# Blended Learning and Math Achievement: A Meta-Analytic Review Highlighting the Effectiveness and Heterogeneity

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**Abstract**: The role of technology in mathematics education is growing more significant as contemporary learning evolves, particularly with the advent of blended learning approaches that merge traditional in-person instruction with digital and online tools. A significant amount of research has examined the connection between blended learning and mathematics education. Nevertheless, the effect of blended learning on math achievement has shown inconsistent results, indicating a need for a more comprehensive analysis. This research seeks to address this gap by analyzing the varying effects of blended learning on math achievement across different educational systems and learning environments. To achieve this objective, a meta-analytic review was conducted, synthesizing 34 empirical studies published between 2014 and 2023. These studies involved a total of 2,996 students and provided 34 units of effect size for analysis. Various statistical techniques were employed, including sensitivity analysis, publication bias assessment, Z-test, and Cochrane's Q test, all conducted using Comprehensive Meta-Analysis software. The findings from this meta-analysis reveal that the implementation of blended learning in mathematics has a significantly positive and robust effect on students' math achievement ($g = 1.090$; $p < 0.05$). This suggests that blended learning, when implemented effectively, can enhance students' understanding and performance in mathematics. Furthermore, the current meta-analytic review has examined that two moderating factors, such as educational level and digital platform, significantly differentiated students' math achievement in the environment of blended learning. Meanwhile, there has not been adequate evidence to conclude that class capacity and geographical location significantly differentiated students' math achievement in the blended learning environment. These findings highlight that while some contextual factors, such as educational level and the choice of digital platforms, play a crucial role in influencing math achievement, others, like class size and geographical location, may not be as impactful in blended learning contexts. This study offers an in-depth insight into the ways blended learning can effectively optimize math achievement across different educational settings. The positive outcomes associated with blended learning suggest that educators and policymakers should consider incorporating digital tools and resources into the mathematics curriculum more strategically.

**Keywords**: Blended learning, Math achievement, Meta-Analysis, Effect size, Systematic review

## 1. Introduction

Math achievement plays a critical role in students' academic success, serving as a key indicator of their ability to develop logical reasoning, problem-solving skills, and critical thinking (Nida, Usodo and Saputro, 2020). It encompasses a range of competencies, including mastery of mathematical concepts, problem-solving, mathematical representation, critical thinking, mathematical communication, and mathematical literacy (Ayob et al., 2023; Kilpatrick, 2001; Lin, Tseng and Chiang, 2016). These skills are essential for students to navigate various real-world contexts, apply mathematical reasoning to complex situations, and make informed decisions (Azid et al., 2022). Although these competencies are crucial, international assessments like the Programme for International Student Assessment (PISA) continue to reveal significant disparities in students' math achievement (Putri et al., 2024). The 2022 PISA findings, for example, showed a 15-point decline in average mathematics performance among OECD countries compared to 2018, raising concerns about the current state of math education worldwide (OECD, 2023). Various studies suggest that this decline has been attributed to multiple factors, including the disruptions caused by the coronavirus disease 2019 (COVID-19), insufficient teacher training in modern pedagogical methods, and unequal access to learning resources, particularly in underprivileged areas (İDİL, GÜLEN and DÖNMEZ, 2024; Nguyen et al., 2021). These underlying issues underscore the need for targeted interventions to address these challenges and improve students' mathematical abilities (Tong, Uyen and Ngan, 2022).

Traditional instructional methods in mathematics often fall short of fostering the full range of skills required for comprehensive math achievement (Alsalhi et al., 2021). These methods, while effective in developing procedural



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knowledge, are often limited in promoting deeper conceptual understanding, critical thinking, and active engagement with mathematical concepts. As a result, students may become disengaged, leading to suboptimal learning outcomes and limited preparedness for solving complex, real-world problems (Aldalalah, Shatat and Ababneh, 2019). These limitations emphasize the need for innovative approaches that not only build foundational skills but also encourage higher-order thinking and personalized learning experiences. Blended learning has emerged as a promising alternative to overcome these challenges (Hrastinski, 2019; Lin, Tseng and Chiang, 2016). Blended learning is an educational approach that merges traditional classroom instruction with online learning components, aiming to create a more adaptable, interactive, and customized learning experience (Almasi and Zhu, 2018; Bonk and Graham, 2012; Graham, 2006; Machumu, Zhu and Sesabo, 2016). By combining in-person teaching with online resources, interactive activities, and personalized learning pathways, blended learning caters to individual student needs and learning styles (Garrison and Kanuka, 2004). This pedagogical approach allows students to not only access diverse resources but also engage in collaborative problem-solving and receive real-time feedback, enabling them to build both procedural and conceptual mathematical competencies effectively (Fardian, Suryadi and Prabawanto, 2025).

In mathematics education, this flexible instructional model provides opportunities for differentiated instruction, real-time feedback, and collaborative learning, thereby fostering deeper conceptual understanding and problem-solving skills among students (Cao, 2023). The rationale for investigating the effect of blended learning on math achievement lies in its potential to address longstanding challenges and limitations associated with traditional instructional methods (Pokorny, 2019). Research indicates that conventional approaches to teaching mathematics often fail to effectively engage students, resulting in disinterest, frustration, and poor academic performance (Aldalalah, Shatat and Ababneh, 2019). Blended learning, emphasizing active learning, student-centered pedagogy, and multimedia integration, offers a promising alternative to reinvigorate the learning process and improve outcomes in mathematics education (Bernard et al., 2014; Garrison and Kanuka, 2004). Despite its growing popularity, significant debate persists about the effectiveness of blended learning in improving students' math achievement (Indrapangastuti, Surjono and Yanto, 2021). While numerous studies have explored its impact, the results have often been mixed, with some research highlighting significant benefits while others report minimal or no effect (Kiviniemi, 2014). These inconsistent findings suggest the presence of heterogeneity in the effectiveness of blended learning, which may be influenced by various factors such as instructional design, implementation strategies, student characteristics, and contextual variables (Cao, 2023; Kintu, Zhu and Kagambe, 2017).

Several prior studies employing systematic reviews and meta-analyses have examined blended learning's impact on mathematics skills. For example, Mawardi, Budiningsih and Sugiman (2023) reviewed 26 primary studies and synthesized 37 effect sizes, finding an effect size of 1.01, which is considered large. This suggests that blended learning significantly enhances students' mathematical abilities compared to traditional methods. In contrast, Setiawan, Muhtadi and Hukom (2022) analyzed 36 effect sizes, with a random-effects model revealing an effect size of 1.269, categorized as very high. This indicates that, on average, blended learning effectively improves mathematical skills among Indonesian students. Similarly, Vo, Zhu and Diep (2017) conducted a meta-analysis on blended learning at the course level in higher education, reporting a significant positive effect ($g+ = 0.385$, $p < .001$). Although smaller than the findings of Mawardi and Setiawan, this result further confirms blended learning's potential in improving student performance across diverse disciplines. However, these studies have limitations, as they primarily focus on specific regions and datasets that may not incorporate the latest developments in educational technology. Additionally, there is often a lack of comprehensive analysis of moderator variables that could affect blended learning's effectiveness across different educational settings.

This study offers several significant advantages over previous meta-analyses on blended learning by addressing key limitations and broadening the scope of investigation. One of its main strengths lies in utilizing primary data from the most recent studies up to 2023, ensuring a more up-to-date understanding of blended learning's impact on students' mathematical achievement. For instance, earlier meta-analyses, such as Setiawan, Muhtadi and Hukom (2022), only included data up to 2021, which overlooked recent advancements in educational technology. For example, the integration of advanced platforms such as GeoGebra for interactive mathematical modeling, Google Classroom for streamlined communication and resource sharing, and gamified tools like Kahoot! and Quizizz for improving student engagement are now widely adopted. These tools have transformed how blended learning is implemented, making it more personalized and interactive.

Similarly, Mawardi, Budiningsih and Sugiman (2023) synthesized findings from studies focusing predominantly on Indonesian students and platforms like LMS and social media, limiting the generalizability of their conclusions to global contexts. Their work primarily centered on a narrow range of tools, leaving gaps in understanding the broader technological innovations in blended learning. In contrast, this study bridges these gaps by incorporating a wider range of studies and platforms, offering a more global and comprehensive framework for understanding the effectiveness of blended learning in mathematics education. Unlike Setiawan, Muhtadi and Hukom (2022), which concentrated on a single geographical region, this study examines geographical location as a moderator, recognizing how blended learning's impact varies across cultural and contextual settings. This aligns with findings by Cao (2023), which highlights significant variations in blended learning outcomes across countries. In addition, this study also investigates critical moderators, such as class size, educational levels, and technological tools, to provide a nuanced perspective compared to previous research.

This research further extends prior analyses by exploring a diverse array of technological platforms. While Samritin et al. (2023), focused on a limited set of tools, this study incorporates a broader spectrum, including GeoGebra, Edmodo, Google Classroom, LMS, Microsoft Mathematics, Moodle, PowerPoint, Schoology, Video, and WhatsApp. By examining these platforms, this research provides detailed insights into how specific tools influence the effectiveness of blended learning in varied educational contexts, addressing the gaps left by Mawardi, Budiningsih and Sugiman (2023) and others. Additionally, this study builds on prior meta-analyses, such as Vo, Zhu and Diep (2017), which demonstrated the variability of blended learning's impact across disciplines and educational levels. However, unlike Vo, Zhu and Diep (2017), this research specifically addresses mathematics education, integrating findings from studies like Cao (2023) and Samritin et al. (2023) to validate and expand its conclusions. By synthesizing these perspectives, this study offers a holistic understanding of blended learning's effectiveness while addressing gaps in previous research.

The main goal of this meta-analysis is to provide a comprehensive evaluation of the impact of blended learning on students' mathematics performance, emphasizing various aspects such as comprehension of mathematical concepts, problem-solving abilities, representation, critical thinking, communication, and mathematical literacy. By integrating a wide array of empirical studies, this research seeks to uncover both the potential advantages and challenges associated with the adoption of blended learning in mathematics education. Through a detailed examination of moderator variables and the inclusion of the latest data, this meta-analysis aspires to provide meaningful insights for educators and policymakers on optimizing blended learning strategies to improve mathematics achievement in diverse educational settings. This study specifically aims to explore these key research inquiries:

*RQ1: What is the general effect of blended learning interventions on students' math achievement, and how significantly does the integration of blended learning enhance students' math achievement?*

*RQ2: How do blended learning interventions impact students' math achievement when considering factors like class size, grade level, digital platform, and geographical location?*

## 2. Literature Review

### 2.1 Math Achievement

Mathematics achievement refers to the extent to which students attain proficiency in mathematical skills and knowledge, as evidenced by their performance on assessments and their ability to apply mathematical concepts in various contexts (Azid et al., 2022; Lin, Tseng and Chiang, 2016). According to Kilpatrick (2001) mathematics achievement encompasses not only the ability to solve mathematical problems but also the understanding of fundamental concepts and the ability to communicate and represent mathematical ideas effectively. This perspective is endorsed by the National Council of Teachers of Mathematics (NCTM), which defines mathematics achievement as a complex construct encompassing students' conceptual understanding, procedural fluency, and the ability to apply mathematics in real-world contexts (Leinwarnd, 2014).

In the context of this study, mathematics achievement is understood through several key components that collectively define students' proficiency in mathematical skills. Student achievement is typically measured through performance on mathematical tasks, including standardized assessments, classroom tests, and problem-solving exercises, which reflect both procedural fluency and conceptual understanding (Fazal and Bryant, 2019). Understanding of mathematical concepts involves the ability to grasp fundamental principles, recognize patterns, and establish connections between different mathematical ideas, enabling students to apply their knowledge flexibly in various contexts (Yaghmour, 2016). Mathematical problem-solving refers to the capacity to analyze, strategize, and systematically resolve complex mathematical situations, which is crucial for higher-order thinking and real-world application (Pertiwi et al., 2019). Mathematical representation plays a vital role in expressing mathematical ideas through symbols, graphs, tables, and models, facilitating a deeper comprehension of abstract concepts and their applications (Khairiyyah, Mulyono and Fauzi, 2021). Critical thinking and mathematical communication are also essential, as they allow students to articulate their reasoning, justify solutions, and engage in discussions that enhance their understanding of mathematical concepts (Nida, Usodo and Saputro, 2020; Setiyani, 2019). Mathematical literacy reflects the ability to apply mathematical knowledge in everyday situations, such as financial decision-making, data interpretation, and problem-solving in professional settings, highlighting the importance of mathematics beyond academic contexts (Kilpatrick, 2001).

Furthermore, theoretical frameworks provide a deeper understanding of how mathematical achievement develops. Vygotsky's social constructivism highlights the role of collaboration and guided learning, where social interactions play a crucial role in developing problem-solving skills and conceptual understanding (Gredler, 2011). Cognitive load theory explains the importance of reducing extraneous cognitive load during the learning process, allowing students to focus on intrinsic mathematical tasks (Paas, Van Gog and Sweller, 2010). These theories offer insights into the mechanisms that underpin mathematical achievement across various educational settings.

### 2.2 Blended Learning

Blended learning is an educational approach that merges traditional classroom instruction with online learning components, aiming to create a more adaptable, interactive, and customized learning experience (Alsalhi et al., 2021; Graham, 2006; Setiawan, Muhtadi and Hukom, 2022). This study defines blended learning as any instructional model that combines face-to-face and online components, particularly in mathematics education. Staker and Horn (2012) categorize blended learning into four models: Rotation Model, Flex Model, Self-Blend Model, and Enriched Virtual Model. The Rotation Model involves structured shifts between online and face-to-face learning and consists of four subtypes: Station Rotation, where students move between different learning stations, including an online component; Lab Rotation, where students alternate between a computer lab and classroom instruction; Flipped Classroom, where students study online at home before engaging in problem-solving activities in class; and Individual Rotation, which personalizes schedules based on student needs. The Flex Model relies primarily on online learning with optional face-to-face support, while the Self-Blend Model allows students to supplement their coursework with online resources. The Enriched Virtual Model prioritizes online instruction with occasional in-person sessions.

Each model varies in effectiveness based on the educational context. Flipped classrooms enhance self-regulated learning and critical thinking, making them ideal for secondary and higher education (Means et al., 2013). In contrast, Rotation Models provide structured guidance, making them more suitable for primary education. The Flex Model supports self-paced learners, while the Self-Blend and Enriched Virtual Models cater to independent students in remote or hybrid settings. By aligning blended learning approaches with specific learner needs, this review highlights their impact on mathematics education. The theoretical underpinnings of blended learning include multimedia learning theory and social constructivism. Multimedia learning theory explains how visual and auditory integration enhances comprehension, particularly in online components of blended learning (Mayer, 2009). In addition, social constructivism emphasizes collaboration and peer interaction, which are fostered through blended learning environments that combine online and in-person activities (Gredler, 2011).

### 2.3 Moderating Factors

The disparity in students' math achievement within technology-assisted learning environments suggests the presence of several moderating factors. These factors indirectly contribute to the variations in students' math achievement, resulting in different levels of achievement. While some students achieve high levels of math achievement, others perform at lower levels, with many falling in the middle. Thus, it is essential to explore and evaluate the impact of these factors on students' math achievement. According to various studies, such as those by Helsa et al. (2023) and Tawaldi et al. (2023), there are generally two types of moderating factors: substantial and extrinsic. Helsa et al. (2023) highlight that substantial factors are those that have a direct connection with either the independent or dependent variables, such as class size, level of education, digital tools, and geographical region. Conversely, extrinsic factors pertain to aspects that do not have a direct link to the independent or dependent variables, including the year of publication, type of document, source, and database. Figure 1 illustrates the categorization of these moderating factors into substantial and extrinsic, along with examples for each category. This study concentrates specifically on substantial factors such as class size, educational level, digital platforms, and geographical region because these elements significantly influence variations in students' math achievement.

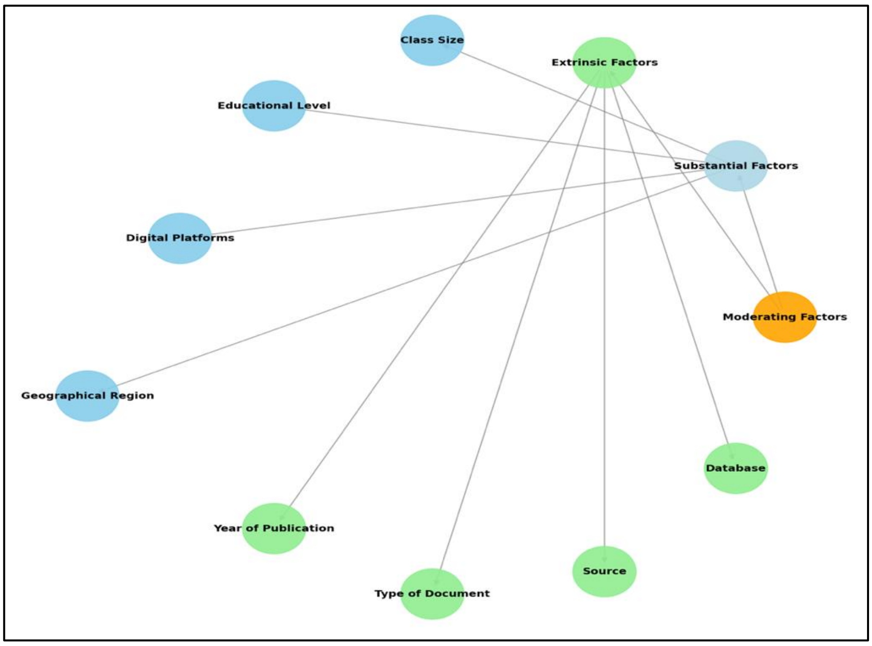


**Figure 1: Circular network analysis: moderating factors**

## 3. Method

### 3.1 Research Design

This study employed a meta-analysis approach, specifically using a random effects model to account for various factors, such as class size, educational level, platform, and geographic region (Borenstein et al., 2021). Numerous academic sources have outlined seven distinct stages for conducting a meta-analysis (Putri, Juandi and Turmudi, 2024; Suparman and Juandi, 2022). Figure 2 presents these methods.

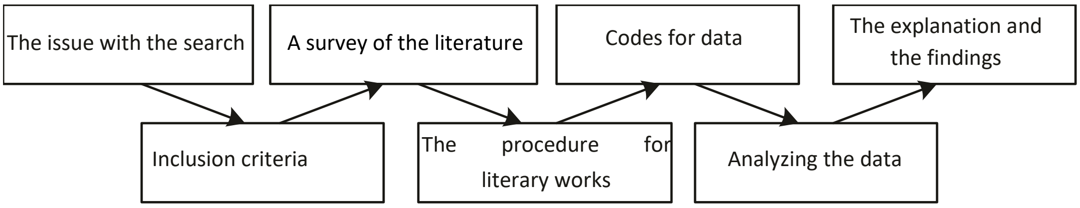


**Figure 2: Diagram of the phases in the meta-analysis process**

### 3.2 Inclusion Criteria

To ensure the rigor and relevance of this meta-analytic review, specific inclusion criteria were established to define the scope of the investigative study. These criteria were designed to ensure that the selected studies align with the research objectives and provide sufficient data for analysis. The inclusion criteria are summarized in Table 1 below:

**Table 1: Inclusion criteria for the investigative study**

| No | Criteria | Inclusion |
|---|---|---|
| 1 | Population | Global student population |
| 2 | Intervention | Implementation of blended learning as the primary intervention strategy |
| 3 | Comparison | Traditional learning as the comparative baseline |
| 4 | Outcome | Mathematics achievement as the measured outcome |
| 5 | Study Design | Experimental design with a control group |
| 6 | Statistical Data Availability | Statistical data available for both experimental and control groups |
| 7 | Peer-Reviewed Sources | Scholarly journal articles or peer-reviewed conference publications |
| 8 | Publication Year Range | Published between 2014–2023 |

| No | Criteria | Inclusion |
|---|---|---|
| 9 | Full-Text Accessibility | Full-text articles accessible online |

### 3.3 Literature Search and Selection

A literature search was carried out using several databases, including Scopus, Semantic Scholar, and Google Scholar, with keyword combinations such as "blended learning" and "math achievement," "blended learning" and "mathematical abilities," or "blended learning" and "math skills." This search retrieved 75 documents from Scopus, 247 from Semantic Scholar, and 1,520 from Google Scholar, all related to blended learning and math achievement. The document selection process followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Moher et al., 2009). Figure 3 outlines the detailed steps of the selection process.

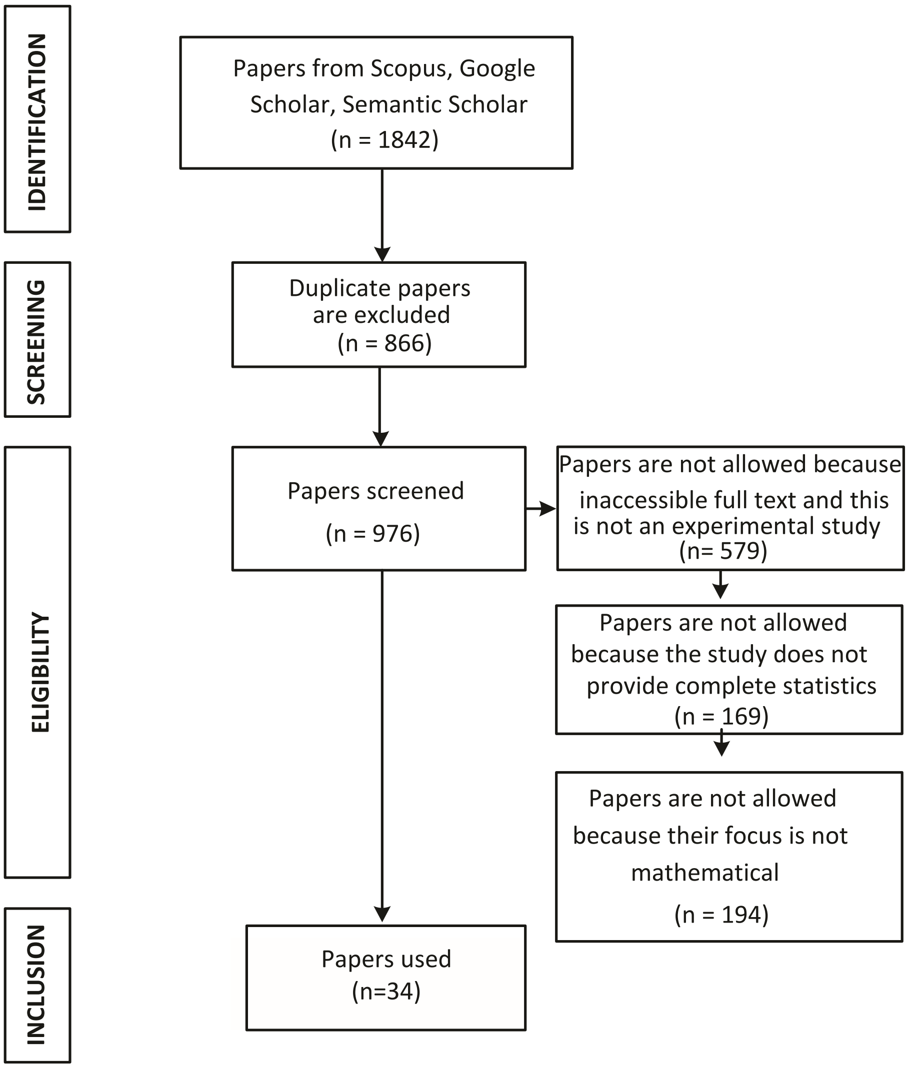


**Figure 3: PRISMA diagram outlining the document selection process.**

Figure 3 illustrates the flow diagram of the literature search conducted following the PRISMA protocol. From 2014 to 2023, a total of 1,842 articles were initially retrieved through various meta-search engines. A data cleanup tool was then used to remove duplicates, resulting in the elimination of 790 duplicate articles. The tool failed to detect certain duplicates because of discrepancies in formatting, including variations in wording, number formatting, and the presentation of information. As a result, manual review and removal became necessary to ensure accuracy, leading to the identification and elimination of 76 duplicates. Afterward, the remaining articles were carefully reviewed, and those that fulfilled the predetermined inclusion and exclusion criteria were assessed.

### 3.4 Data Extraction

This meta-analysis used an extensive coding sheet to document essential parameters and variables crucial to the research, including the researcher's identity, publication year, class size, educational level, platform used, and geographic location. These data points were meticulously recorded in Google Sheets. Additionally, the coding form incorporated essential metrics such as sample size for both groups, as well as mean and standard deviation values. This thorough coding methodology was implemented to enhance the reliability and robustness of the research findings. To ensure accuracy, two experts in meta-analytic reviews were consulted to verify and validate the data. After recoding and reviewing the data, no discrepancies were found between the experts' codings and those of the researchers, thus confirming the integrity and precision of the data for this meta-analytic study.

### 3.5 Data Analysis

This meta-analysis utilized Hedge's g to compute effect size (Borenstein et al., 2021), given the limited sample sizes in the blended learning classes (Harwell, 2020). Effect sizes were categorized according to the guidelines of Cohen (Putri, Juandi and Turmudi, 2024): g=0.00-0.20 indicating a weak effect, g=0.21-0.50 denoting a modest effect, g=0.51-1.00 representing a moderate effect, and g >1.00 indicating a robust effect. Additionally, the impact of blended learning on math achievement was analyzed using the Z test (Borenstein et al., 2021). The study also employed the Q Cochrane test to examine the effects of class size, grade level, platform, and geographical location. The formulation of Hedge's g is detailed bellow (Borenstein et al., 2021):

$$g = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}}} \times \left(1 - \frac{3}{4df - 1}\right)$$

Heterogeneity among the included studies was evaluated using Cochran's Q test and the $I^2$ statistic. The Q-test yielded a value of $257.379$ with $df = 33$ ($p < 0.001$), indicating significant heterogeneity among the studies. Furthermore, the $I^2$ statistic was calculated at $87.18\%$, suggesting that $87.18\%$ of the observed variability in effect sizes was attributable to true differences across studies rather than random sampling error. This high degree of heterogeneity underscores the importance of examining moderator variables to account for the variability. Moderator analysis was conducted to explore factors such as class size, educational level, digital platform, and geographical region, providing insights into the conditions under which blended learning interventions are most effective.

Evaluating publication bias and sensitivity is vital to guarantee the accuracy and stability of statistical data in major studies, as no research outcomes are completely unaffected by publication bias (Bernard et al., 2014). Funnel plots and the fill and trim method were employed in the analysis to evaluate publication bias (Harwell, 2020). Sensitivity analysis was performed using the "One study deleted" function within the Comprehensive meta-analysis (CMA) program.

## 4. Results

This meta-analytic review aims to provide a comprehensive examination of the impact of blended learning on mathematics achievement. It explores key aspects, including sensitivity analysis, publication bias, estimated effect size, and subgroup analysis. These components are systematically discussed in the following subsections to provide an in-depth understanding of the study's findings.

### 4.1 Sensitivity Analysis and Publication Bias

To verify phenomena of publication bias indication, it can be carried out by observing the dispersion of effect size data in the funnel plot (refer to Figure 4).

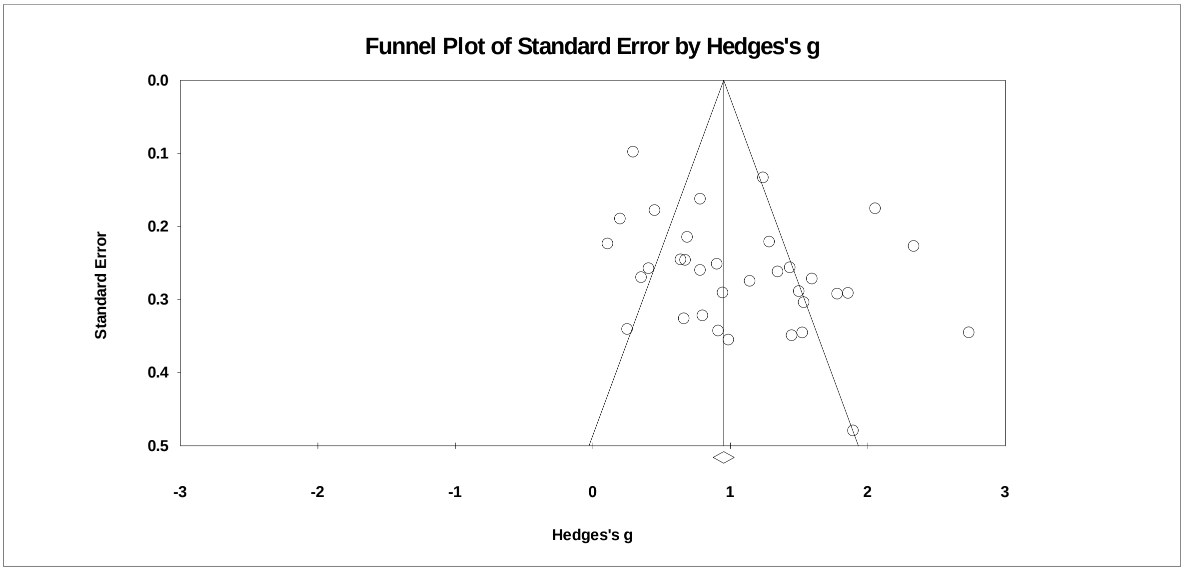


**Figure 4: The spread of effect size data in the funnel plot**

As shown in Figure 4, the effect size data in the funnel plot exhibited a symmetrical distribution. To justify the symmetry of the distribution, the test of trim and fill was conducted (refer to Table 2).

**Table 2: The outcomes of the fill and trim analysis**

| | Studies Trimmed | Effect Size in g | Lower Limit | Upper Limit | Q-value |
|---|---|---|---|---|---|
| **Observed Values** | | 1.090 | 0.867 | 1.313 | 257.379 |
| **Adjusted Values** | 0 | 1.090 | 0.867 | 1.313 | 257.379 |

As shown in Table 2, There was no need to exclude any effect size data from the distribution, neither from the right side nor the left side. This justifies that there was really symmetrical distribution of effect size data in the funnel plot. Consequently, this interprets that there is no phenomenon of publication bias of the collection of effect size data (Tawaldi et al., 2023).

Researchers conducted a sensitivity analysis to examine the effect size data by identifying outliers within the range of the highest and lowest effect sizes. The findings revealed that the smallest effect size in g was 0.867, while the largest was 1.313. On the other hand, the estimated point in g of 34 effect size data was 1.090. As a consequence of these findings, the estimated point was located in the interval between 0.867 and 1.313, and moreover, there was no data that could be outlier. This interprets that there no phenomena which indicated sensitive data when there was a variation in the amount of data within the effect size collection (Putri, Juandi and turmudi, 2024).

## 4.2 Estimated Effect Size

34 eligible documents included in this meta-analytic review generated 34 units of effect size in g and involved 2,996 students. The unit of effect size was heterogeneous in the perspective of direction, significance, and strength (refer to Table 3).

**Table 3: The results of calculations of effect size**

| Document | Effect Size in g Unit | P-value |
|---|---|---|
| **Lin, Tseng and Chiang (2016)** | 0.356 [-0.174; 0.886] | 0.188 |
| **Fazal and Bryant (2019)** | 0.298 [0.104; 0.491] | 0.003 |
| **Setyaningrum (2018)** | 0.454 [0.104; 0.805] | 0.011 |
| **Alsalhi et al. (2021)** | 2.058 [1.713; 2.404] | 0.000 |
| **Tong, Uyen and Ngan (2022)** | 0.691 [0.269; 1.113] | 0.001 |
| **Yaghmour (2016)** | 1.288 [0.853; 1.723] | 0.000 |

 

| Document | Effect Size in g Unit | P-value |
|---|---|---|
| Pertiwi et al. (2019) | 0.906 [0.412; 1.400] | 0.000 |
| Noviyanti, Sugiharta and Farida (2019) | 1.146 [0.606; 1.686] | 0.000 |
| Nugraha, Astawa and Ardana (2019) | 0.676 [0.193; 1.160] | 0.006 |
| Mutaqin, Marethi and Syamsuri (2016) | 1.539 [0.942; 2.136] | 0.000 |
| Septiyan, Anriani and Hendrayana (2019) | 0.410 [-0.096; 0.916] | 0.112 |
| Trisnayanti, Sariyasa and Suweken (2020) | 1.861 [1.289; 2.433] | 0.000 |
| Apsari (2020) | 0.112 [-0.328; 0.552] | 0.618 |
| Jayanti and Rahmawati (2017) | 1.349 [0.835; 1.864] | 0.000 |
| Khairiyyah, Mulyono and Fauzi (2021) | 0.255 [-0.414; 0.924] | 0.456 |
| Sudiarta and Sadra (2016) | 1.438 [0.934; 1.942] | 0.000 |
| Nugraha, Astawa and Ardana (2019) | 1.898 [0.957; 2.838] | 0.000 |
| Zein et al. (2019) | 0.785 [0.274; 1.295] | 0.003 |
| Satriani, Wangid and PA (2020) | 1.598 [1.064; 2.132] | 0.000 |
| Supriadi et al. (2014) | 2.740 [2.062; 3.417] | 0.000 |
| Nida, Usodo and Saputro (2020) | 0.785 [0.465; 1.104] | 0.000 |
| Mashuri and Nasrum (2020) | 1.529 [0.851; 2.207] | 0.000 |
| Ektafia, Fitri and Najibufahmi (2021) | 1.783 [1.208; 2.357] | 0.000 |
| Anwar and Setyaningrum (2021) | 0.643 [0.161; 1.125] | 0.009 |
| Ayuningtyas and Prastowo (2022) | 1.451 [0.766; 2.137] | 0.000 |
| Nasution, Sintia and Putri (2022) | 0.991 [0.294; 1.688] | 0.005 |
| Setiyani (2019) | 0.803 [0.170; 1.435] | 0.013 |
| Darmono and Maryam (2019) | 0.949 [0.378; 1.520] | 0.001 |
| Muncarno and Astuti (2021) | 0.916 [0.243; 1.589] | 0.008 |
| Pokorny (2019) | 1.242 [0.980; 1.505] | 0.000 |
| Ayob et al. (2023) | 0.202 [-0.170; 0.575] | 0.287 |
| Indrapangastuti, Surjono and Yanto (2021) | 1.504 [0.936; 2.071] | 0.000 |
| Angreanisita and Mastur (2021) | 0.667 [0.027; 1.307] | 0.041 |
| Seage and Türegün (2020) | 2.339 [1.892; 2.785] | 0.000 |
| Estimated Effect Size | 1.090 [0.867; 1.313] | 0.000 |

Table 3 shows that the estimated point for the 34 effect size data units in g was 1.090, indicating that the use of blended learning has a strong positive impact on students' math achievement. Additionally, the Z-test significance value was below 0.05, demonstrating that the implementation of blended learning had a significant effect on improving students' math performance. This suggests that incorporating blended learning into math instruction effectively enhances students' math achievement.

### 4.3 Subgroup Analysis

The Q Cochrane test was applied to test some moderating factors (e.g., educational level, class capacity, digital platform, and geographical location) predicted in differentiating students' math achievement in the mathematics learning implementing blended learning (refer to Table 4).

**Table 4: The results of Q Cochrane test**

| Substantial Factor | Groups | Effect Size in g Unit | P-value |
|---|---|---|---|
| Educational Level | Primary School | 1.582 | 0.004 |
| | Junior High School | 0.714 | |
| | Senior High School | 1.328 | |

| Substantial Factor | Groups | Effect Size in g Unit | P-value |
|---|---|---|---|
| | College/University | 1.313 | |
| Class Capacity | Large Class | 1.158 | 0.291 |
| | Small Class | 0.938 | |
| Digital Platform | Edmodo | 1.085 | 0.000 |
| | GeoGebra | 2.740 | |
| | Google Classroom | 0.643 | |
| | LMS | 1.201 | |
| | Microsoft Mathematics | 0.949 | |
| | Moodle | 0.955 | |
| | PowerPoint | 1.288 | |
| | Schoology | 1.378 | |
| | Video | 0.835 | |
| | WhatsApp | 1.046 | |
| Geographical Location | Asia | 1.070 | 0.605 |
| | America | 1.308 | |
| | Europe | 1.242 | |

Figure 5 illustrates the comparison of effect sizes across various moderating factors influencing students' mathematics achievement in blended learning environments. This visualization highlights the patterns and magnitudes of effect sizes for each factor, such as 'Educational Level,' 'Class Capacity,' 'Digital Platform,' and 'Geographical Location.' It complements the data presented in Table 4, providing a clearer and more intuitive understanding for readers.

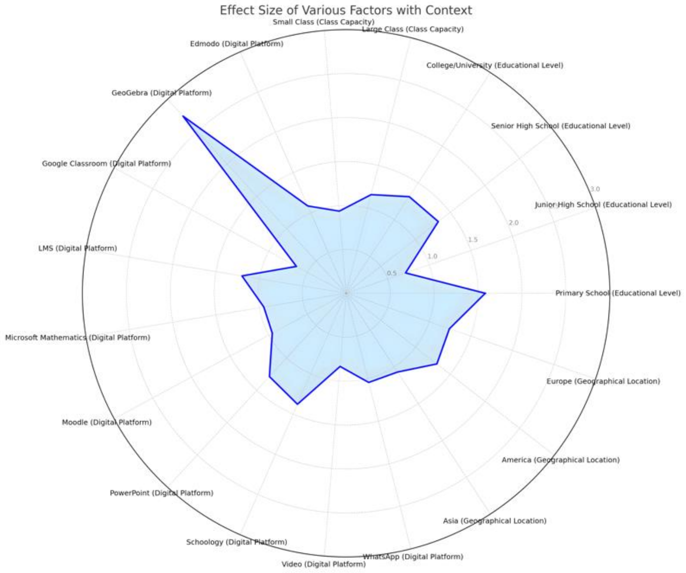


**Figure 5: Effect sizes of moderating factors in blended learning**

From Table 4, it can be stated that two moderating factors (e.g., educational level and digital platform) significantly differentiated students' math achievement in the environment of blended learning. Educational level showed a strong impact, with the highest effect size observed at the primary school level (g = 1.582, p = 0.004), suggesting that blended learning may be particularly effective for younger students who benefit from foundational and interactive learning approaches. Digital platforms also played a crucial role, with GeoGebra demonstrating the largest effect size (g = 2.740), highlighting the importance of dynamic, visually engaging tools in enhancing mathematical understanding. Meanwhile, there have not been adequate evidences to state that class capacity and geographical location significantly differentiated students' math achievement in the environment of blended learning ($p > 0.05$). This suggests that blended learning's effectiveness may be consistent across classroom sizes and regions, though further research is needed to explore these factors in detail, as discussed later.

## 5. Discussion

### 5.1 The Effectiveness of Blended Learning for Students' Math Achievement

This meta-analytic review demonstrates that the blended learning environment has a notably strong positive effect on enhancing students' math achievement. Furthermore, it indicates that implementing blended learning can significantly improve students' math achievement. Two other related meta-analytic studies similarly concluded that blended learning had a significant positive impact on students' success in math education (Mawardi, Budiningsih and Sugiman, 2023; Setiawan, Muhtadi and Hukom, 2022). Specifically, Mawardi, Budiningsih and Sugiman (2023) meta-analysis of 26 empirical studies found that blended learning had a significant positive effect ($d = 1.01$; $p = 0.00$) on students' math skills. Similarly, Setiawan, Muhtadi and Hukom (2022), in a meta-analysis of 36 empirical studies, showed that blended learning had a substantial positive effect ($\Delta = 1.27$; $p < 0.05$) on students' mathematical abilities. These findings reinforce the conclusion of this study, confirming that blended learning environments significantly enhance students' math achievement. This highlights the effectiveness of blended learning in enhancing students' math achievement.

Blended learning merges conventional in-class teaching with online educational activities. This method provides a flexible and interactive learning experience, enabling students to progress at their own speed and utilize a range of resources (Almasi and Zhu, 2018). Generally, Cronje and Van Zyl (2022) explained that blended learning consisted of face-to-face learning (teachers provide direct guidance, facilitate discussions, and address individual student needs) and online learning (students access interactive content, complete assignments, and receive personalized feedback). Blended learning offers several benefits for mathematics education. By combining face-to-face learning and online learning, it can cater to different learning styles, promote student engagement, and improve academic performance (Garrison and Kanuka, 2004). In detail, Hrastinski (2019) explained that blended learning has several advantages in mathematics, such as: (1) Improved student engagement: The use of technology and interactive activities fosters active participation, such as virtual simulations, gamified exercises, and collaborative tools like online discussion forums, which captivate students' attention and encourage deeper involvement in learning. (2) Increased student achievement: By incorporating multimedia resources and real-time feedback mechanisms, students gain a more comprehensive understanding of mathematical concepts, enabling them to achieve better outcomes in assessments. (3) Personalized instruction: Teachers can utilize data analytics from learning platforms to identify individual students' strengths and weaknesses, allowing for tailored lesson plans and adaptive learning paths that accommodate diverse learning styles and paces. (4) Flexibility and accessibility: Students can access recorded lectures, digital resources, and assignments anytime and anywhere, providing opportunities for review and reinforcement outside traditional classroom hours, particularly beneficial for students with varied schedules or geographical limitations. The advantages of blended learning enable mathematics teachers to optimize students' math achievement.

Within a blended learning environment, technology plays a critical role in enhancing mathematics education by providing interactive tools and resources. Tools such as online simulations, graphing calculators, and adaptive platforms support students in visualizing abstract concepts and engaging in problem-solving activities, fostering critical thinking and deeper comprehension (Lin, Tseng and Chiang, 2016; Vo, Zhu and Diep, 2017). Through tailored instruction and immediate feedback, blended learning effectively addresses individual learning needs, contributing significantly to improved mathematics achievement. Although the implementation of blended learning presents challenges, such as access to reliable technology, teacher training, and curriculum alignment (Ayob et al., 2023), this study focuses on its demonstrated benefits for mathematics education. By integrating traditional teaching methods with technological innovations, blended learning enhances student engagement, promotes personalized instruction, and positively influences mathematics achievement in diverse educational contexts (Tong, Uyen and Ngan, 2022).

### 5.2 A Variety of Students' Math Achievement in the Environment of Blended Learning

The current meta-analytic review has examined that two moderating factors, such as educational level and digital platform significantly differentiated students' math achievement in the environment of blended learning. Meanwhile, there has not been adequate evidence to conclude that class capacity and geographical location significantly differentiated students' math achievement in the blended learning environment. Each substantial factor is explained in the following subsections.

#### 5.2.1 Educational level

A variety of educational levels significantly differentiate students' math achievement in the environment of blended learning. This was line to Means et al. (2013) who showed that there has been existing evidence to conclude that the factor of educational level differentiated students' academic achievement in the environment of blended learning. Elementary school students benefit more from blended learning because interactive tools like GeoGebra cater to their developmental stage, enabling scaffolded learning and fostering engagement. This is supported by Piaget's theory of cognitive development, which emphasizes the importance of concrete experiences for younger learners. Visual and interactive resources in blended learning help establish foundational mathematical concepts, making the approach particularly effective at this level. In contrast, secondary school and college students engage with more abstract reasoning and complex problem-solving, which may require additional pedagogical strategies beyond blended learning's basic framework. These findings suggest that implementing blended learning at the elementary level maximizes its impact on students' math achievement, while its effectiveness diminishes as the need for advanced cognitive skills increases at higher educational levels.

#### 5.2.2 Class capacity

Class capacity did not significantly differentiate students' math achievement in blended learning environments. This finding aligns with Mawardi, Budiningsih and Sugiman (2023), who observed no significant differences in mathematical skills between students in large and small classes. These reviews show that class capacity is the factor which does not differentiate students' math achievement in the environment of blended learning. Interestingly, descriptive analysis indicates that the effect of blended learning was higher in large classes compared to small classes. This could be attributed to the collaborative nature of blended learning, which fosters peer interactions and leverages the collective knowledge within larger groups. From a theoretical standpoint, Vygotsky's social constructivism supports this observation. In larger classes, students have more opportunities to engage in collaborative learning and benefit from scaffolding provided by both peers and interactive digital tools. Blended learning platforms, such as Google Classroom and Moodle, enhance these interactions by providing structured activities and immediate feedback, ensuring that students remain engaged and supported, regardless of class size. Consequently, the integration of blended learning technologies not only mitigates challenges associated with larger classes but also optimizes students' math achievement by leveraging the social dynamics of learning.

#### 5.2.3 Digital platform

A variety of digital platforms significantly differentiated students' math achievement in the environment of blended learning. This was line to Mawardi, Budiningsih and Sugiman (2023) who revealed that the factor of media platforms significantly differentiated students' mathematical skills in the environment of blended learning. Specifically, the use of GeoGebra software in blended learning environments was found to have a greater effect on improving students' math achievement compared to other digital platforms, such as Edmodo, Google Classroom, LMS, Microsoft Mathematics, Moodle, PowerPoint, Schoology, Video Conference, and WhatsApp. GeoGebra's interactive features, such as real-time graphing, manipulation of equations, and dynamic modeling, enhance engagement and foster a deeper understanding of mathematical concepts. This is supported by Mayer's multimedia learning theory, which emphasizes that learning is most effective when visual and verbal materials are combined in a coherent and meaningful way (Mayer, 2009). GeoGebra stands out because it enables students to experiment directly with mathematical representations, providing immediate feedback and promoting active learning. Unlike text-based platforms, GeoGebra's ability to make abstract concepts more tangible makes it particularly impactful for enhancing students' math achievement.

#### 5.2.4 Geographical location

A variety of geographical location did not significantly differentiate students' math achievement in the environment of blended learning. This was similar to Schmid et al. (2023), who reported no significant differences in academic outcomes across various regions in blended learning contexts. However, descriptive analysis indicated that the effect of blended learning was highest in the United States compared to Asia and Europe. This may be attributed to better access to technology, advanced teacher training programs, and well-established educational policies supporting the integration of digital tools. The consistent effectiveness of blended learning across regions highlights its universal applicability. Nevertheless, these results emphasize critical implications for educational policy. Governments and institutions in regions with lower effects, such as Asia and Europe, could focus on addressing barriers to technology adoption and enhancing teacher professional development. Providing affordable digital tools and equitable access to resources would help bridge these gaps. To scale blended learning initiatives and address broader disparities in mathematics achievement, public-private partnerships could be explored. These partnerships could provide funding and technical support for infrastructure development. Additionally, policymakers could develop nationwide frameworks to promote collaboration between institutions, enabling the sharing of best practices and resources. These efforts would ensure that the benefits of blended learning are accessible to students globally, regardless of their geographical or socioeconomic background.

### 5.3 Implications to Mathematics Education

The recent meta-analytic review offers several practical implications for mathematics education and future empirical studies. The findings indicate that blended learning significantly enhances students' math achievement. Specifically, using blended learning approaches, mathematics educators including teachers and lecturers can effectively boost student performance. The review highlights that incorporating GeoGebra software into blended learning environments yields a greater positive impact on math achievement compared to other digital platforms. GeoGebra stands out because of its dynamic and interactive features, such as real-time graphing, equation manipulation, and geometric modeling. These features allow students to visualize and interact with mathematical concepts, which enhances understanding and retention. Unlike text-based platforms, GeoGebra transforms abstract mathematical concepts into tangible, interactive models, making it particularly effective in improving math outcomes. Moreover, the review reveals that blended learning is more effective at the primary school level than at the secondary school and college/university levels. Thus, implementing blended learning in elementary schools is likely to be more beneficial for optimizing math achievement compared to higher educational levels. Therefore, mathematics educators should consider applying blended learning strategies, especially with tools like GeoGebra, to maximize student achievement in elementary education.

### 5.4 Limitations and Suggestions

This meta-analytic review has several limitations. Of the total studies identified, only 34 met the inclusion criteria and provided sufficient data for calculating effect sizes. The dataset mainly included studies from specific educational contexts, limiting its generalizability. Many studies also lacked detailed demographic information, such as socioeconomic backgrounds or prior exposure to digital learning tools, which could have enriched the analysis. Additionally, some relevant studies were inaccessible due to publisher restrictions or insufficient statistical reporting. Future research should ensure transparent data reporting and consider publishing in open-access platforms to improve accessibility and inclusion of diverse studies in future meta-analyses.

## 6. Conclusion

Blended learning significantly enhances students' math achievement worldwide. Moreover, its implementation has proven effective in improving math performance across Asia, America, and Europe from 2014 to 2023. Various moderating factors, including educational level and digital platforms, play significant roles in influencing students' math achievement in blended learning settings. Meanwhile, there is insufficient evidence to suggest that class capacity and geographical location significantly differentiate students' math achievement in blended learning settings.

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