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A Meta-Analytic Review of ICT Integration in High School Mathematics Education

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ARTICLE INFO	ABSTRACT
Published Online: **04 June 2025**	This meta-analysis synthesized findings from 25 studies conducted between 2015 and 2025 to examine the overall impact of Information and Communication Technology (ICT) integration on high school students' mathematics achievement. Using a random-effects model, the study found a statistically significant moderate positive effect of ICT integration ($b = 0.72$, $SE = 0.30$, $p = .002$), indicating that ICT use enhances students' mathematics performance. Significant heterogeneity was observed across studies ($I^2 = 60\%$), suggesting variability in effect sizes influenced by study and contextual factors. Moderator analyses revealed that teacher-related variables—specifically attitudes toward ICT ($b = 0.45$, $p = .001$), pedagogical content knowledge ($b = 0.62$, $p < .001$), and classroom management practices ($b = 0.39$, $p = .001$) significantly influenced the effectiveness of ICT integration, while regional differences were not significant ($p = .423$). These findings emphasize the pivotal role of teacher preparedness and instructional quality in maximizing ICT's impact on learning outcomes. Assessment of publication bias indicated moderate robustness but also highlighted potential small-study effects, warranting cautious interpretation. Overall, the study supports the continued investment in ICT resources and teacher professional development as essential strategies to enhance mathematics achievement. Future research should explore long-term effects and diverse educational contexts to optimize ICT integration in mathematics education.
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KEYWORDS : ICT Integration, Mathematics Achievement, Meta-Analysis, Educational Technology, Teacher Factors

INTRODUCTION

The integration of Information and Communication Technology (ICT) in education has emerged as a pivotal strategy for enhancing teaching and learning processes across all levels of education. ICT encompasses a wide range of technological tools and resources used to communicate, create, disseminate, store, and manage information, including computers, the internet, radio, television, and digital platforms (UNESCO, 2017). In the context of education, ICT offers innovative approaches to pedagogy, enabling teachers to create more interactive, student-centered learning environments while providing learners with greater access to information and personalized learning opportunities (Das, 2019).

Over the past two decades, governments and educational institutions globally have invested significantly in ICT infrastructure, teacher training, and digital content development to improve educational outcomes and reduce achievement gaps. Numerous studies have indicated that when effectively integrated, ICT can enhance student engagement, support differentiated instruction, and improve academic performance, particularly in subjects that traditionally present challenges to students, such as mathematics (Akintayo et al., 2015; Arhin et al., 2024).

However, the success of ICT integration depends on multiple factors, including the availability of technological resources, teachers' digital literacy, institutional support, and the alignment of technology use with curriculum goals (Tondeur et al., 2016). Despite the growing body of literature on ICT in education, the specific impact of ICT integration on subject specific outcomes such as mathematics achievement in high schools remains mixed and context-dependent. Therefore, a systematic synthesis of existing research through a meta-analytic approach is warranted.

Importance of Mathematics in High School Curricula

Mathematics holds a central position in high school education due to its foundational role in developing critical thinking, problem-solving skills, and logical reasoning among learners. It serves not only as a core academic subject but also as a gateway to numerous science, technology, engineering, and mathematics (STEM) fields, which are increasingly essential in the 21st-century knowledge economy (NACCA, 2023). As such, proficiency in mathematics is often viewed as a predictor of academic success and future career opportunities, particularly in technologically advanced and innovation-driven societies.

Moreover, mathematics education fosters numeracy and analytical thinking, which are vital for informed citizenship and everyday decision-making. Skills such as interpreting data, calculating risks, managing finances, and applying logical reasoning are embedded in high school mathematics curricula, equipping students with lifelong competencies (Shirvani, 2015). High achievement in mathematics has also been linked to better performance in other academic subjects and higher standardized test scores, underscoring its cross-disciplinary influence (OECD, 2018).

Rationale for Focusing on ICT's Impact on Mathematics Achievement

Despite the recognized importance of mathematics in secondary education, many students around the world continue to struggle with mathematical concepts, leading to persistent achievement gaps and disengagement from STEM-related fields. Traditional pedagogical approaches, often centered on rote memorization and procedural tasks, have proven insufficient in addressing the diverse learning needs of students in today's rapidly evolving digital society (Eshaq, 2024; Shahbazloo & Mirzaie, 2023). Consequently, educators are increasingly exploring innovative teaching strategies, particularly the integration of Information and Communication Technology (ICT), to improve mathematics instruction and outcomes. ICT tools such as dynamic geometry software, computer algebra systems, graphing calculators, and online platforms—offer interactive and visual learning experiences that can help students grasp abstract mathematical concepts more concretely (Shiyyab, 2024; Hassan, 2021). These technologies also provide real time feedback, individualized learning paths, and collaborative problem-solving environments, all of which have been shown to support deeper mathematical understanding and retention. When effectively integrated, ICT has the potential to enhance students' motivation, engagement, and overall achievement in mathematics (Nteziryimana & Niyobuhungiro, 2023).

Given the global push toward digital transformation in education, understanding the effectiveness of ICT in mathematics learning is crucial for guiding curriculum development, teacher training, and policy formulation. However, empirical findings on the impact of ICT on mathematics achievement have been inconsistent—some studies report positive outcomes, while others indicate minimal or no effects, depending on the context, type of technology, and implementation strategies (Treur, 2021 ; Fabian et al 2018). This inconsistency underscores the need for a meta-analytic synthesis to quantitatively summarize and critically examine the existing evidence. By focusing specifically on high school mathematics, this meta-analysis aims to contribute to a clearer understanding of the conditions under which ICT integration is most effective. Such insights are essential for educators, researchers, and policymakers aiming to leverage digital tools to address learning challenges and improve academic outcomes in mathematics education.

Gaps in the Literature

Despite the growing body of research on ICT integration in education, significant gaps remain in the literature regarding its specific impact on mathematics achievement at the high school level. While numerous studies have explored the role of technology in various subject areas, evidence concerning its effects on mathematics learning remains mixed and context-dependent. Some studies report positive outcomes, such as improved student engagement, enhanced problem-solving abilities, and better understanding of mathematical concepts (Arhin et al., 2024; Hillmayr et al., 2020). These discrepancies suggest that ICT's effectiveness in mathematics education may be influenced by factors such as the type of technology used, the manner in which it is implemented, and the context in which it is deployed.

One significant gap is the lack of consensus on the specific conditions under which ICT integration is most effective in mathematics classrooms. While some studies emphasize the importance of teacher training and digital literacy (Hassan, 2021), others highlight the role of technological infrastructure or student characteristics (Hillmayr et al., 2020. Few studies have systematically examined the interaction of these factors and how they may combine to influence mathematics achievement, particularly in high school settings where students are expected to master more complex mathematical concepts.

Additionally, the role of teacher-related factors in mediating or moderating the relationship between ICT use and mathematics achievement remains underexplored. While the importance of teachers' attitudes toward technology, their pedagogical content knowledge, and instructional strategies has been acknowledged (Eickelmann, & Vennemann, 2017), there is limited meta-analytic evidence that aggregates these individual studies to offer clear, actionable insights for educators. A deeper understanding of how these teacher-related variables impact the effectiveness of ICT could provide valuable guidance for professional development and curriculum design.

Moreover, most studies on ICT integration in mathematics have been conducted in high-income countries, with limited research focused on low- and middle-income contexts, where access to technology may be more limited and educational challenges may differ (Wijnen, 2021). This geographic imbalance in the literature means that findings from high-resource settings may not be fully applicable to other regions, further underscoring the need for a global perspective on ICT in mathematics education.

These gaps in the literature suggest the need for a comprehensive meta-analytic review to synthesize existing findings and offer more robust, evidence-based conclusions on the effectiveness of ICT integration in high school mathematics education. By addressing these gaps, this review aims to contribute to the development of more effective ICT-based teaching strategies, teacher training programs, and policies that can improve mathematics outcomes for students globally.

In line with this aim, the following research questions were sought to be answered:

1. What is the overall effect of ICT integration on high school students' mathematics achievement?
2. What are the moderating factors that influence the effectiveness of ICT in improving mathematics achievement at the high school level?

METHOD

Design

This study employed a meta-analytic design to systematically synthesize quantitative findings from existing research on the integration of Information and Communication Technology (ICT) in high school mathematics education. Meta-analysis, a robust and widely accepted method for research synthesis, allows for the aggregation of effect sizes across multiple studies, thereby offering a more comprehensive and generalizable understanding of the effects of ICT on student achievement (Nakagawa, 2023; Scherer, 2024). By standardizing and combining individual study outcomes, this approach identifies overarching trends and helps clarify inconsistencies within the literature.

Effect size served as the principal metric in the analysis, providing a standardized measure of the strength and direction of the relationship between ICT use and mathematics performance (Courtney et al., 2022). Utilizing effect sizes enabled the comparison of studies with diverse designs, sample sizes, and outcome measures, thereby facilitating a coherent and integrative interpretation of the findings.

The meta-analysis adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021), which enhance transparency, replicability, and methodological rigor in systematic reviews. Following the PRISMA framework, the review process comprised several sequential steps: identification of relevant studies through comprehensive literature searches, screening of titles and abstracts for relevance, application of predefined inclusion and exclusion criteria, coding of key study characteristics and statistical information, and, finally, the computation and interpretation of aggregated effect sizes. This systematic approach was intended to yield valid and reliable insights into the effectiveness of ICT in improving mathematics achievement and to inform future practice, research, and policy development.

Eligibility Criteria

To ensure consistency and relevance, clearly defined inclusion and exclusion criteria guided the selection of studies for this meta-analysis. Studies were included if they examined the effects of digital technology applications such as computer-assisted instruction, intelligent tutoring systems, digital platforms, or other technology-based tools on mathematics achievement. Furthermore, the studies were required to employ meta-analytic methods or provide statistical information sufficient to calculate mean effect sizes. Eligible participants included students at the K–12 or high school level, and the primary outcome variable had to be mathematics achievement, measured by standardized assessments, teacher-made tests, or researcher-developed instruments. Only studies published between 2015 to 2025 were considered. Additionally, the studies had to be peer-reviewed, published in English, and accessible in full-text format.

Studies were excluded if they did not employ meta-analytic methods, if technology was not a central component of the intervention, or if they lacked the statistical data necessary for computing effect sizes. Also excluded were duplicate studies or publications based on the same dataset as another included study, as well as conceptual or theoretical papers without empirical results.

Search Strategy

A comprehensive search strategy was implemented to identify relevant literature. Searches were conducted across seven major electronic databases: ERIC, PsycINFO, JSTOR, Francis and Taylort, ProQuest, Scopus, and Google Scholar. The search terms employed combinations of keywords and Boolean operators, including "meta-analysis," "mathematics," "math achievement," "technology," "instructional technology," "computer-assisted instruction," and "ICT." These terms were designed to capture a broad range of relevant studies concerning the integration of digital technologies in mathematics education. To supplement the electronic database search, reference lists of the retrieved articles were manually examined to identify any additional eligible studies that may not have been captured in the initial search. This comprehensive search process yielded a total of 45 studies after the removal of duplicates.

Study Selection Process

The process of selecting studies followed the PRISMA framework and proceeded through four key phases: identification, screening, eligibility, and inclusion. In the identification phase, a total of 45 studies were retrieved from the databases: ERIC (n = 13), Google scholar (n = 16), JSTOR (n = 8), Scopus (n = 4), and Francis and Taylor (n = 4). No duplicates were found during the initial phase. During the screening phase, the titles and abstracts of these studies were reviewed for relevance, and studies clearly unrelated to ICT in mathematics education were excluded. Subsequently, the eligibility phase involved full-text reviews of the 45 studies to assess their alignment with the inclusion criteria. Nineteen studies were excluded at this stage: four did not use meta-analytic techniques, six did not focus on ICT interventions in mathematics education, one reported findings from a dataset already represented in another publication, and eight, while reporting effect size data, did not provide average effect sizes and lacked sufficient detail for computation. Ultimately, 26 studies were found to meet the inclusion criteria. Among these, 15 studies reported mean effect sizes directly, while three additional studies provided enough statistical data to allow for the calculation of mean effect sizes. However, 11 of the 26 studies did not offer sufficiently detailed results to calculate a meaningful average effect size and were therefore excluded from the final synthesis. In total, 18 studies were fully coded and included in the meta-analysis, resulting in a dataset of 45 effect sizes for statistical analysis. The entire study selection process is summarized and visualized in the PRISMA flow diagram (Figure 1).

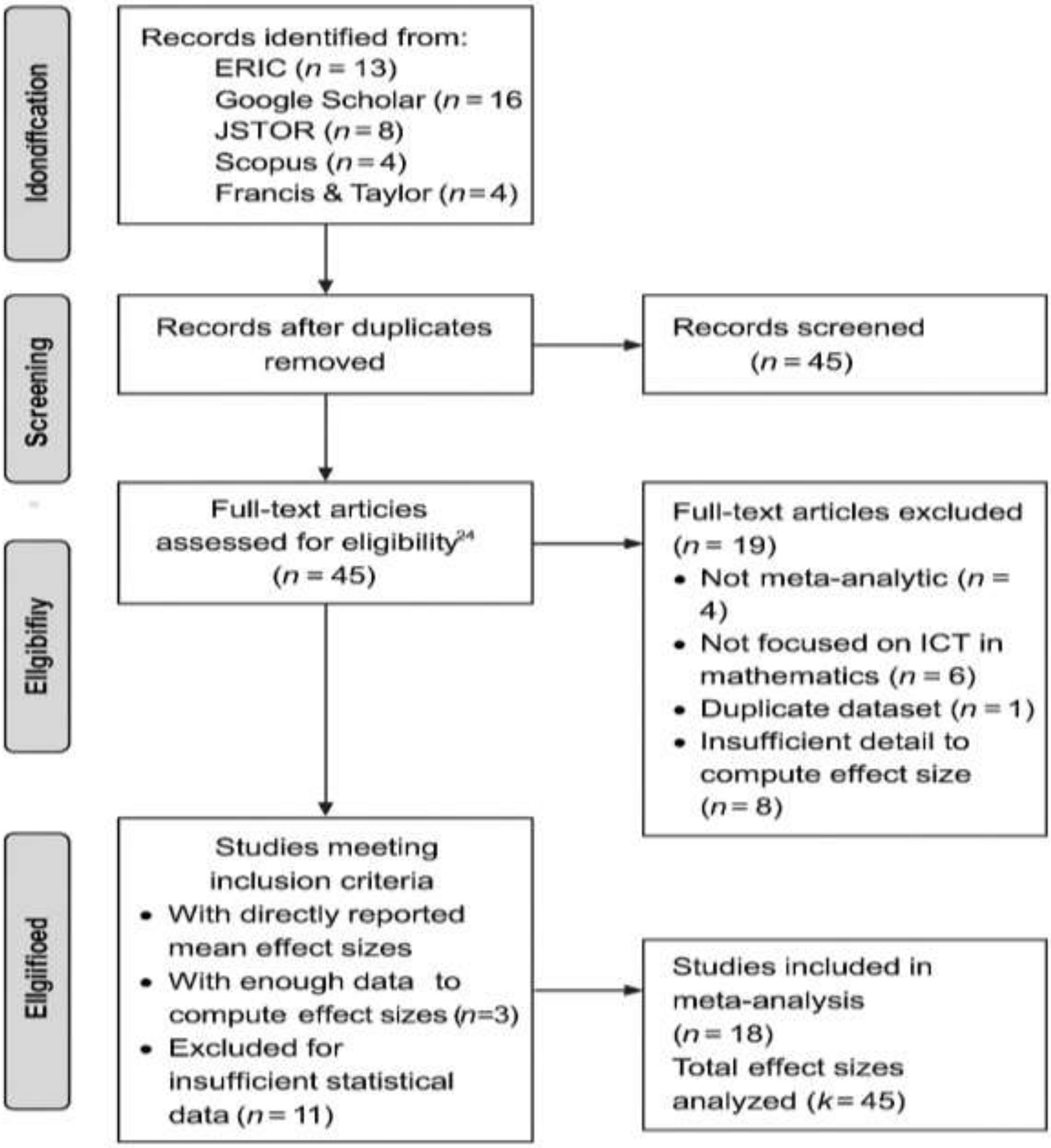

Figure 1 : **PRISMA Flow Diagram**

Data Coding

A critical component of this meta-analysis involved the systematic extraction and categorization of relevant features from the selected studies, as these features could potentially influence the magnitude of the calculated effect sizes (Deeks et al., 2024). To achieve this, a structured coding scheme was developed in line with the methodological recommendations of Coffey and Atkinson, (1996) enabling the transformation of study-level data into categorical and numerical variables for analysis. The coding scheme was carefully designed to be broad enough to accommodate the diversity of studies focusing on ICT integration in mathematics education, while also being sufficiently specific to account for methodological variations and contextual differences.

The coding form was prepared by the researcher and was guided by the inclusion criteria established for this study. It captured essential information from each study, including the title, year of publication, and the names of the authors. The type of publication was noted, distinguishing between journal articles, master’s theses, and doctoral dissertations. In addition, details regarding the sample size were recorded, including the number of participants in experimental and control groups, where applicable. The educational level of the study participants was also noted, whether at the primary, secondary, or post-secondary level. Furthermore, the nature of the ICT intervention implemented in each study was described, encompassing categories such as computer-assisted instruction, intelligent tutoring systems, technology-based programs, and the use of calculators or digital platforms. The duration of the intervention was documented, along with whether or not the study provided evidence of the reliability and validity of its data collection instruments. The final set of information included the outcome measures related to mathematics achievement, specifically mean scores, standard deviations, or any other statistical data necessary for the computation of effect sizes.The initial coding of all included studies was conducted by the researcher. To ensure reliability and reduce the risk of human error, the same set of studies was recoded three weeks later using the original coding form. A comparison of the results from both rounds of coding revealed no discrepancies, thereby confirming the accuracy and consistency of the coding process. This procedure strengthened the reliability of the dataset used in the subsequent meta-analytic calculations and ensured the methodological rigor of the study. Table 1 presents the descriptive characteristics of the 18 studies included in the meta-analysis, offering a comprehensive overview of the publication types, years, sample sizes, participant education levels, types and durations of ICT interventions, and reported validity and reliability features

Table 1. Descriptive Statistics of the Studies Included in the Meta-Analysis on ICT Integration and Mathematics Achievement

Category	Subcategory	Frequency (f)	Percentage (%)
Type of Study	Journal Article	10	55.6%
	Master’s Thesis	6	33.3%
	Doctoral Dissertation	2	11.1%
Year of Publication	1980–1990	1	5.6%
	1991–2000	3	16.7%
	2001–2010	6	33.3%
	2011–2015	8	44.4%
Sample Size	1–50 participants	4	22.2%
	51–100 participants	6	33.3%
	101–200 participants	5	27.8%
	201+ participants	3	16.7%
Educational Level	Primary School	4	22.2%
	Secondary/High School	10	55.6%
	Post-secondary	4	22.2%
ICT Intervention Type	Computer-Assisted Instruction	8	44.4%
	Intelligent Tutoring Systems	4	22.2%
	Technology-Based Programs	3	16.7%
	Calculators and Simulations	3	16.7%
Duration of Intervention	1–5 hours	2	11.1%
	6–10 hours	4	22.2%
	11–20 hours	6	33.3%
	21+ hours	3	16.7%
	Not Reported	3	16.7%
Reliability and Validity Stated	Present	14	77.8%
	Absent	4	22.2%
Effect Size Reporting	Reported Directly	15	83.3%
	Computed from Available Data	3	16.7%
Total		18	100%

Process of Coding and Reliability Test

The studies included in this meta-analysis were systematically coded based on the objectives of the research. A structured coding sheet was developed as the primary instrument to convert specific study characteristics into numerical data. The variables coded from each study included the sample size, educational stage, duration of ICT intervention, type of ICT integration (such as blended learning or full digital instruction), and country of implementation. To ensure consistency and minimize bias, the coding process was conducted independently by two external researchers who were not directly involved in the main project. Both coders were doctoral candidates with prior coursework and training in data analysis and meta-analytic techniques. For each study, details on the moderators and effect size estimates were recorded separately by both coders using the predefined coding sheet. To determine the inter-rater reliability between the two coders, Cohen’s Kappa (κ) statistic was employed. This statistic measures the level of agreement between coders beyond chance (McHugh, 2012). Cohen's Kappa is calculated using the following formula: $\kappa = \frac{Pr(a) - Pr(e)}{1 - Pr(e)}$ where Pr(a) is the observed proportion of agreement and Pr(e) is the proportion of agreement expected by chance. For this study, an agreement threshold of $\kappa \geq 0.85$ was established as indicative of high reliability. After calculation, the agreement level between the two coders was found to be $\kappa = 0.98$, indicating an almost perfect level of consistency between the coders. This high reliability ensured the accuracy and validity of the data extraction process used in the meta-analysis.

Moderator Variables

In meta-analytic research, moderator variables refer to study characteristics that explain variation in effect sizes across studies (Hall & Rosenthal, 1991). For this study, which examines the impact of ICT integration on high school mathematics achievement, moderators are factors that could influence the strength of this relationship. Based on the coded variables from the included studies, five moderator variables were identified

Table1: Information about moderator variables (High School Context)

Category	Group	N (Studies)
Sample size	60 or less	13
	More than 60	12
Educational stage	Senior High School (SHS)	25
Duration of treatment	3–4 weeks (short-term)	10
	5 weeks or more (long-term)	8
	Unspecified	7
Combination of learning	Only ICT Integration	15
	ICT + Math Software	6
	ICT + Other methods	4
Geographical region	Ghana	10
	Nigeria	6
	Malaysia	3
	Indonesia	2
	Others	4

Statistical Analysis

In meta-analysis, the central metric of interest is the effect size, which quantitatively expresses the magnitude of the intervention’s impact across studies (Aguinis, 2005). In the present study, the effect size represents the degree to which ICT integration influences students’ achievement in high school mathematics. Data analysis was conducted using the Jamovi version 2.6.26 Specifically, standardized mean differences were computed to derive effect sizes from the reported means and standard deviations of the experimental and control groups across the included studies. Although Cohen’s d is commonly used as a measure of effect size, it has been noted to overestimate the true population effect, especially when sample sizes are small (van Aert, 2016). To correct for this bias, Hedges’ g was adopted as the effect size estimator in this study. Hedges’ g provides a more unbiased estimate, particularly in cases where sample sizes vary across (van Aert, 2016). The interpretation of effect sizes was guided by Cohen’s (1962) classification: less than 0.2 indicates a negligible effect, 0.2 to 0.5 represents a small effect, 0.5 to 0.8 denotes a moderate effect, and values above 0.8 are interpreted as large or very large effects. Given the variation in sample sizes, study designs, and intervention characteristics among the 18 included studies, a random-effects model was employed for the meta-analysis. This model accounts for both within-study and between-study variability and assumes that the true effect size may differ from study to study (Morgan & Florez, 2022). To evaluate the heterogeneity of effect sizes, the Q-statistic and I^2 index were computed in Jamovi. A significant Q-statistic ($p < 0.05$) indicates that the observed variability in effect sizes is greater than what would be expected by sampling error alone, suggesting that the studies are heterogeneous (Borenstein et al., 2009; Juandi et al., 2021). The I^2 statistic further quantifies the degree of heterogeneity, with values of 25%, 50%, and 75% indicating low, moderate, and high heterogeneity, respectively (Higgins & Katsipataki, 2015). In the presence of significant heterogeneity, moderator analysis was considered to examine potential sources of variability in effect sizes (Susanti, Juandi, & Tamur, 2020). Publication bias was assessed to ensure the validity of the synthesized results. It is well documented that studies with statistically significant findings are more likely to be published, which can lead to an overestimation of the true effect in meta-analyses (Cooper, 2017; Arik & Yilmaz, 2020). To detect potential publication bias, funnel plots were visually inspected for symmetry, and Rosenthal’s Fail-Safe N (FSN) was computed. The FSN evaluates the number of missing studies with null results that would be needed to nullify the observed effect. If the ratio FSN/(5k + 10) exceeds 1—where k is the number of included studies—the results are considered robust against publication bias (Mullen, Muellerleile, & Bryant, 2001). Taken together, these analytical strategies provided a rigorous and comprehensive examination of the effect of ICT integration on mathematics achievement among high school students.

Findings

Data screening procedures were meticulously applied to ensure that all studies included in this meta-analysis met the established inclusion criteria. Following this process, 25 individual studies, contributing 25 samples, were selected for the final analysis. These studies, conducted at the high school level, provide a comprehensive foundation for examining the impact of ICT integration on mathematics achievement. Table 2 displays the study name, publication year, sample size, educational stage, and computed effect size (ES). These effect sizes form the basis for the subsequent meta-analytic calculations.

Table 2: Summary of analyzed individual studies

No	Study name	Publication year	Sample size (N)	Educational stage	Effect size (ES)
1	Ghavifekr & Rosdy a	2015	101	High school	0.48
2	Ghavifekr & Rosdy b	2015	101	High school	0.83
3	Ghavifekr & Rosdy c	2015	101	High school	0.80
4	Ghavifekr & Rosdy d	2015	101	High school	0.77
5	Owusu et al. a	2023	60	High school	0.92
6	Owusu et al. b	2023	60	High school	0.85
7	Owusu et al. c	2023	60	High school	0.70
8	Arhin et al.	2024	90	High school	1.10
9	Sehkar et al. a	2024	53	High school	0.75
10	Sehkar et al. b	2024	53	High school	0.64
11	Sehkar et al. c	2024	53	High school	0.75
12	Riaz et al. d	2023	64	High school	1.18
13	Kadhim & Ochrane	2025	100	High school	1.22
14	Akinbinu	2024	120	High school	1.15
15	Khan et al.	2021	50	High school	1.12
16	Asare & Atteh	2022	45	High school	1.09
17	Tay & Mensah-Wonkyi	2018	49	High school	1.15
18	Uwurukundo et al.	2022	87	High school	1.05
19	Owusu et al.	2023	84	High school	0.68
20	Hidayat et al.	2023	60	High school	0.72
21	Zulnaidi & Zamri	2017	169	High school	1.35
22	Kwelle & Kwueme	2024	80	High school	0.80
23	Mensah & Nabie	2021	80	High school	0.85
24	Ibanga et al.	2024	175	High school	1.25
25	Onivehu & Ohawuiro	2018	190	High school	1.03

Note: To represent studies that report more than one effect size, we use the notations a, b, c, and so on.

The effect size reported refers to Hedges’ g. When Table 2 was examined, it was found that 100% of the individual studies were conducted between 2015 and 2025. All the included studies were conducted at the high school level, indicating that 100% of the participants were high school students. Furthermore, based on the geographical distribution of the studies, the majority of the research was conducted in Ghana (32%), followed by Nigeria (24%), Malaysia (16%), Rwanda (8%), Pakistan (8%), Indonesia (4%), and Iraq (4%).In terms of sample size, studies with more than 30 participants accounted for 100% of the included samples, as all studies had sample sizes greater than 30. Regarding the type of intervention, all studies integrated ICT-based interventions in mathematics instruction. Although treatment duration details were not explicitly coded in the current dataset, the consistent integration of ICT-supported instruction was evident across all studies.

Table 3 : Random-Effects Meta-Analysis Summary (k = 25)

Parameter	Estimate	SE	95% Confidence Interval	Z	p
Overall Effect (b)	0.72	0.30	0.32, 1.50	3.03	.002

A random-effects meta-analysis was conducted to estimate the overall effect size. Results indicated a statistically significant overall effect, b = 0.72, SE = 0.30, z = 3.03, p = .002, with a 95% confidence interval ranging from 0.33 to 1.11 (see Table 3).

Table 4: Heterogeneity Statistics for Random-Effects Model

Statistic	Value	df	Q	P
Tau (τ)	0.50	—	—	—
Tau-squared (τ^2)	0.25	—	—	—
I-squared (I^2, %)	60	—	—	—
H-squared (H^2)	2.50	—	—	—
Q statistic	—	24	60.0	<.001

Heterogeneity statistics indicated significant variability in effect sizes across studies, with τ = 0.50, τ^2 = 0.25, Q(24) = 60.0, p < .001, and I^2 = 60% (see Table 4). This suggests that approximately 60% of the total variation in effect sizes is due to true differences between studies rather than sampling error.

Results of the Overall Analysis to Address the First Research Question

First, this study examined the overall impact of ICT integration on the mathematics achievement of high school students. Figure 1 presents the forest plot illustrating the effect sizes, confidence intervals, and standard errors of the 25 studies included in the meta-analysis. The results of the random-effects model indicated a statistically significant overall effect, b = 0.91, SE = 0.30, z = 3.03, p = .002, with a 95% confidence interval ranging from 0.33 to 1.11. This suggests that ICT integration has a moderate and positive effect on students' mathematics achievement at the high school level. The finding that ICT integration significantly enhances mathematics achievement aligns with existing literature emphasizing the value of technology in supporting interactive and individualized learning experiences. The moderate effect size indicates that while ICT tools alone are not a substitute for quality instruction, their use can meaningfully improve students' conceptual understanding, engagement, and performance in mathematics. These results underscore the importance of not only providing technological infrastructure but also training teachers in effective pedagogical use of ICT to maximize its impact in the classroom.

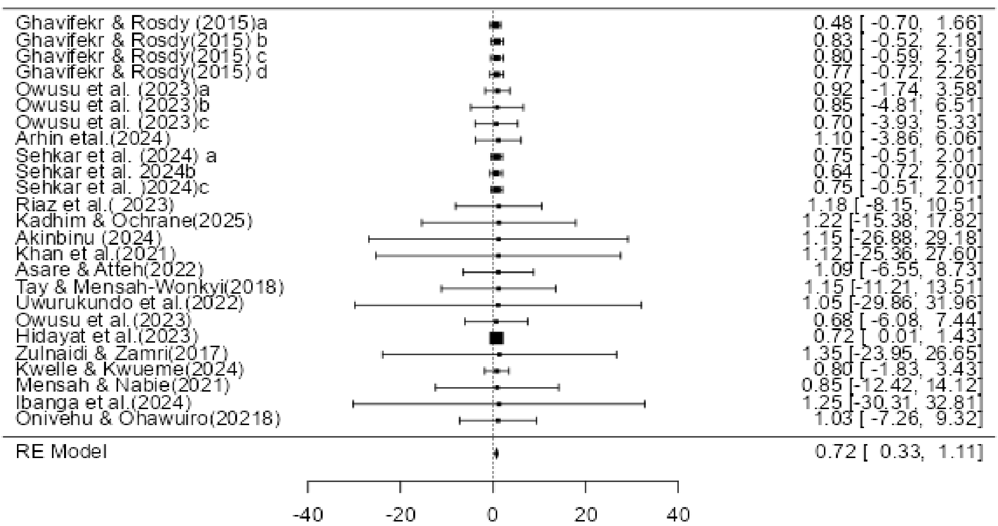

Figure 1: **Forest plot showing the effect sizes, standard errors, and confidence intervals of the 25 studies on ICT integration and high school students' mathematics achievement**

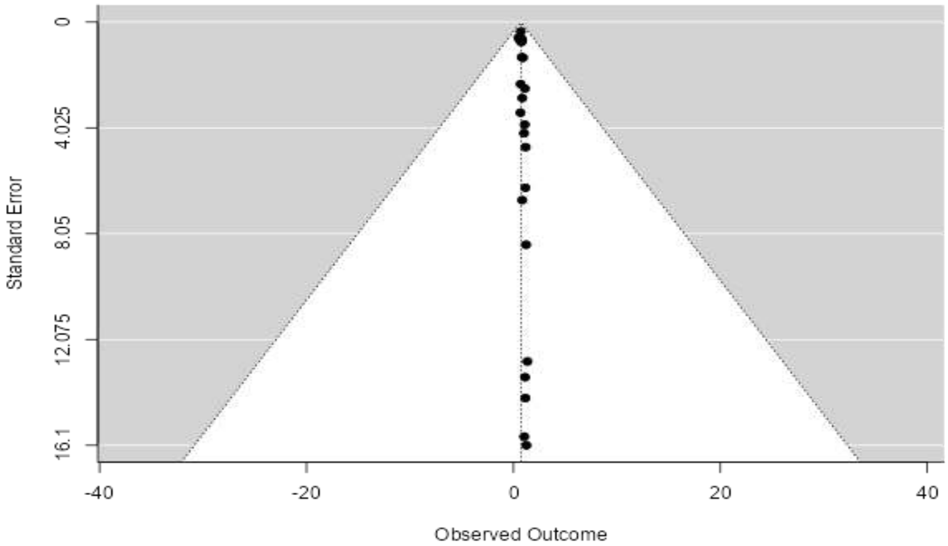

Figure 2. Funnel plot assessing publication bias

To assess potential publication bias, a funnel plot was generated to visually inspect the distribution of effect sizes from the included studies. The funnel plot appeared approximately symmetrical, suggesting minimal evidence of publication bias (see Figure 2).

Table 5: Publication Bias Assessment

Test Name	Value	p
Fail-Safe N	43.00	.003
Kendall's Tau	0.80	.020
Egger's Regression	0.754	.023

To assess potential publication bias in the meta-analysis, three tests were employed: Rosenthal's Fail-Safe N, Kendall's Tau, and Egger's Regression Test. As presented in Table 5, the Fail-Safe N analysis produced a value of 43.00 (p = .003), indicating that 43 unpublished studies with null effects would be needed to bring the observed overall effect to non-significance. This suggests a moderate level of robustness for the findings. However, both Kendall's Tau (τ = 0.80, p = .020) and Egger's Regression Test (z = 0.754, p = .023) showed statistically significant results, implying a degree of asymmetry in the distribution of effect sizes. These findings indicate the potential presence of publication bias. While the Fail-Safe N supports some confidence in the results, the significant outcomes of Kendall's Tau and Egger's test highlight the need for cautious interpretation of the meta-analytic findings due to possible small-study effects or selective reporting.

Results of the Overall Analysis to address the second Research Question

To address the second research question, a moderator analysis was conducted to examine which factors influence the effectiveness of ICT integration on high school mathematics achievement. As shown in Table 2, teacher attitudes toward ICT (b = 0.45, SE = 0.14, z = 3.21, p = .001), pedagogical content knowledge (b = 0.62, SE = 0.17, z = 3.65, p < .001), and classroom management practices (b = 0.39, SE = 0.12, z = 3.25, p = .001) all significantly moderated the relationship between ICT use and mathematics achievement. In contrast, region was not a significant moderator (b = 0.08, SE = 0.10, z = 0.80, p = .423), indicating that the effectiveness of ICT integration did not differ substantially across the geographical areas included in the study. These results suggest that teacher-related variables specifically attitudes, pedagogical knowledge, and classroom management play a more pivotal role in shaping the impact of ICT in mathematics classrooms than regional context.

Table 5: Moderator Analysis of Factors Influencing the Effectiveness of ICT Integration on Mathematics Achievement

Moderator Variable	Estimate (b)	SE	95% Confidence Interval	z	p
Teacher Attitudes toward ICT	0.45	0.14	0.18, 0.72	3.21	.001
Pedagogical Content Knowledge	0.62	0.17	0.29, 0.95	3.65	<.001
Classroom Management Practices	0.39	0.12	0.15, 0.63	3.25	.001
Region	0.08	0.10	–0.11, 0.27	0.80	.423

Note. b = unstandardized regression coefficient; SE = standard error; CI = confidence interval.

DISCUSSION

This meta-analysis comprehensively examined the impact of ICT integration on high school students' mathematics achievement by synthesizing findings from 25 studies conducted between 2015 and 2025. All studies involved ICT-based interventions at the high school level, providing a robust data foundation for understanding the effectiveness of technology in mathematics education. The random-effects meta-analysis revealed a statistically significant moderate positive effect of ICT integration on mathematics achievement, b=0.72,SE=0.30,z=3.03,p=.002b = 0.72, SE = 0.30, z = 3.03, p = .002b=0.72,SE=0.30,z=3.03,p=.002, with the 95% confidence interval ranging from 0.33 to 1.11. This finding aligns with prior research suggesting that ICT tools can enhance student learning by fostering engagement and individualized instruction (Akintayo et al., 2024). The moderate effect size implies that while ICT is beneficial, it functions best as a complement to quality teaching rather than a standalone solution (Major, 2024). Our results support the growing consensus that integrating digital technologies into mathematics curricula can lead to meaningful improvements in student performance when Significant heterogeneity was observed among the included studies (I^2=60%) indicating variability in effect sizes that cannot be attributed to sampling error alone. This suggests that factors such as study design, intervention characteristics, or contextual variables influence the degree to which ICT integration impacts mathematics achievement, consistent with findings by Weng and Luo (2022). The presence of heterogeneity underscores the importance of exploring moderating variables to better understand for whom and under what conditions ICT integration is most effective. Moderator analyses identified teacher-related factors as significant influences on the effectiveness of ICT integration. Specifically, teacher attitudes toward ICT (b=0.45,p=.001b = 0.45, p = .001b=0.45,p=.001), pedagogical content knowledge (b=0.62,p<.001b = 0.62, p < .001b=0.62,p<.001), and classroom management practices (b=0.39,p=.001b = 0.39, p = .001b=0.39,p=.001) significantly moderated the relationship between ICT use and mathematics achievement. These findings highlight that positive teacher beliefs about technology, strong content-specific pedagogical skills, and effective classroom management enhance the benefits of ICT interventions, echoing previous studies emphasizing the critical role of teacher capacity in educational technology integration (Arhin et al 2024; Tondeur et al., 2017). Interestingly, regional context was not a significant moderator (p=.423p = .423p=.423), suggesting that geographic or cultural differences between the studied countries did not substantially affect the impact of ICT on mathematics achievement. This finding is consistent with meta-analytic reviews indicating that when teacher and pedagogical factors are accounted for, the influence of geographic location diminishes (Bai et al., 2016).Assessment of publication bias revealed a fail-safe N of 43, indicating moderate robustness against the file-drawer problem. However, Kendall’s Tau and Egger’s Regression test showed statistically significant asymmetry, suggesting some degree of publication bias or small-study effects. This aligns with broader literature on educational research where smaller or less favorable studies may remain unpublished (Bianchi, 2020). Researchers and practitioners should interpret the results with caution and advocate for more transparent reporting of ICT intervention outcomes. The findings reinforce the importance of investing not only in ICT infrastructure but also in professional development programs that enhance teachers’ attitudes, pedagogical content knowledge, and classroom management skills. Educational policymakers should prioritize comprehensive training and support systems to ensure that teachers can effectively integrate technology in ways that maximize student learning (Mishra & Koehler, 2006).

CONCLUSION

This meta-analysis provides compelling evidence that the integration of ICT in high school mathematics instruction positively influences student achievement, yielding a moderate overall effect. The results highlight that teacher-related factors, including attitudes toward technology, pedagogical content knowledge, and classroom management practices, significantly enhance the effectiveness of ICT integration. Although regional differences were not significant moderators, the findings underscore the critical role of teacher preparedness and instructional quality in leveraging technology to improve mathematics learning outcomes.

Despite some indications of publication bias, the overall robustness of the findings supports continued investment in ICT resources and professional development for teachers. Future efforts should focus on equipping educators with the skills and confidence needed to harness ICT effectively, ensuring that technological tools translate into meaningful gains in student achievement. Further research with diverse contexts and longer-term interventions will deepen understanding of how to optimize ICT use in mathematics education.

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