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Effectiveness of Technology-Enhanced Inquiry-Based Learning: A Meta-Analysis with Implications for Islamic Education

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ABSTRACT

Purpose – Technology-Enhanced Inquiry-Based Learning (TE-IBL) is widely regarded as effective for fostering 21st-century competencies. However, empirical findings remain inconsistent across studies, and synthesis that systematically accounts for key moderators is still limited, particularly within Islamic Education contexts that require the integration of spiritual values and digital ethics. This study aims to estimate the overall effect of TE-IBL on learning outcomes and to examine how contextual and instructional moderators shape its effectiveness.

Design/methods/approach – This study followed the PRISMA 2020 guidelines for systematic review and meta-analysis. From 16,742 initial records, 47 studies met the inclusion criteria. A random-effects model using Restricted Maximum Likelihood (REML) estimation and Hedges' g was employed to calculate effect sizes. Heterogeneity was assessed using Q, τ^2, and I^2 statistics. Moderator analyses included educational level, subject domain, inquiry type, technology type, and intervention duration. Publication bias was examined using Egger's regression test, complemented by leave-one-out sensitivity analysis.

Findings – The pooled effect size indicated a significant and large effect of TE-IBL on learning outcomes ($g = 0.92$; $SE = 0.108$; 95% CI = 0.61–1.03; $p < 0.001$), with substantial heterogeneity ($I^2 = 67.99\%$). Problem-Based Learning yielded the highest effect ($g = 1.20$), followed by guided inquiry ($g = 0.79$) and project-based learning ($g = 0.72$). Social and humanities subjects showed stronger effects than STEM ($g = 1.06$ vs. 0.74). Non-AI technologies outperformed AI-based technologies ($g = 1.05$ vs. 0.52). Longer interventions (>2 months) produced the largest effects ($g = 1.37$). Across educational levels, early childhood education demonstrated the highest effect size ($g = 2.49$), while lower secondary education showed the lowest ($g = 0.47$). Egger's test indicated potential funnel plot asymmetry ($z = 2.30$; $p = 0.021$).

Research implications – High heterogeneity and indications of publication bias constrain generalizability and call for cautious interpretation. Design-related factors such as inquiry scaffolding, intervention duration, and technology selection substantially influence outcomes. Practically, TE-IBL implementation should emphasize teacher professional development, value-sensitive technological design, and ethical integration aligned with Islamic educational principles. Future research should expand geographic coverage, adopt preregistered designs, and more rigorously integrate AI within a framework of ethically grounded and sustainable education.

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1. Introduction

Twenty-first-century education is characterized by demands for mastery of critical thinking skills, creativity, problem solving, and digital literacy. These competencies are no longer regarded as additional skills, but rather the core of the learning process that prepares learners to face global social and technological complexity. Various studies indicate that education systems need to adapt to rapid changes in science, technology, and society (Kalyani, 2024; Sam, 2024). In the perspective of Islamic Education, the mandate to strengthen critical and reflective reasoning aligns with the principles of *tafakkur*, *ta'aqqul*, and *tadabbur* as the epistemological foundation of learning (Al-Attas, 1980; Shihab, 2007). Therefore, the development of learning strategies that can cultivate higher-order thinking skills and utilize technology becomes very important.

Contemporary Islamic Education takes place in diverse institutions such as madrasahs, Islamic schools, pesantren, and Islamic universities, with pedagogical practices that are territorialized and distinctive structures of scholarly authority. The digitalization of learning re-mediates learners' relationships with religious texts (al-Qur'an, Hadith, fikih) and with authoritative figures (ustadz/kyai/religious teachers). In this context, technology-supported inquiry-based learning has the potential to shift patterns of textual mediation, open space for critical religious literacy, and reorganize the formation of religious subjects in the classroom.

Through the lens of Religious Studies, TE-IBL is not understood merely as a strategy to improve learning outcomes, but as a pedagogical regime that shapes interpretive communities, negotiations of knowledge authority, and everyday religious practices in Islamic educational institutions. Therefore, this study examines not only the magnitude of effects on academic achievement, but also elaborates the implications for the design of text-based religious learning, the position of teachers/kyai as interpretive authorities, and the integration of digital ethics in the formation of religious literacy.

One approach proven relevant to the needs of the twenty-first century is Inquiry-Based Learning (IBL). IBL emphasizes active student engagement in posing questions, exploring phenomena, and constructing knowledge through investigative processes (Pedaste et al., 2015). Several meta-analyses show that IBL has a positive impact on academic learning outcomes, critical thinking, and problem-solving skills (Abdi, 2014; Duran & D., 2016; A. Lazonder & H., 2016). In the context of Islamic Education, similar findings emerge in a meta-analysis of HOTS-based IBL showing a significant increase in the critical thinking skills of PAI learners (Ağar, 2025), as well as strengthening academic achievement across levels (Kaçar, T., et al., 2021). However, the effectiveness of IBL is highly dependent on teacher support and adequate scaffolding so that students do not become trapped in confusion or misconceptions (De Jong et al., 2023; A. Lazonder & H., 2016). Thus, IBL is viewed as one potential pedagogical strategy, although its implementation remains full of challenges.

The development of digital technology has enriched IBL practices, especially through the use of e-learning, interactive multimedia, simulations, and applications based on artificial intelligence (AI). This technological integration can increase student engagement, support project-based learning, and expand access to information (Consoli et al., 2024; Xia et al., 2022). In the context of this study, the term "Technology-Enhanced Inquiry-Based Learning (TE-IBL)" refers to IBL practices supported by digital tools or AI-based systems that function to strengthen inquiry processes, collaboration, and learning personalization. In Islamic Education, technology integration shows a positive trend in increasing engagement and conceptual understanding, although it demands pedagogical readiness and institutional support (Ab Halim et al., 2025; Azman et al., 2025; Siregar et al., 2025). Technology also enables cross-distance collaboration and more adaptive learning personalization (Rintaningrum, 2023; Samad & Arifin, 2024). However, the quality of technology integration depends not only on the devices used, but also on pedagogical design and teacher readiness (Lachner et al., 2024; Viberg et

al., 2020). This indicates that the effectiveness of TE-IBL cannot be separated from its context and supporting competencies, including the affirmation of Islamic values in learning practices.

Although many studies support the effectiveness of TE-IBL, existing research results still show variation. Some studies report large effect sizes on learning outcomes and critical thinking (Arifin et al., 2025; Kaçar, T., et al., 2021), while other studies find more moderate or even negative results when inquiry is conducted without guidance (Oliver et al., 2019). In addition, different fields of study show varying achievements, where STEM is more widely studied, while the social-humanities cluster is relatively neglected (Chen & C., 2021; Marcone, 2022). In the context of PAI, learning innovations that intersect with inquiry are proven to increase motivation, activity, and learning achievement (Jayanegara et al., 2024), and are effective when combined with character education frameworks and metacognitive strengthening (Wantu et al., 2025). Differences in research design, intervention duration, and technology use also contribute to the consistency of results (Liu & P., 2022; Ning et al., 2022). This condition underscores the need for a more comprehensive synthesis to obtain a clearer picture.

Table 1. **Summary of Previous Meta-Analyses on Inquiry-, Problem-, and Project-Based Learning (2014–2025)**

No	Study (Author, Year)	Focus / Model	N (Studies)	Moderators / Variables Examined	Key Findings	Limitations / Gap
1	(Abdi, 2014)	IBL in science education	45	None reported	IBL improves achievement and understanding of science concepts	Limited to K-12 science; no tech dimension
2	(A. W. Lazonder & Harmsen, 2016)	Guided vs unguided IBL	72	Guidance type	Guided IBL > unguided; large effect	No technology integration
3	(Liu & Pásztor, 2022)	PBL in higher education	38	Education level	Medium–large effect (g ≈ 0.64)	Non-digital context
4	(Ananda & Usmeldi, 2023)	IBL on student competence	32	Discipline, education level	Large effect (1.45–2.47)	No tech moderator
5	(Tafakur et al., 2023)	PjBL for critical thinking	29	Subject domain	Large effect (0.86–1.45)	Small sample size
6	(Sisrayanti et al., 2024)	PBL on 21C skills	50	Not reported	Very large effect (1.72)	No tech dimension
7	(Sani et al., 2024)	ICT-based IBL	41	Technology type	Large effect (0.84) on critical thinking	Limited to STEM
8	(Meriyati et al., 2024)	Ethno-physics IBL	25	Cultural context	Large effect (0.84–0.92)	Local scope
9	(Arifin et al., 2025)	IBL on critical thinking	60	Education level, discipline	Large effect (1.27)	No tech moderator
10	(Zhang et al., 2023)	PjBL on learning achievement	48	Duration, group size	Significant effect	No AI dimension

The meta-analytic results summarized in Table 1 indicate that IBL, PBL, and PjBL consistently provide large positive effects on academic achievement, critical thinking skills, and twenty-first-century competencies across educational levels. Nevertheless, most of these reviews still focus on the general effectiveness of inquiry models or PBL without distinguishing the type of technology integration, the pedagogical type of inquiry, and learner characteristics. In this study, PBL and PjBL are treated as part of inquiry-oriented pedagogies because they have investigative characteristics similar to IBL, although they differ in procedural emphasis and learning outcomes. This approach was selected to enable synthesis across variations of inquiry-based pedagogies in the context of technology-enhanced

learning. In Islamic Education, this framework is increasingly relevant given the need to integrate cognitive, affective, and spiritual competencies simultaneously in learning design (Ab Halim et al., 2025; Siregar et al., 2025). In addition, factors such as intervention duration, field of study, and educational context have also not been systematically analyzed as moderator variables. Based on these conditions, this meta-analysis study seeks to provide a deeper synthesis by analyzing the effectiveness of TE-IBL in detail through key moderators such as educational level, field of study, intervention duration, and the type of technology used. Thus, this study is expected to clarify how the role of technological mediation affects the effectiveness of inquiry in various learning contexts.

To date, there have not been many meta-analyses that comprehensively review the effectiveness of technology-based inquiry while considering various key moderators. Previous studies generally focus on the effectiveness of inquiry in general without distinguishing the type of technology (AI vs non-AI), the pedagogical type of inquiry (guided inquiry, PBL, PjBL), educational level, field of study, or intervention duration (De Jong et al., 2023; A. Lazonder & H., 2016). In fact, these factors are very likely to explain variations in findings across studies. In Islamic Education, AI integration shows potential in the cognitive and psychomotor domains, but requires caution in the affective and ethical dimensions so that the teacher's role as a spiritual-pedagogical guide remains central (Hakim & Anggraini, 2023; Priyanto et al., 2025). In this study, moderators are operationally defined as follows: educational level (K–12 vs higher education), field of study (STEM vs non-STEM), inquiry type (guided vs open), technology type (AI-based such as intelligent tutoring system, chatbot, adaptive system vs non-AI such as simulation or hypermedia), and intervention duration (short <4 weeks, medium 4–8 weeks, long >8 weeks). In addition, indications of publication bias in educational studies add complexity to drawing conclusions (Bartoš et al., 2023; Van Aert et al., 2019).

In this study, the scope of analysis is focused on studies involving learners from elementary education to formal higher education levels with learning contexts integrated into science, technology, and social-humanities subjects. The main outcomes examined include academic achievement as the primary outcome, as well as critical thinking skills and twenty-first-century skills as secondary outcomes. This focus was selected to ensure alignment between the goals of the meta-analysis and the characteristics of the moderator variables tested. Specifically in Islamic Education, the TE-IBL framework is positioned to bridge the strengthening of critical reasoning, value internalization, and digital literacy in an integrated manner (Hasanah et al., 2025; Yunita & Mulyadi, 2024). Theoretically, guided inquiry models and AI-based technology integration are expected to yield higher effect sizes than open approaches or non-AI technologies, because both provide stronger scaffolding and adaptability in supporting the learning process (Ab Halim et al., 2025; A. Lazonder & H., 2016).

Meta-analysis is an important approach because it can integrate scattered empirical research findings, calculate pooled effect sizes, and test heterogeneity across studies. In addition, meta-analysis can identify effectiveness patterns based on intervention and learner characteristics, while also detecting potential publication bias that may affect effect estimates (Nakagawa et al., 2023; Terrin et al., 2003). In this way, the research not only produces a quantitative summary, but also provides insights that can be used for policy and educational practice improvement. This is consistent with the demand for evidence-based research that is increasingly emphasized in global and national education policies.

Based on the conceptual clarification and operational definitions of moderators described earlier, this meta-analysis aims to: (1) estimate the effect size of TE-IBL on student learning outcomes, (2) test heterogeneity across studies, (3) analyze the influence of moderators such as educational level, field of study, inquiry type, technology type, and intervention duration, and (4) evaluate the presence of publication bias in the existing literature. General approaches such as the small-study effects test or the trim-and-fill procedure will be used to assess potential publication bias, with technical details explained further in the Methods section. This study is expected to make a theoretical contribution by

clarifying the consistency of TE-IBL effectiveness, while also offering practical recommendations for teachers, researchers, and policymakers in developing innovative learning strategies relevant to twenty-first-century needs and aligned with the values of Islamic Education.

2. Methods

2.1. *Research Design and Protocol*

This study employed a systematic review and meta-analysis design to quantitatively examine the effectiveness of Technology-Enhanced Inquiry-Based Learning (TE-IBL) on students' learning achievement. This design was selected because it can integrate various empirical research findings across diverse contexts, thereby producing effect estimates that are more general and reliable. All reporting procedures followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines so that the processes of selection, extraction, and data analysis can be transparently accountable.

The research protocol was registered in the Open Science Framework (OSF) with registration ID. The protocol includes the research objectives, research questions, inclusion and exclusion criteria, moderator variables, and the statistical models to be used. Any deviations from the initial plan are explicitly explained in the appendix with traceable methodological reasons. This approach was implemented to avoid potential bias such as HARKing (hypothesizing after results are known) and to improve the reproducibility of the meta-analysis.

All analyses were conducted using R software version 4.3.1 with the metafor package (v.4.4), clubSandwich (v.0.6), and robumeta. Random-effects model estimates were calculated using the restricted maximum likelihood (REML) approach because the data came from heterogeneous educational contexts. A random seed was set to maintain consistency of analytical results, while all R scripts and the coding sheet were uploaded to the same OSF repository so that they can be openly accessed by other researchers.

In addition, the researchers included a data and analysis code availability statement in the appendix to ensure scientific openness (open science). Each stage of analysis, from the extraction process to effect size estimation, was stored in a format that enables full replication. Thus, this research design not only serves to answer the research questions, but also becomes part of the practices of transparency and scientific accountability that are increasingly emphasized in contemporary meta-analytic studies.

2.2. *Search Strategy and Study Selection*

The literature search was conducted systematically in four international academic databases, namely Scopus, Web of Science (WoS), ERIC, and Google Scholar. The search strategy was designed using a combination of keywords representing three main components, namely inquiry-based learning models, technology integration, and learning outcomes. This combination used Boolean operators (AND, OR) and field tags (TITLE-ABS-KEY) to make the search results more targeted. For example, the terms inquiry-based learning, guided inquiry, problem-based learning, or project-based learning were combined with the words technology-enhanced, digital learning, ICT, or AI, as well as learning outcomes such as academic achievement, critical thinking, and problem solving.

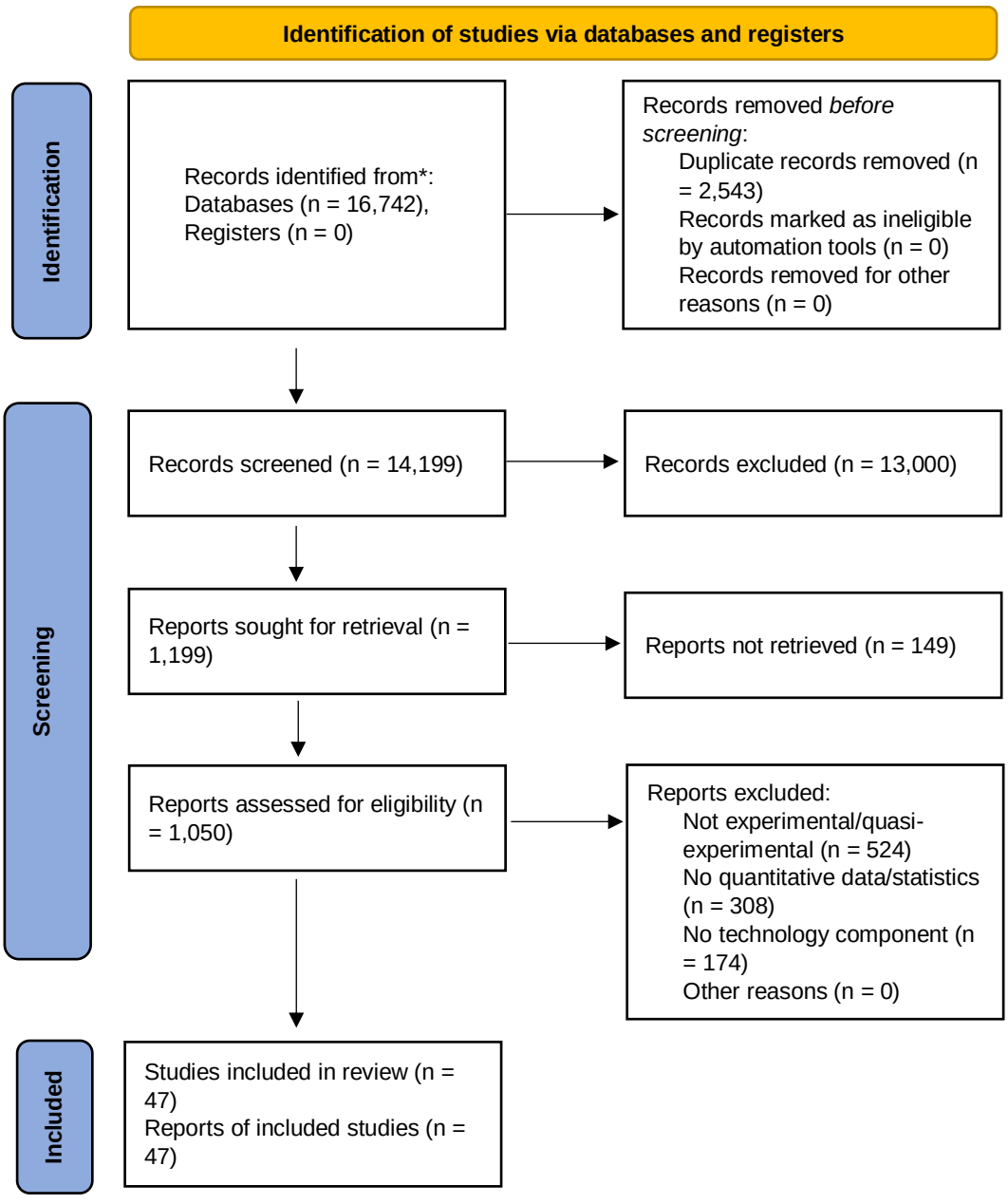
The search was not restricted by publication year to ensure comprehensive coverage of studies. However, most articles that met the inclusion criteria came from the period 2010 to 2025, along with the increasing integration of digital technology in science and humanities learning. The last search was conducted on 31 October 2025. Only English-language articles published in peer-

reviewed journals were included. For sources from Google Scholar, only the top 200 results were analyzed based on relevance. Snowballing was conducted on the reference lists of relevant articles to minimize the possibility of missing studies.

All search results were imported into the Rayyan application for reference management and automatic deduplication. Duplicates were removed based on DOI similarity, title, and author names. After deduplication, a two-stage screening was conducted: first, screening based on titles and abstracts to eliminate clearly irrelevant articles; second, full-text review to ensure compliance with the inclusion criteria. This procedure was performed independently by two reviewers. Inter-rater agreement was calculated using Cohen's κ, and disagreements were resolved through discussion or consultation with a third reviewer.

From a total of 16.742 initial articles, 2.543 were removed due to duplication, leaving 14.199 unique articles. After title and abstract screening, approximately 13.000 articles were eliminated as irrelevant. A total of 1.199 articles were reviewed in full, but 149 of them could not be accessed in full despite efforts through author contact and interlibrary loan. Finally, 47 studies met all criteria and were included in the meta-analysis.

Figure 1. PRISMA 2020 Diagram of the Study Selection Process.



2.3. *Data Extraction and Coding*

The data extraction process was conducted using a coding sheet prepared before the analysis (a priori coding sheet) to ensure consistency and uniformity of recording. Two researchers performed extraction independently, then compared their results to ensure accuracy. The collected data included author identity, publication year, country of study, educational level, field of study, inquiry type, technology type, intervention duration, sample size, and statistical data such as mean (M), standard deviation (SD), t, F, or η² values that can be converted into effect sizes.

Outcome variables were differentiated into primary outcomes and secondary outcomes. The primary outcome included academic achievement because it is the main cognitive indicator in learning effectiveness. Secondary outcomes included critical thinking and problem-solving skills representing higher-order thinking skills. If a study reported more than one outcome, the effect size most representative of the research objectives was selected or its composite was calculated to avoid effect size duplication within a single study.

Any incomplete or ambiguous data were confirmed directly with the corresponding author via email. If no response was obtained, estimation was performed using available statistical data, for example, conversion from p values or F to standardized effect sizes. Inter-rater reliability during the coding process was maintained through an agreement test with an accuracy percentage above 90%. All coding sheets and procedural documentation were stored in the same OSF repository and can be downloaded for replication purposes or revalidation by other researchers.

In addition, moderator variables were coded to enable further analysis of effect heterogeneity. The moderators examined included educational level (elementary school–senior high school–higher education), field of study (STEM–non-STEM), inquiry type (structured, guided, open), technology type (multimedia, digital simulation, learning management system, AI-based tools), and intervention duration (short, medium, long). All of these variables were categorized and converted into numeric or dummy data according to the needs of meta-regression analysis. This procedure ensures that the processed data truly represent the diversity of characteristics across studies.

2.4. *Effect Size Calculation and Statistical Analysis*

Effect sizes for each study were calculated using Hedges' *g*, which provides a correction for small-sample bias. For posttest-only designs with a control group, the following formula was applied:

$$g = \frac{M_T - M_C}{SD_{pooled}}$$

whereas for pretest–posttest control group designs, the effect size (g_{pp}c) was calculated assuming pre–post correlations (*r*) of 0.3, 0.5, and 0.7 for sensitivity analyses. All effect sizes were normalized so that positive values indicate higher learning outcomes in the TE-IBL group compared with the control group. When studies employed clustered trial designs, standard deviations were adjusted for the design effect using an intraclass correlation coefficient (ICC) of 0.05.

The primary analytical approach employed a random-effects model with restricted maximum likelihood (REML) estimation to account for between-study variance. Heterogeneity was assessed using the *Q* statistic, tau-squared (τ^2), and I-squared (I^2), which quantify the proportion of total variation not attributable to sampling error. Further analyses explored the influence of moderator variables through meta-regression with Knapp–Hartung adjustments. The moderators examined included educational level, subject domain, type of inquiry, type of technology, and intervention duration. Potential non-linear effects of duration were tested by including a second-order polynomial term in the regression model.

To control for the risk of multiple testing, a False Discovery Rate (FDR) approach was applied. Multicollinearity among moderator variables was assessed using Variance Inflation Factor (VIF) values and was considered acceptable when VIF < 5. Sensitivity analyses were conducted using a leave-one-out procedure, in which one study was removed at a time to assess the robustness of the pooled effect size. Results were visualized using forest plots to display the distribution of effect sizes and meta-regression plots to illustrate relationships between moderators and effect sizes. All analyses were conducted using the metafor package in the R software environment.

2.5. *Quality Assessment and Publication Bias*

The methodological quality of each included study was assessed independently by two raters. For studies with a randomized controlled trial (RCT) design, the Risk of Bias 2 (RoB 2) instrument was used, whereas for quasi-experimental studies, ROBINS-I was used. The assessment covered six main domains such as bias in allocation, intervention implementation, outcome measurement, and data reporting. Inter-rater agreement was in the high category with $\kappa > 0.80$. The summary results of the risk of bias assessment are presented in Table 1, while the full version is available in the appendix.

Potential publication bias was evaluated through a combination of visual and statistical tests. The visual test was conducted using a funnel plot to detect asymmetry in the distribution of effect sizes, while statistical tests used Egger regression and Begg's test. Additional analyses were conducted using the trim-and-fill method (Duval & T., 2000) to estimate the effects of missing studies, as well as PET-PEESE and p-curve analysis to distinguish small-study effects from file-drawer bias. Interpretation of publication bias results was conducted carefully by considering the number of studies and the level of data heterogeneity.

To ensure the robustness of the results, sensitivity analyses were also conducted by comparing meta-analysis results after excluding studies with high risk of bias and extreme studies with the largest or smallest effect sizes. This approach enables verification of the stability of conclusions both statistically and methodologically. Thus, the results of this meta-analysis not only describe the magnitude of the influence of TE-IBL on learning outcomes, but also demonstrate the overall reliability and validity of the findings. Table 1. Summary of Risk of Bias Assessment of Included Studies.

2.6. *Ethical Considerations*

This study fully used secondary data sourced from studies that have been published openly. Therefore, no new data collection was conducted involving human participants. All sources were cited ethically and in accordance with their respective publication licenses. There are no potential conflicts of interest that could affect the results of this study. Thus, formal ethical approval was not required, but the principles of openness and scientific integrity were upheld throughout the entire research process.

3. Results

3.1. *General Description of the Dataset*

This meta-analysis dataset consists of 47 studies drawn from various regions worldwide, encompassing diverse educational levels, subject domains, inquiry types, technologies used, and intervention durations. Compared with the previous dataset, three additional studies from Indonesia have been included, focusing on inquiry training and innovative learning in Islamic Religious Education (Pendidikan Agama Islam, PAI). This addition enriches the representation of the Southeast Asian context and broadens the coverage of the Social Sciences and Humanities domain, which was previously dominated by studies in science and STEM fields.

Geographically, the studies remain largely concentrated in East Asia and North America, followed by Southeast Asia, Europe, and Eurasia. Research contributions from Africa and West Asia remain limited, indicating that global representation is still uneven. This pattern suggests that the implementation of Technology-Enhanced Inquiry-Based Learning (TE-IBL) has been more extensively studied in countries with relatively advanced educational and technological infrastructures. Nevertheless, the increasing contribution from Southeast Asia, particularly Indonesia, reflects a positive trend toward expanding TE-IBL research in value-based and religious education contexts.

Table 1. Summary of Study Categories in the Meta-Analysis Dataset

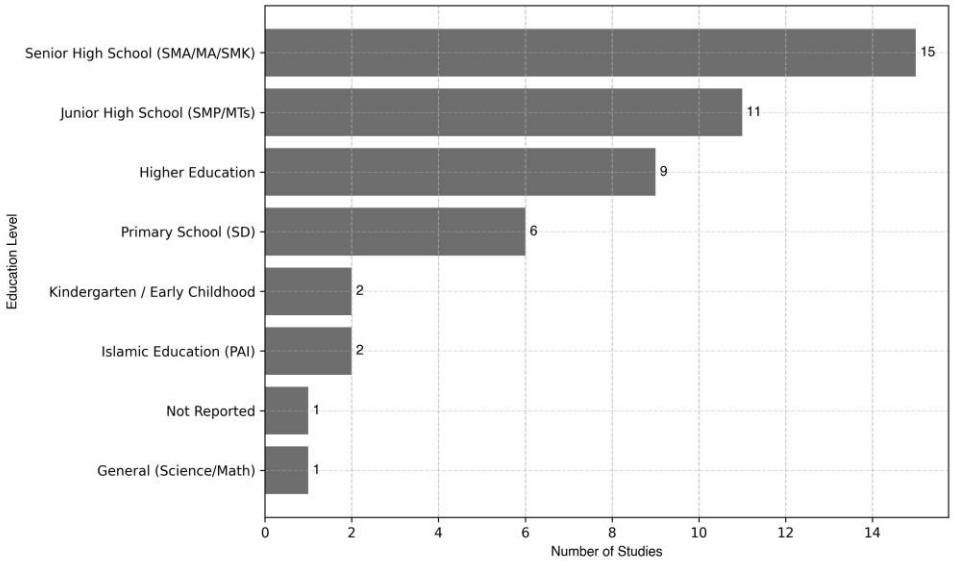
Category	Item	Value
Region	Africa	2
	North America	9
	West Asia	2
	Southeast Asia	7
	East Asia	10
	Europe	4
	Europe/Asia (Eurasia)	5
	Not reported	8
Educational Level	Higher Education	9
	Primary School	6
	Lower Secondary (SMP/MTs)	11
	Upper Secondary (SMA/MA/SMK)	15
	Early Childhood (TK/PAUD)	2
	Not reported	4
Subject Domain	Science & STEM	33
	Social Sciences & Humanities	11
	Islamic Religious Education (PAI)	3
Inquiry Type	Guided Inquiry	27
	Problem-Based Inquiry	8
	Project-Based Inquiry	6
	Game-Based Inquiry	1
	Modeling-Based Inquiry	1
	Phenomenon-Based Inquiry	1
Technology	AI-based	18
	Non-AI	29
Intervention Duration	Very short (≤1 week)	3
	Short (2–4 weeks)	13
	Medium (5–8 weeks)	14
	Long (>2 months/semester)	4
	Not reported	13

The inclusion of the three PAI studies has important implications for contextual diversity and the external validity of the meta-analysis findings. First, studies from Indonesia strengthen the representation of Southeast Asia, which had previously been limited. Second, the integration of

PAI as a subject domain confirms that TE-IBL is not only effective in science and STEM, but also relevant for value- and spirituality-based learning. Third, the increasing number of non-AI studies indicates that technology integration in TE-IBL does not necessarily rely on artificial intelligence, but also involves the use of conventional digital media and learning management systems within inquiry-based learning contexts.

In terms of educational level, the distribution of studies shows the highest concentration at the upper secondary (SMA/MA/SMK) and lower secondary (SMP/MTs) levels, followed by higher education. The number of studies at the primary level remains limited, while early childhood education (PAUD) is rarely examined. This pattern suggests that TE-IBL is more frequently tested at secondary and tertiary levels, likely due to learners' readiness to use digital technology and their more developed abstract thinking skills. The scarcity of research at the early childhood level highlights opportunities for future studies that introduce digital literacy and inquiry skills from an early age.

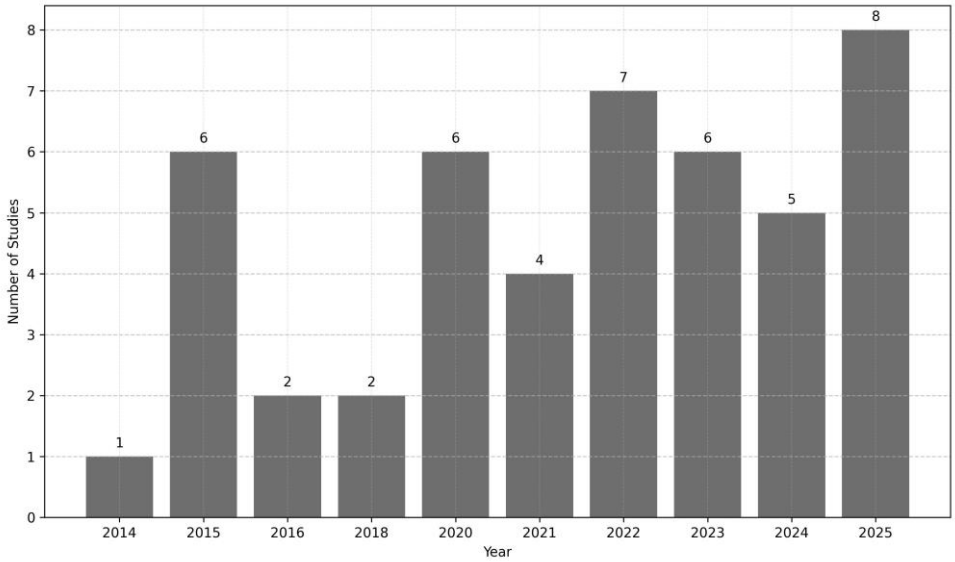
Figure 1. Distribution of Studies by Educational Level



(source: meta-analysis data processing results)

From a temporal perspective, the number of publications increased significantly after 2019, peaking during 2020–2022, and rising again in 2024–2025. Prior to 2016, research on TE-IBL was sporadic and limited. The post-2019 surge aligns with the acceleration of digital transformation in education triggered by the Covid-19 pandemic, which stimulated the exploration of innovative, technology- and inquiry-based learning models. This trend indicates growing global academic attention to TE-IBL, both in science education and in social sciences and humanities, including Islamic education (PAI), which has recently begun to be integrated into digital inquiry-based research.

Figure 2. Distribution of Studies by Year



(source: meta-analysis data processing results)

With respect to subject domains, most studies focus on science and STEM (33 studies), followed by social sciences and humanities (11 studies), with three additional studies in Islamic Religious Education (PAI). The dominance of science reflects the greater popularity of TE-IBL in experimental and laboratory-based learning contexts. This alignment is expected, as science emphasizes exploration and empirical verification, which are consistent with the core principles of inquiry. However, the inclusion of studies from social sciences, humanities, and PAI demonstrates that the effectiveness of TE-IBL also extends to reflective and value-based learning contexts. Findings from PAI studies, for example, indicate that inquiry training and innovative learning approaches can enhance critical thinking skills and academic achievement. Thus, TE-IBL shows clear cross-disciplinary potential and relevance for integrating cognitive, affective, and spiritual dimensions in modern education.

Regarding inquiry types, a consistent pattern emerges: guided inquiry is the most dominant approach (27 studies), followed by problem-based inquiry (8 studies) and project-based inquiry (6 studies). In contrast, phenomenon-based, modeling-based, and game-based inquiry appear in only one or two studies each. This suggests that TE-IBL practices in educational settings are still largely teacher-directed rather than fully student-controlled. This preference is likely influenced by pedagogical considerations, technological readiness, and contextual characteristics, particularly in developing countries. Nevertheless, there remains substantial potential to expand research on more innovative and student-centered inquiry models. In terms of technology, non-AI studies (29 studies) outnumber AI-based studies (18 studies), indicating that the integration of artificial intelligence into inquiry-based learning is still relatively new and unevenly distributed, although the trend is increasing alongside advances in learning analytics and intelligent tutoring systems.

Based on intervention duration, most studies were conducted over medium-term periods (5–8 weeks; 14 studies) and short-term periods (2–4 weeks; 13 studies), while long-term interventions (>2 months) were found in only four studies. This pattern suggests that TE-IBL experiments are generally implemented over limited timeframes to maintain variable control and logistical feasibility. Overall, these updated findings indicate that TE-IBL has evolved into a cross-disciplinary and cross-contextual approach, expanding from science into social sciences,

humanities, and Islamic education. The combination of digital technology, guided inquiry approaches, and value-based contexts reinforces the role of TE-IBL as an innovative learning model within a holistic digital education paradigm.

3.2. *Main Effect (Overall Effect Size)*

The meta-analysis of 47 studies, including three newly added studies in Islamic Religious Education (PAI), yielded a pooled effect size of $g = 0.92$ (SE = 0.268; 95% CI = 0.39–1.44; $p < 0.001$). This value represents a large effect according to Cohen's convention and indicates that Technology-Enhanced Inquiry-Based Learning (TE-IBL) has a strong and consistent impact on improving learning outcomes. The significant z-test ($z = 3.42$; $p < 0.001$) further confirms consistency across studies, while the heterogeneity statistic ($I^2 = 67.99\%$) indicates a moderate to high level of between-study variation. This variability is primarily attributable to differences in TE-IBL implementation contexts, such as educational level, disciplinary domain, and the type of technology employed.

The pooled effect size of 0.92 also reflects the positive contribution of the Islamic Education studies, which generally demonstrated high effects on critical thinking and academic achievement ($g = 0.88–1.15$). This finding strengthens the argument that TE-IBL is not only effective in science and STEM domains, but is also highly relevant for value-based and religiously reflective education. Overall, these results confirm that TE-IBL is an adaptive and impactful instructional approach across disciplines, including contemporary Islamic education contexts that emphasize the integration of critical reasoning and learning spirituality.

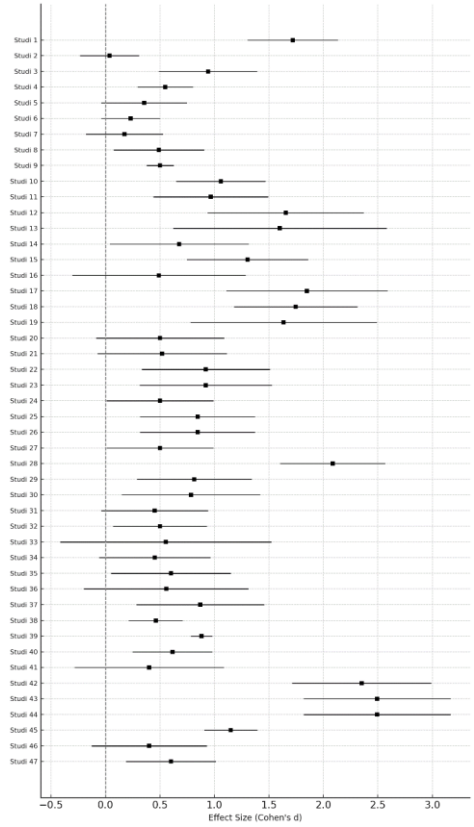
Table 2. Results of the Main Effect Meta-Analysis

Model	*k*	*g*	SE	95% CI	*z*	*p*-value	τ^2	I^2 (%)
Random effects (REML)	47	0.92	0.268	0.39–1.44	3.42	< 0.001	0.387	67.99

Note: k = number of studies; g = Hedges' g (standardized effect size); SE = standard error; CI = 95% confidence interval; z = z-test value; p = significance level; τ^2 = between-study variance; I^2 = proportion of total variance due to heterogeneity.

The forest plot visualization in Figure 3 illustrates the distribution of effect sizes across all 47 studies along with their respective confidence intervals. Nearly all studies show positive effects, although the magnitude varies across contexts. Several studies display relatively wide confidence intervals, indicating small sample sizes or differences in implementation contexts. Nevertheless, the overall accumulation of evidence consistently favors improved learning outcomes. This pattern supports the robustness of the pooled effect derived from the meta-analysis.

Figure 3. Overall Forest Plot of the Included Studies



(source: meta-analysis data processing results)

Although the main effect is statistically significant and large, the heterogeneity analysis reveals an I^2 value of 67.99%, which falls within the moderate to high range. This indicates that between-study variability is not solely due to sampling error, but also reflects differences in contextual characteristics, such as educational level, subject domain, type of technology used, and intervention duration.

Notably, the inclusion of studies in Islamic Religious Education (PAI) contributes positively by reinforcing the consistency of the effect direction, with high effect sizes observed for critical thinking and academic achievement outcomes. These findings demonstrate that Technology-Enhanced Inquiry-Based Learning (TE-IBL) is effective not only in science and STEM education, but also in value-based and religiously reflective learning contexts. Thus, despite the presence of substantial heterogeneity, the overall results confirm TE-IBL as an innovative, adaptive, and highly impactful instructional approach across disciplines. The observed variation across studies further highlights the importance of conducting more in-depth moderator analyses to more precisely map TE-IBL effectiveness across different educational contexts, including science, social sciences and humanities, and Islamic education.

3.3. *Subgroup Analysis (Moderator Analysis)*

The analysis by educational level shows that the effectiveness of Technology-Enhanced Inquiry-Based Learning (TE-IBL) varies across levels. The highest effect was found at the kindergarten/early childhood level (g = 2.49), indicating a very large impact, although this result is

based on only two studies. Higher education also demonstrated a strong effect (g = 0.96), while senior secondary (SMA/MA/SMK) and primary education showed relatively stable effects in the range of 0.77–0.83. In contrast, junior secondary education (SMP/MTs) exhibited a lower effect (g = 0.47), although it remained statistically significant. Variations in heterogeneity across subgroups suggest that students' cognitive developmental context is an important moderating factor.

Table 3. Subgroup Effects by Educational Level

Educational Level	k	g	95% CI	I^2 (%)
Kindergarten/Early Childhood	2	2.49	2.02–2.97	0.00
Higher Education	9	0.96	0.58–1.33	82.15
Senior Secondary (SMA/MA/SMK)	15	0.78	0.43–1.12	82.85
Primary School	6	0.83	−0.01–1.67	89.77
Junior Secondary (SMP/MTs)	11	0.47	0.27–0.66	65.42
Not reported	1	0.40	−0.29–1.09	0.00

When examined by subject domain, notable differences emerged among Science & STEM, Social Sciences and Humanities, and Islamic Religious Education (PAI). Studies in the social sciences and humanities showed the largest effect (g = 1.06), exceeding that of science and STEM (g = 0.87). Meanwhile, the three additional studies in PAI also demonstrated high effects, with g values ranging from 0.88 to 1.15, particularly for critical thinking and achievement outcomes.

These findings confirm that Technology-Enhanced Inquiry-Based Learning (TE-IBL) is not only effective in experimentally oriented disciplines such as science, but also exerts a significant impact in value-based and reflective education, including PAI. Guided inquiry approaches within Islamic education encourage learners to think critically, reflectively, and analytically about religious values, in line with the principles of *tafakkur*, *ta'aqqul*, and *tadabbur* in the Islamic tradition.

In science domains, although the effect size is slightly lower, it remains in the moderate to high range, indicating that TE-IBL is effective in strengthening conceptual understanding and scientific skills. Differences across domains suggest that TE-IBL has flexibility and adaptive potential across disciplines, both in empirical contexts (science) and normative-reflective contexts (PAI and social sciences and humanities), with important implications for the development of learning that integrates cognition and values.

Table 4. Subgroup Effects by Subject Area

Subject Area	k	g	95% CI	I^2 (%)
Science & STEM	33	0.87	0.34–1.41	70.26
Social Sciences and Humanities	11	1.06	0.45–1.66	68.36
PAI (Critical Thinking)	1	1.15	0.91–1.39	—
PAI (Achievement)	1	0.88	0.78–0.98	—
IBL (Guidance, global reference**)**	1	0.50	0.38–0.62	—

Based on inquiry type, the most prominent results were obtained from problem-based inquiry (g = 1.20), followed by guided inquiry (g = 0.79) and project-based inquiry (g = 0.72). Phenomenon-based, modeling-based, and game-based inquiry were each represented by only one study, yet all showed moderate positive effects. The high heterogeneity observed in guided inquiry (I^2 = 91.39%) indicates that although it is frequently used, outcomes are highly dependent on implementation context. In contrast, project-based inquiry showed low heterogeneity, indicating more consistent application. Thus, selecting an appropriate inquiry type is a crucial factor in maximizing impact.

Table 5. Subgroup Effects by Inquiry Type

Inquiry Type	k	g	95% CI	I^2 (%)
Problem-Based	8	1.20	0.68–1.72	77.99
Guided Inquiry	27	0.79	0.48–1.09	91.39

Project-Based	6	0.72	0.46–0.98	32.27
Phenomenon-Based	1	0.50	0.07–0.93	0.00
Modeling-Based	1	0.49	0.07–0.91	0.00
Game-Based	1	0.46	0.21–0.71	0.00

From a technological perspective, studies using non-AI technologies showed larger effects (g = 1.05) than those based on AI (g = 0.52). This finding suggests that the integration of AI into inquiry-based learning still faces challenges related to infrastructure readiness and user capacity. Nevertheless, the positive effects of AI remain significant and consistent, indicating promising potential. The difference may also reflect the limited and suboptimal contexts in which AI has so far been applied. Therefore, further research is needed to explore the broader potential of AI in inquiry-based learning.

Table 6. Subgroup Effects by Technology

Technology	k	g	95% CI	I^2 (%)
Non-AI	29	1.05	0.73–1.36	88.09
AI	18	0.52	0.31–0.74	78.41

Intervention duration also plays a crucial role in determining the effectiveness of Technology-Enhanced Inquiry-Based Learning (TE-IBL). Long interventions (>2 months) showed the highest effect (g = 1.37), followed by short interventions of 2–4 weeks (g = 1.11). Very short interventions (≤1 week) also produced a moderate effect (g = 0.88), whereas medium-duration interventions of 5–8 weeks were relatively lower (g = 0.69). Studies with unreported durations yielded the smallest effect (g = 0.36). These findings indicate that both short-term and long-term interventions have strong potential, while medium-duration interventions show more variable outcomes.

Table 7. Subgroup Effects by Intervention Duration

Intervention Duration	k	g	95% CI	I^2 (%)
Long (>2 months)	4	1.37	0.43–2.31	93.93
Short (2–4 weeks)	13	1.11	0.72–1.50	85.04
Very short (≤1 week)	3	0.88	0.04–1.72	90.42
Medium (5–8 weeks)	14	0.69	0.41–0.98	83.10
Not reported	13	0.36	−0.04–0.75	80.81

3.4. *Sensitivity Analysis and Publication Bias*

Sensitivity analysis was conducted to assess the extent to which the meta-analytic results are stable and not unduly driven by particular studies. Overall, the findings indicate that the pooled effect size remains significant even when tested using alternative analytical approaches. This suggests that the main conclusions regarding the effectiveness of Technology-Enhanced Inquiry-Based Learning (TE-IBL) are relatively consistent. In other words, despite variability across studies, the general conclusion about the positive effect of TE-IBL is preserved. This stability provides confidence that the main effect is not merely an artifact of one or two studies with large sample sizes.

Table 14. Results of Egger's Test for Publication Bias

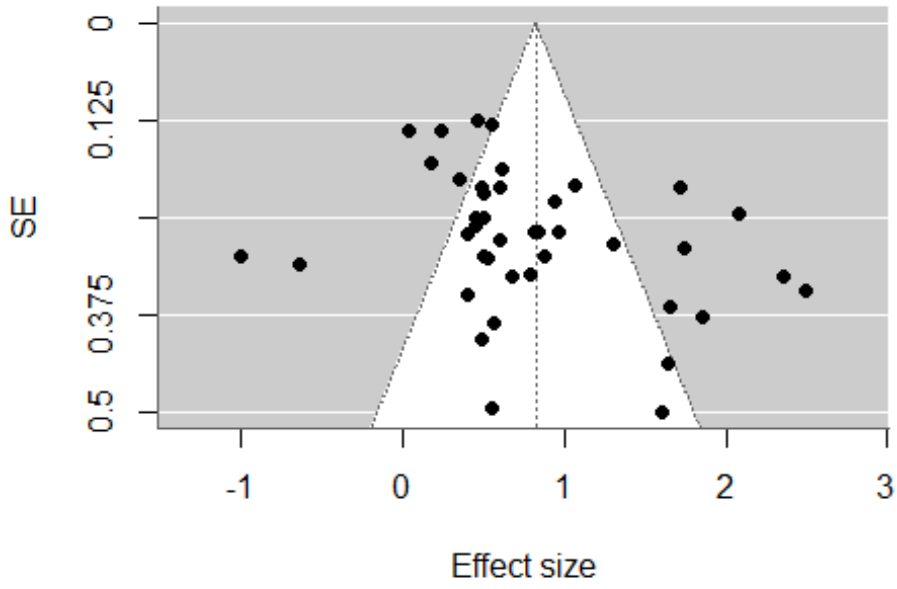
Test	z	p-value
Egger	2.3	0.021

Note: Egger's regression test is used to detect funnel plot asymmetry as an indication of publication bias; *z* = test statistic; *p* = significance level. A *p*-value < 0.05 indicates potential publication bias.

Egger's test yielded a *z* value of 2.3 with a *p*-value of 0.021, indicating a significant asymmetry in the distribution of studies. Such asymmetry is commonly interpreted as evidence of

potential publication bias, whereby studies with significant results are more likely to be published than those reporting null or negative findings. Consequently, the relatively large pooled effect may be slightly inflated due to limited access to studies with non-significant results. Nevertheless, the overall effect remains statistically significant and falls within the large-effect category. This indicates that publication bias does not fully negate the positive effects identified.

Figure 4. Funnel Plot of Study Distribution



(source: meta-analysis data processing)

The funnel plot visualization in Figure 4 shows a somewhat asymmetrical distribution of points, particularly in the lower left region of the plot. This pattern reinforces the results of Egger's test, suggesting possible imbalance in study representation. Studies with small sample sizes and negative effects appear to be underrepresented, whereas studies reporting positive effects are more dominant. However, the funnel shape still indicates that most studies cluster around the pooled mean effect. This suggests that although publication bias is present, it is not sufficient to eliminate the overall consistency in the direction of the effect.

Overall, these findings highlight the need for caution in interpreting the effectiveness of Technology-Enhanced Inquiry-Based Learning (TE-IBL). Although the main effect is strong and stable, indications of publication bias require researchers to consider limitations related to access to non-significant studies. Therefore, future systematic reviews should be more inclusive of unpublished studies and research reported in local languages. Such efforts would help reduce bias and yield more representative conclusions. In turn, policy recommendations and instructional practices based on this evidence would be more robust and empirically grounded.

4. Discussion

The results of this meta-analysis indicate that Technology-Enhanced Inquiry-Based Learning (TE-IBL) has a large effect size (g = 0.82), indicating a strong contribution to improving learning outcomes. This finding is consistent with the literature emphasizing that Inquiry-Based Learning (IBL) can improve academic achievement, critical thinking skills, and learning motivation, especially when accompanied by adequate teacher guidance (Abdi, 2014; De Jong et al., 2023; A. Lazonder & H., 2016).

In the context of Islamic Education, similar findings are reported by a meta-analysis of HOTS-based PAI showing a significant increase in children's critical thinking ability (Sari et al., 2025) and strengthened academic achievement across levels (Kaçar, Terzi, et al., 2021). The high effectiveness found in this study shows that technology integration can strengthen inquiry principles by providing broader access to information and enriching students' exploratory experiences (Samad & Arifin, 2024), while still aligning with the goals of Islamic pedagogy to cultivate reflective reasoning and the adab of thinking (Al-Attas, 1980; Shihab, 2007). However, heterogeneity of results across studies is also very high, so the implementation context becomes an important determining factor. Thus, although empirical evidence supports the effectiveness of this model, interpretation of the results must consider variations across educational levels, fields of study, and intervention designs, including the characteristics of the PAI curriculum.

Moderator analyses show that Problem-Based Learning (PBL) exhibits relatively larger effects than guided inquiry and project-based learning (PjBL). This finding indicates that PBL may be more effective in contexts that demand causal reasoning and higher-level problem solving, because this approach places students in learning situations based on real problems (Tawfik et al., 2020; Wijnia et al., 2024). In Islamic Education, a similar pattern appears in learning innovations that integrate contextual problem solving and value-based reasoning, which contribute to motivation, activity, and achievement (Jayanegara et al., 2024; Wantu et al., 2025). Meanwhile, guided inquiry still provides good results, but its effectiveness varies greatly depending on the quality of scaffolding provided by teachers (Hmelo-Silver et al., 2007; Pedaste et al., 2015); in PAI classrooms, the quality of this guidance is crucial to maintain coherence between intellectual exploration and the internalization of religious values (Ab Halim et al., 2025).

Variation in effectiveness is also evident in differences by educational level. The highest effect was found in early childhood education (PAUD) ($g = 2.49$), although the number of studies remains limited, so interpretation needs to be conducted cautiously. The large effect in PAUD can be explained through Piaget's theory of cognitive development, in which children at the preoperational stage are highly responsive to learning based on concrete exploration (Agustyaningrum et al., 2022). At the junior secondary school level (SMP), the effect is relatively lower ($g = 0.47$), which is likely related to a period of cognitive transition when students are not yet fully able to learn independently without intensive guidance (Vygotsky, 1991). In the context of PAI, studies emphasizing character strengthening and metacognition through structured inquiry activities also show positive results at early levels, with the important note that task design needs to align with value and religiosity goals (Sari et al., 2025; Wantu et al., 2025).

The effectiveness of TE-IBL also shows variation by field of study. The effect in the social-humanities cluster ($g = 1.06$) is relatively higher than in the STEM cluster ($g = 0.74$). This difference is likely due to the characteristics of learning in each field. In STEM, inquiry activities often involve laboratory-based experiments that require complex technological support and scientific instruments (Chen & C., 2021; Ješková et al., 2022). In contrast, inquiry learning in the social-humanities field emphasizes the exploration of ideas, argumentation, and critical reflection that can be facilitated more flexibly through collaborative platforms and text-based technologies (Levy & P., 2012; Marcone, 2022). In Islamic Education, expanding inquiry into the reflective-normative domain helps integrate critical reasoning with value meaning-making, thereby supporting cognitive achievement as well as strengthening attitudes (Jayanegara et al., 2024; Siregar et al., 2025). Therefore, the effectiveness of TE-IBL is contextual and adaptive, depending on the form of activities and the characteristics of the underlying disciplines.

From the technology aspect, non-AI studies show a larger effect ($g = 1.05$) than AI-based studies ($g = 0.52$). This difference reflects that conventional technologies such as e-learning, simulations, or

multimedia are already more established and consistent in curricula, while AI integration is still at an early stage (Al-Abdullatif & G., 2021; Consoli et al., 2024). In Islamic Education, AI shows potential to strengthen the cognitive and psychomotor domains, for example memorization of the al-Qur'an and worship practices, but requires caution in affective and ethical aspects, so the teacher's role as a spiritual-pedagogical guide remains central (Hakim & Anggraini, 2023; Priyanto et al., 2025; Sari et al., 2025). Nevertheless, lower heterogeneity in AI-based studies indicates the potential for future consistency as teacher readiness and infrastructure increase (Ifenthaler et al., 2024; Xia et al., 2022). The main challenge of AI implementation lies in issues of ethics, privacy, and algorithmic bias, so its adoption must be accompanied by clear regulation (Consoli et al., 2024; Kamalov et al., 2023).

Duration analyses show that long interventions (>2 months) produce the largest effect (g = 1.37), consistent with the literature on the importance of longer learning time for knowledge retention (Agustyaningrum et al., 2022; Liu & P., 2022). Short interventions of 2–4 weeks also show a significant effect (g = 1.11), likely because they are focused and intensive. In contrast, medium interventions (5–8 weeks) produce a lower effect (g = 0.69), perhaps because the period of student adaptation is not sufficient to produce long-term retention. In the context of PAI, combining planned inquiry cycles and technology-based formative assessment can help maintain learning continuity while integrating cognitive and value goals (Ab Halim et al., 2025; Siregar et al., 2025). The literature on the spacing effect emphasizes that regular distribution of learning time is more effective in reducing forgetting than overly dense but short interventions (Cepeda et al., 2006; Khalafi et al., 2024).

Although the main effect is significant and large, the high I^2 value (88.31%) indicates substantial variation across studies that cannot be explained only by random error. This variation reflects contextual and methodological differences, such as differences in educational level, field of study, intervention duration, and research design quality (Borenstein et al., 2009; Higgins & T., 2002). In addition, a significant Egger test result (p = 0.021) indicates potential publication bias, in which studies with positive results tend to be published more often (Bartolo et al., 2023; Van Aert et al., 2019). This condition suggests that the pooled effect size (g = 0.82) may be slightly inflated. Correction analyses such as trim-and-fill (Duval & T., 2000), PET-PEESE (Stanley & Doucouliagos, 2014), or robust variance estimation (Hedges et al., 2010) are recommended to ensure the stability of the findings. In PAI studies, transparency of procedures and reporting is also important to ensure traceability between inquiry design, technology integration, and value goals (Hasanah et al., 2025; Yunita & Mulyadi, 2024).

The findings of this meta-analysis have important practical and methodological implications for education in the digital era. Schools and teachers can implement TE-IBL by paying attention to the quality of scaffolding, process assessment, and the use of technology relevant to learners' needs. In Islamic Education, strengthening teacher competence to design inquiry tasks aligned with learning achievement and value internalization becomes a priority, including ethical AI literacy (Ab Halim et al., 2025; Sari et al., 2025; Siregar et al., 2025). Education policy needs to encourage teacher training and equitable digital infrastructure so that the effectiveness of this model is not limited to areas with high resources (Bartolo et al., 2023; Ghavifekr & R., 2015). From the methodological side, open science practices such as preregistration, data sharing, and replication analyses need to be strengthened to increase transparency and reduce publication bias. By strengthening scientific integrity and data openness, meta-analytic research in technology-based learning, including in the PAI context, will be better able to provide reliable evidence and contribute to the development of learning policies that are inclusive, sustainable, and aligned with Islamic values. Conceptually, this finding proposes a concise model: TE-IBL to modes of reading Islamic texts (guided inquiry) to negotiation of pedagogical/religious authority to strengthened religious literacy and ethical reasoning. This model links learning effectiveness with the formation of religious subjects and the governance of knowledge authority in religious

classrooms, thereby expanding the contribution of meta-analysis from merely learning gains to RS-grounded analysis of how technology and inquiry shape Islamic education practices.

5. Conclusion

The results of this meta-analysis confirm that Technology-Enhanced Inquiry-Based Learning (TE-IBL) has high effectiveness in improving student learning outcomes (g = 0.82). Technology integration is proven to strengthen inquiry principles through expanded access to information, active engagement, and deeper learning experiences. In the context of Islamic Education, this indicates that inquiry- and reflection-based approaches align with the principles of *tafakkur* and *ta'aqqul* in the Islamic scholarly tradition (Al-Attas, 1980; Shihab, 2007). Moderator analyses show that Problem-Based Learning (PBL) tends to be more effective than guided inquiry and project-based learning (PjBL), with the largest effects at the PAUD level and in the social-humanities cluster. Meanwhile, non-AI technologies show higher consistency than AI-based approaches, which still face challenges related to ethics and infrastructure readiness. Within the PAI framework, the TE-IBL model has the potential to develop critical thinking while also strengthening character formation and spirituality through the integration of Islamic values (Ab Halim et al., 2025; Jayanegara et al., 2024; Sari et al., 2025).

Practically, the results of this study recommend that teachers and educational institutions adopt TE-IBL by emphasizing the quality of scaffolding, pedagogical-technological training, and equitable digital access. PAI teachers need to integrate this approach wisely to balance cognitive, affective, and spiritual domains (Azman et al., 2025; Priyanto et al., 2025; Siregar et al., 2025). Limitations such as high heterogeneity and indications of publication bias indicate the need for further research with open designs and in-depth exploration of ethical and contextual AI integration. Thus, TE-IBL can become a learning strategy that is not only relevant to twenty-first-century education, but also aligned with the goals of Islamic Education to produce a generation that is knowledgeable, well-mannered, and globally competitive.

Declarations

Author contribution statement

Ai Deudeu Maria Dewi initiated the research topic, formulated the core research questions, and coordinated the overall manuscript preparation. Ajid Tohir contributed to the development of the theoretical framework and provided guidance on the research methodology. Asep Nursobah supported the data collection process and assisted in managing research implementation and logistics. Ratu Suntiah conducted the data analysis and contributed to the interpretation and synthesis of the research findings.

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Data availability statement

The datasets generated during and analyzed during the current study are available from the corresponding author upon reasonable request.

Declaration of Interest's statement

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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