014). In this meta-analysis, effect sizes were interpreted using Cohen's (1988) benchmarks: large ($g \geq 0.80$), medium (0.50–0.79), small (0.20–0.49), and negligible ($g < 0.20$). A positive effect size indicates improvement in performance following the intervention.

The effect sizes for the 10 studies were first calculated individually using Microsoft Excel based on the available means, standard deviations, and sample sizes. These values were then input into Jamovi (MAJOR Meta-Analysis module) to generate a random-effects model, assess heterogeneity, and produce a forest plot for visual interpretation. To explore potential publication bias, a funnel plot was generated. Additionally, the Fail-safe *N* calculation using the Rosenthal approach was employed. In line with Harbord et al. (2009), the test for funnel plot asymmetry was considered appropriate as the dataset included at least 10 studies.

Results

Table 1 summarizes the 10 studies included in the meta-analysis. These studies investigated the effectiveness of Technology-Integrated Problem-Based Learning (TIPBL) across various mathematics topics, including differential calculus, geometry, arithmetic and geometric sequences, statistics, and general mathematics achievement.

Table 1. Summary of Studies Included for Meta-Analysis

Authors	Specific Mathematics Lesson or Concept	Type of Technology Used	Type of PBL Strategy
Ting, F. S. T., Lam, W. H., & Shroff, R. H. (2019)	Basic Principles of Differential Calculus	Kahoot!	Active Learning via Problem-Based Collaborative Games
Eviliasani, K., Sabandar, J., & Fitriani, N. (2022)	Pythagorean Theorem	GeoGebra Software	GeoGebra-Assisted Problem Based Learning (PBL) Approach
Khalda, K. A., Hendrayana, A., &	Creative Thinking Abilities Based on Early Mathematical	GeoGebra	Problem-Based Learning (PBL) Approach Using

Authors	Specific Mathematics Lesson or Concept	Type of Technology Used	Type of PBL Strategy
Jaenudin. (2023)	Abilities		Psychological Tools
Korucu, A. T., & Çakır, H. (2018)	Academic Achievement in the Problem-Based Collaborative Learning Environment	Dynamic Web Technologies (DWT)	Problem-Based Collaborative Learning
Wardani, D. S., & Sugandi, A. I. (2024)	Pythagorean Theorem	LKPD Live Worksheets	Live Worksheets-Assisted Problem Based Learning
Amin, A. K., Degeng, I. N. S., Setyosari, P., & Djatmika, E. T. (2021)	Arithmetic Sequences and Progression, and Geometric Sequences and Progression	Mobile Learning Technologies and Online Learning Technology (Schoology platform for online activities)	Mobile Blended Problem Based Learning (MBPBL)
Nasir, A. M., & Hadijah. (2019).	Geometry (Tetragon Material)	Animation Media (Mathematical Learning Media)	Problem Based Learning Model with the Assistance of Animation Media
Meke, K. D. P., Wutsqa, D. U., & Alfi, H. D. (2018)	Cognitive Ability in Mathematics Learning	Manipulative Materials (Online)	Problem-based Learning Using Manipulative Materials Approach
Montgomery, J. (2015)	Common Core State Standards (CCSS) in Mathematics	Web 2.0 Applications	Problem-Based Learning with Flipped Learning
Çetinkaya, L. (2019)	Data Topic (Central Tendency and Disperse Measures, and Displaying Data in Graphs)	Mobile Applications	Problem Based Mathematics Teaching Through Mobile Based Applications

The types of technology used varied across studies and included Kahoot!, GeoGebra, dynamic web technologies, mobile learning applications, animation media, Web 2.0 tools, LKPD Live Worksheets, and manipulative materials. These technologies were integrated into diverse PBL strategies, such as flipped learning, collaborative games, psychologically supported PBL, and mobile-based learning environments. The range of mathematical topics, technologies, and instructional strategies indicates the broad application and adaptability of TIPBL in both secondary and tertiary mathematics education.

A random-effects meta-analysis was conducted across 10 studies ($k = 10$). The overall effect size was statistically significant, $g = 2.85$, $SE = 0.72$, $z = 3.95$, $p < .001$, with a 95% confidence interval of [1.44, 4.26]. The effect size was calculated using the Restricted Maximum-Likelihood (REML) estimator, indicating a consistent and substantial positive effect of technology-integrated problem-based learning on students' mathematics performance across the included studies (see Table 2).

Table 2. Random-Effects Model (k = 10)

	Estimate	se	Z	p	CI Lower Bound	CI Upper Bound
Intercept	2.85	0.721	3.95	<.001	1.437	4.264

Note. τ^2 Estimator: Restricted Maximum-Likelihood

The analysis revealed substantial heterogeneity among the included studies. The between-study standard deviation (τ) was 2.23, and the between-study variance (τ^2) was 4.95 ($SE = 2.45$). The heterogeneity was statistically significant, $Q(9) = 206.14, p < .001$, indicating that the observed variance in effect sizes was greater than what would be expected by chance (see Table 3). The I^2 value was 99.31%, suggesting that approximately 99% of the total variation across studies was due to true heterogeneity rather than sampling error. The heterogeneity ratio (H^2) was 145.21, further supporting the presence of considerable variability across the included studies.

Table 3. Heterogeneity Statistics

Tau	Tau ²	I ²	H ²	R ²	df	Q	p
2.226	4.9538 (SE= 2.4499)	99.31%	145.213	.	9.000	206.144	<.001

The forest plot displays the individual effect sizes and 95% confidence intervals for the 10 studies included in the meta-analysis (see Figure 2).

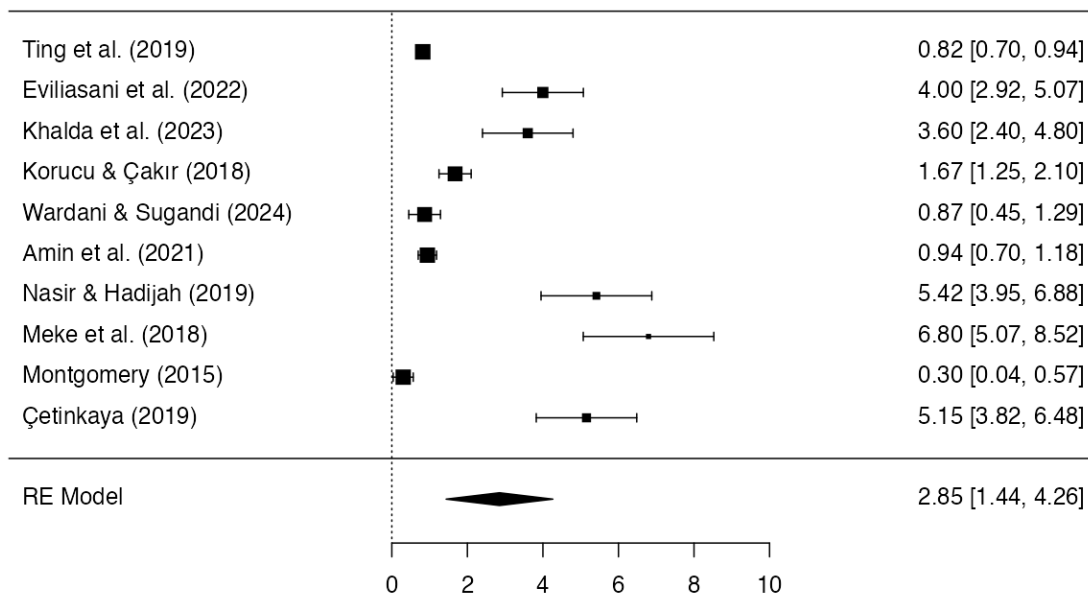


Figure 2. Forest Plot

The studies demonstrated positive effect sizes favoring the intervention, with varying magnitudes. The overall pooled effect size, represented by the diamond at the bottom of the plot, was substantial and statistically significant, consistent with the computed $g = 2.85$ (95% CI [1.44, 4.26]). The width of the diamond reflects the precision of the pooled estimate under the random-effects model. The consistency of positive effects across studies visually reinforces the conclusion that technology-integrated problem-based learning has a significant and favorable impact on students' mathematics performance.

To assess the presence of publication bias, several statistical tests were conducted. The Rosenthal Fail-safe N was 1,846 ($p < .001$), indicating that 1,846 additional studies with null results would be required to reduce the overall effect size to non-significance (see Table 4). This suggests that the observed effect is highly robust and unlikely to be the result of publication bias alone.

Table 4. Publication Bias Assessment

Test Name	Value	p
Fail-Safe N	1846.000	<.001
Kendalls Tau	0.778	<.001
Egger's Regression	9.757	<.001

Note. Fail-safe N Calculation Using the Rosenthal Approach

Additionally, Kendall's tau rank correlation test revealed a coefficient of 0.78 ($p < .001$), suggesting a significant association between effect size and standard error, which may reflect funnel plot asymmetry. Egger's regression test also indicated significant asymmetry, with an intercept of 9.76 ($p < .001$), further pointing to the potential presence of publication bias in the included studies.

Visual inspection of the funnel plot revealed marked asymmetry, with a pronounced clustering of studies on one side of the mean effect size (see Figure 3).

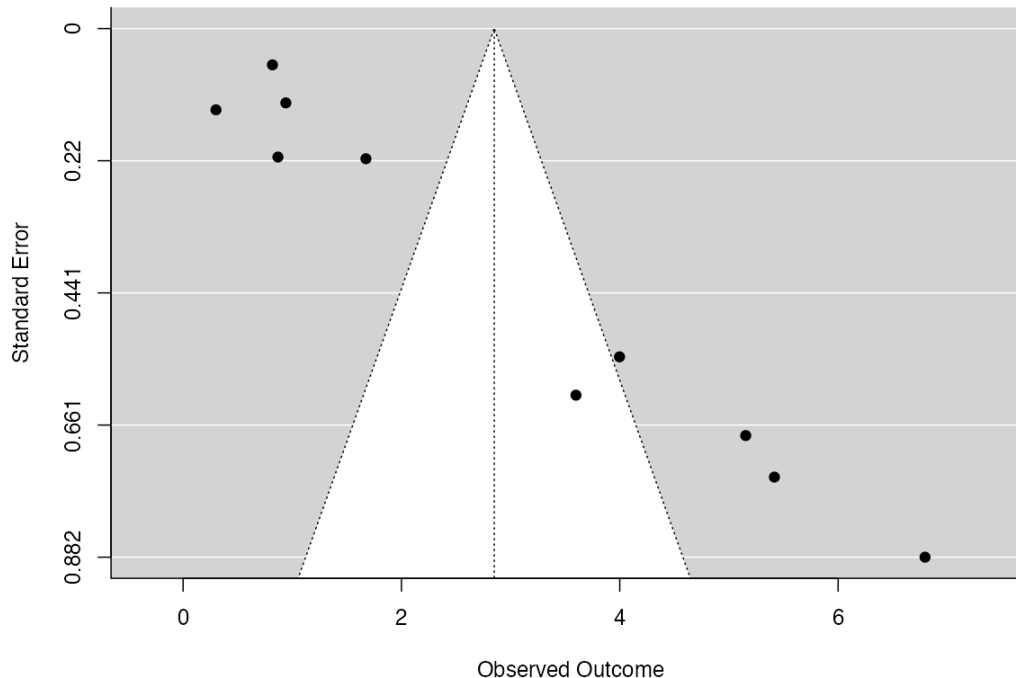


Figure 3. Funnel Plot

The distribution showed a clear absence of smaller or null effects in regions where they would be expected under unbiased conditions. This pattern was corroborated by statistically significant results from Egger's regression, Kendall's tau, and Rosenthal's fail-safe N tests ($ps < .001$), collectively indicating evidence of publication bias.

The substantial fail-safe N further suggests that while the observed effect is robust to potential unpublished null findings, the systematic omission of certain studies may have influenced the meta-analytic estimates. These results underscore the need to consider the potential impact of selective reporting when interpreting the findings.

A Two One-Sided Tests (TOST) procedure was conducted to examine statistical equivalence of the effect size within a specified equivalence interval (see Table 5). The lower bound z -value was 4.65 ($p < .001$) and the upper bound z -value was 3.26 ($p = 0.999$). The 90% confidence interval for the TOST ranged from 1.66 to 4.04, while the 95% confidence interval for the standard z -test ranged from 1.44 to 4.26. These results indicate that the observed effect size falls entirely within the equivalence bounds, providing statistical evidence that the effect is not only significantly different from zero but also falls within a predefined range considered to be practically meaningful.

Table 5. Two One-Sided Tests Equivalence Testing

Z-Value	P-Value	Z-Value	P-Value	LL_CI_TOST	UL_CI_TOST	LL_CI_ZTEST	UL_CI_ZTEST
Lower Bound	Lower Bound	Upper Bound	Upper Bound				
4.645	<.001	3.259	0.999	1.664	4.036	1.437	4.264

Equivalence testing using the Two One-Sided Tests (TOST) procedure was conducted to determine whether the overall effect size could be considered statistically equivalent within a predefined range of practical significance (see Figure 4). The results indicated that the observed effect size falls well within the equivalence bounds.

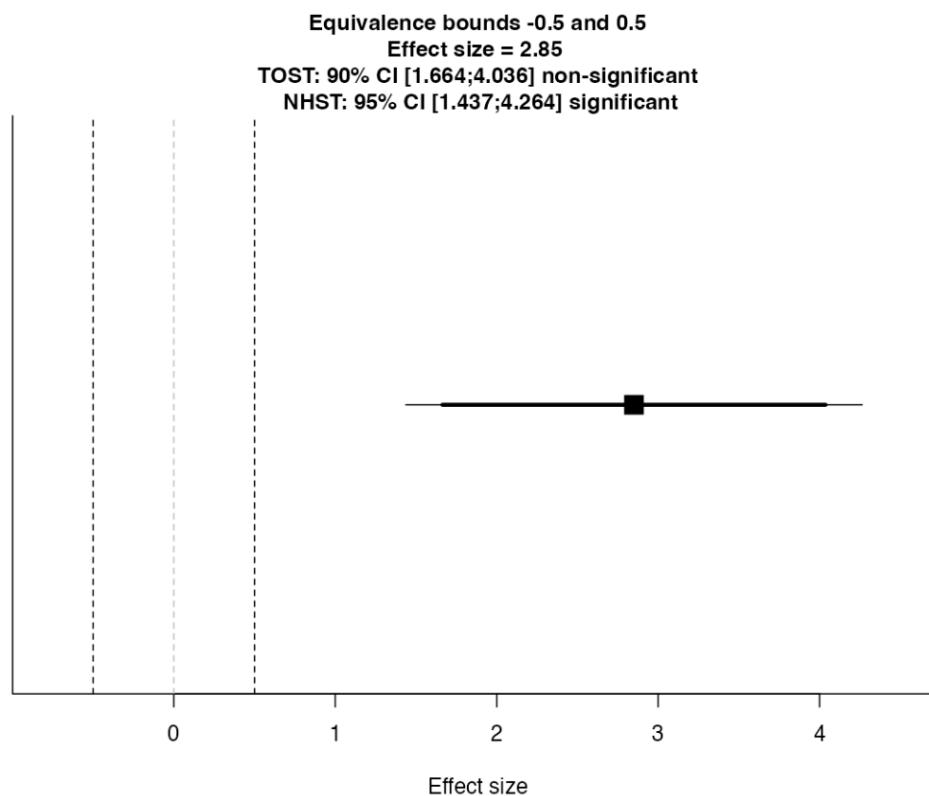


Figure 4. Equivalence Test Plot

The lower-bound z -value was 4.65 ($p < .001$), and the upper-bound z -value was 3.26 ($p = 0.999$). The 90% confidence interval for the TOST ranged from 1.66 to 4.04, while the 95% confidence interval from the standard z -test extended from 1.44 to 4.26. The equivalence plot visually confirmed that the entire confidence interval lies within the region of practical equivalence.

These results provide statistical evidence that the observed effect size is not only significantly different from zero but also falls within a range considered meaningfully large, thereby supporting the robustness and practical importance of the pooled effect size.

Discussion

This meta-analysis aimed to investigate the effectiveness of Technology-Integrated Problem-Based Learning (TIPBL) on students' mathematics performance and to identify the mathematical concepts, technologies, and PBL strategies most commonly used in existing research. The aggregated result (Hedges' $g = 2.85$, $p < .001$) indicates a large and statistically significant effect, demonstrating that TIPBL is a highly effective pedagogical approach for enhancing mathematics achievement across various educational settings and learning environments.

Regarding mathematical content, the 10 studies included in the meta-analysis addressed a broad range of topics such as geometry, calculus, statistics, and sequences. This supports previous findings that problem-based learning (PBL), particularly when integrated with digital tools, is applicable across diverse mathematics domains (Boaler, 2016). Such flexibility is a key strength of TIPBL, as it allows educators to align instruction with specific content standards while fostering conceptual understanding and learner engagement. The versatility of TIPBL across different topics suggests its potential for curriculum-wide adoption, not just in advanced mathematics courses, but also in foundational mathematics instruction.

In terms of technology and PBL strategies, the most effective approaches employed dynamic tools such as GeoGebra, mobile apps, learning management systems (e.g., Schoology), web-based games like Kahoot!, and interactive worksheets. These digital platforms supported various PBL formats, including flipped learning, problem-based tasks, and collaborative inquiry. Their use aligns with current educational priorities that emphasize active learning, self-regulation, and student agency. Studies have shown that when students engage with technology in problem-based settings, they develop deeper reasoning skills and retain information more effectively (Yoon et al., 2021; Heid & Blume, 2008). Moreover, the affordances of these tools, such as real-time feedback, manipulable visual representations, and asynchronous access, can significantly enhance students' opportunities for meaningful learning experiences.

The combination of PBL and technology aligns with constructivist learning theories, particularly Piaget's (1970) emphasis on active knowledge construction and Vygotsky's (1978) theory of social constructivism, which underscores the importance of collaborative discourse and mediated learning. In TIPBL environments, students co-construct knowledge by engaging in meaningful, technology-supported problem-solving activities, often within group settings. These theoretical foundations are also supported by Mayer's (2009) Cognitive Theory of

Multimedia Learning, which asserts that learners process information more effectively when instructional materials incorporate both visual and verbal elements. By integrating these elements, TIPBL reduces extraneous cognitive load and enhances working memory, leading to more durable learning outcomes.

The findings of this study are consistent with earlier meta-analyses that reported positive effects of technology-integrated instruction. For instance, Cheung and Slavin (2013) found that educational technology applications in mathematics produced a mean effect size of $d = 0.15$, while Steenbergen-Hu and Cooper (2014) reported that intelligent tutoring systems and blended learning environments significantly improved STEM learning outcomes. Compared to these findings, the effect size of $g = 2.85$ in the present study suggests that the integration of technology within a problem-based learning framework may yield even greater instructional benefits when appropriately implemented.

Nonetheless, the analysis revealed substantial heterogeneity among the included studies ($I^2 = 99.31\%$), indicating considerable variability in reported outcomes. Factors such as the type of technology used, the duration and intensity of the intervention, instructional design, teacher facilitation skills, and students' prior knowledge likely contributed to this variation (Ertmer & Simons, 2006; Tondeur et al., 2017). Furthermore, contextual factors such as school infrastructure, access to reliable devices and internet connectivity, and institutional support for innovation also play critical roles in determining the success of TIPBL. These findings highlight the importance of implementation fidelity and contextual alignment in future deployments of TIPBL models.

Despite some evidence of publication bias, as seen in the asymmetry of the funnel plot and significant results in Egger's regression and Kendall's tau, the Fail-safe N of 1,846 (Rosenthal, 1979) strongly supports the robustness of the overall effect size. This suggests that even if many unpublished studies with null results existed, they would be insufficient to negate the strong overall positive effect observed in this meta-analysis. However, these results still underscore the need for more balanced and transparent reporting in educational research, particularly regarding non-significant findings and contextual challenges.

This meta-analysis provides compelling evidence that TIPBL is not only effective but also adaptable across various mathematical content areas and learning contexts. However, the relatively limited number of high-quality studies ($k = 10$) reflects a need for more rigorous and large-scale research in this area. Future investigations should examine potential moderating variables such as student demographic characteristics, technology type, instructional design elements, and specific mathematics content. In particular, longitudinal and mixed-methods research designs could provide richer insights into the long-term effects of TIPBL on students' mathematical thinking, attitudes toward mathematics, and retention of conceptual understanding (Lai & Bower, 2019; Toh et al., 2022).

TIPBL offers a robust, evidence-based strategy for improving students' mathematics performance. Its effectiveness lies in the synergistic combination of problem-based learning's inquiry-driven structure with the interactivity, visualization, and accessibility afforded by digital tools. For educators, curriculum developers, and policymakers, these findings emphasize the importance of sustained professional development, adequate

technological infrastructure, and the intentional design of student-centered learning environments that support inquiry, creativity, and real-world problem solving in mathematics education.

Conclusion

This meta-analysis examined the effectiveness of Technology-Integrated Problem-Based Learning (TIPBL) in improving students' performance in mathematics. Drawing from 10 empirical studies, the findings revealed a large and statistically significant effect size (Hedges' $g = 2.85, p < .001$), highlighting TIPBL as a highly effective instructional approach. The studies reviewed spanned a variety of mathematical topics, digital tools, and instructional strategies, showing that TIPBL is not only effective but also flexible and applicable across different educational levels and settings.

Despite the overall positive outcome, the high heterogeneity ($I^2 = 99.31\%$) observed across the studies suggests that the success of TIPBL may depend on several factors, such as the type of technology used, the way PBL is implemented, teacher facilitation, and school infrastructure. While the results are robust, as supported by the Fail-safe N, signs of potential publication bias were noted and should be taken into account when interpreting the magnitude of the effect. The findings confirm that integrating technology into problem-based learning environments enhances students' mathematical understanding and performance. TIPBL offers a promising path forward in making mathematics instruction more engaging, interactive, and relevant to real-world contexts.

Recommendations

In light of these findings, several recommendations can be made. Teachers are encouraged to adopt TIPBL in their classrooms to create more meaningful and engaging learning experiences. However, successful implementation depends on adequate preparation. Professional development opportunities should focus on both the pedagogy of problem-based learning and the use of digital tools that support interactive instruction.

Curriculum developers and school leaders should consider embedding TIPBL into instructional design and provide access to the necessary resources and technologies. School systems, especially those in underserved communities, should be supported with infrastructure and training to ensure that TIPBL can be implemented effectively and equitably. For researchers, further studies are recommended to examine how variables such as age, prior knowledge, technology type, and duration of intervention influence TIPBL outcomes. Long-term and mixed-methods research could offer deeper insights into how TIPBL affects student learning over time and what factors support or hinder its success in real-world classrooms.

Statements and Declarations

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Informed Consent: Not applicable.

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