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Research Article

CAPTURING RANDOM-EFFECT META-ANALYSIS TOWARD SCIENTIFIC INQUIRY LEARNING APPROACH IN SCIENCE EDUCATION

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Abstract
Implementing scientific inquiry as a learning approach has accounted for most discussion topics and research areas in science education. Numerous studies have been conducted for decades; therefore, synthesizing the updated results will be worthwhile. Diverse needs require effective implementation of the vision of scientific inquiry for scientists, and various forms of learning output pose a challenge for scholars to provide a systematic summary of evidence regarding its role in science teaching and learning. Therefore, the random effect model was suitable for this paper to capture the impact of scientific inquiry on science learning comprehensively. A meta-analysis study using a random-effects model was chosen to systematically synthesize 22 academic articles gathered from the Scopus and Web of Science indexing databases. An individual paper was first extracted for its sample size, mean, and corresponding standard deviation, which were then calculated to measure the effect size of each piece of evidence using the JASP program. In summary, we highlight the positive and moderate impact of scientific investigation on student learning outcomes as a promising approach to enhancing science learning. This study fills the gap in the previous literature by providing a cross-cultural systematic synthesis of Indonesian and non-Indonesian literature, as well as comprehensively measuring the effects of scientific inquiry interventions. These findings support scientific inquiry as a promising approach to learning and encourage the sustainability of efforts to enhance the quality of science learning in various educational contexts.

Keywords Learning Approach, Meta-Analysis, Random Effect, Science Education, Scientific Inquiry

INTRODUCTION

Practicing scientific inquiry as a learning approach has made many contributions within the educational field, particularly in attaining science learning. The scientific inquiry approach is an axis of innovative learning centering students like scientists. Students can learn from their closest interaction with the physical environment and life phenomena (Ariyatun et al., 2024). Then, a critical climate to propose argumentative skills is also developed through scientific inquiry based on students' observations of their circumstances. Eventually, students are educated to recognize that they need to develop and disseminate science for their living and to build constructive ideas that can be promoted to empower society (Pedaste et al., 2015).

Admittedly, scientific inquiry is rooted in the breadth of the constructivism stream. It starts from the paradigm that the existence of humanity presents to actively construct knowledge from the action of their thinking skill gradually. One may look back over the history of this theoretical stance being first announced. The learning process is unceasingly emphasized within the lens of constructivist learning. Each student or learner is offered to explore their self-thinking and build their self-experience throughout education (Slavin, 1995). The constructivist learning model is revealed from the establishment of the learning theory proposed by Jean Piaget (1896-1980) regarding the transformative idea and the learning development, Lev Vygotsky (1896-1934) about learning development coupled with social competence, and inevitably, John Dewey (1859-1952) that spots the real-world experience taught for the student learning (Bhattacharjee, 2015). Utilizing the concept of constructivism, everyone can be considered an active self-learner who develops their learning and thinking process toward the environment in which they interact. As discussed, this vision can be construed within science education as an approach to scientific inquiry. Science learners can develop their scientific skills and build science knowledge throughout the process to explore our understanding of how the universe works and evolves.

The climate of the constructivism paradigm must provoke science educators to operationalize scientific inquiry as a pedagogical approach (Kusuma et al., 2024). In this stance, students are considered active learners in science classrooms. Essentially, they can interact as a researcher-like actor during the learning process (Antonio & Prudente, 2023; Rachmanto, & Akande, 2024). Therefore, curiosity and systematic methods to conduct empirical study are the heart of scientific inquiry learning(Herianto & Wilujeng, 2020). Teachers can deliver scientific inquiry using several procedures or steps (Mcconney et al., 2014; Summerlee, 2018). Students' scientific inquiry skills can be stimulated by implementing seven aspects consecutively (Sutaphan & Yuenyong, 2019; Habibi, Jiyane, & Özşen, 2024). They should require identifying scientific problems, proposing solutions, extracting knowledge, making judgments, developing learning products/prototypes, testing and evaluating the product, and presenting the discovered results. Nonetheless, this suggestion can be internalized as different practices if scientific inquiry is implemented for different levels of education. Adjusting it to each level of students' cognitive development during specific grades should ensure better scientific inquiry learning. Hence, various levels of scientific inquiry can drive the unique process, and the center of scientific inquiry must remember that science educators want science to be communicated contextually and fascinatingly for all students.

Within the literature, the approach of scientific inquiry has been invented as one of the influential factors for effective science teaching and learning in improving students' performance during the science lesson (Abdi, 2014; Cairns, 2019; Wang & Guo, 2021; Chou et al., 2022; Toma, 2022; Endra, & Villaflor, 2024; Halimah et al., 2024). The scientific inquiry approach had an influence on the development of social behavior and responsible character in students(Astalini et al., 2024). Additionally, some scholars have examined its positive association with students' scientific literacy competence (Aulia et al., 2018; Babaci-Wilhite, 2017; Kang, 2020; Takda et al., 2022). Pedaste et al. (2015) argued that inquiry for education departs the students to recognize themselves as researchers who can discover the scientific knowledge due to their curiosity to understand the universe. An example from biology education is that science teachers can facilitate students to actively comprehend contextual knowledge by including daily activities (Firman et al., 2019). The scientific inquiry approach has become the basis for developing science learning which prioritizes improving students' science process skills (Susongko, 2021; Wirayuda, 2023; Nehru et al., 2024; Yusnidar et al., 2024).

Furthermore, the scientific inquiry approach is hypothesized if this learning can be implemented to boost the focus of critical thinking and, inevitably, the science process skill. (J. Wang et al., 2015) notice that experiment-based learning through the scientific inquiry approach outperforms the conventional method to effectively produce an improved performance in students' learning in terms of science process skill, comprehensive skill, learning attitude, communication skill, and reflective knowledge. An integrated module of science learning using the lens of authentic learning has also been developed (Hairida, 2016). In line with Wang et al., (2015) states that scientific inquiry is a potential factor to influence the learning process that promotes the role of critical thinking and students' performance in inquiry-based activity. In primary education, (Ergul et al., 2011) have investigated the influence of science learning through inquiry activity on students' science process skill and scientific attitudes. Their results also demonstrate the projected results with the former literatures. (Ergul et al., 2011) conclude that their intervention drives substantial factor to the students' learning outcomes. In summary, former works have widely documented scientific inquiry as a prospective learning approach in promoting the diverse form of learning outcome on science education (e.g., students' achievement, science process skill, scientific literacy, and attitudinal attribute).

As introduced in the former section, scientific inquiry has been examined in several research agendas for its potential impact on science education (Ergul et al., 2011; Hairida, 2016). Instead of students' performance or achievement, science education scholars have measured various learning outcomes of science teaching and learning. They are critical thinking, scientific literacy, and science process skills. Those variables are well-known measures within discipline-based educational research (DBER) scholars and can be interpreted across interdisciplinary contexts (Santoso et al., 2022). Meanwhile, many research works demonstrate that scientific inquiry has been effectively implemented to enhance those variables in science education. An intervention designed by (Wang et al., 2015) has been evident that studying science through the didactic approach of scientific inquiry can bring the students more immersed in the circumstance to promote a significant impact on their process skill, comprehensive skill, attitude toward science, social and reflection skill. This evidence helps Hairida (2016) develop learning material designed as an integrated module for scientific inquiry. After pilot-testing the curricular material, she demonstrates that scientific inquiry can be quickly introduced to the students when clear guidance has been explained.

Students are more immersed in the classroom; thus, the effectiveness of the intervention can be upgraded. Hairida, (2016) focuses on the empirical investigation of students' critical thinking and inquiry skills performed by students. Eventually, Ergul et al., (2011) added the former findings with the study administered at the primary education level. They aim to investigate the role of scientific inquiry toward science process skills and attitudinal factors endorsed by primary school students (Olufunminiyi Akinbobola et al., 2022; Spires et al., 2022; Jarnawi et al., 2024; Lisao et al., 2024; Laksono et al., 2025) This paper recognizes those diverse learning outcomes as potential impacts of scientific inquiry on science education. It will be described further beneath that the collected literatures reviewed and summarized in this meta-analysis focuses their investigation under the focus of those learning outcomes.

Even though the aforementioned scientific reports have been presented to advise the scientific inquiry approach for science education, the research circumstance must underpin other multilevel factors. It can be driven by the diverse level of education or the research context, e.g., publications established by domestic and overseas authors, including empirical studies administered in primary, secondary, and higher education. After that, it presents the convoluted challenge for science education researchers to evaluate the former discoveries more extensively. Meta-analysis is a popular tool for summarizing, aggregating, and interpreting quantitative empirical research studies (Kulik & Kulik, 1989; Hedges, 1992). This method can be suggested to summarize the extracted information concerning the existing literature previously discussed. One sort of meta-analysis model, the random-effect model, must be acknowledged if we assume that the impact of specific investigated variables is underpinned by such multidimensional factors as endorsed by the nature of scientific inquiry. As described earlier, scientific inquiry can be construed by the diverse forms of students' learning and manifested in various contexts of learning circumstances. An unanswered evaluation to address this limitation is still present, and this study is worth considering as a novel attempt.

In this paper, twenty-two Asian and non-Asian empirical studies have been determined as our dataset to systematically review and synthesize the summary effect of the scientific inquiry approach on science education with random effect meta-analysis. Furthermore, we broaden the scope of the analysis to explore publication bias and its impact on various learning outcomes in science education practices. To address those intentions, the following research questions are addressed: 1) Based on the existing literature, is there a substantial effect of scientific inquiry against science education?; 2) What impact does publication bias have on this meta-analysis's effect sizes?

For decades, scientific inquiry has been proposed as an innovative approach to science education. In the present study, we review the existing literature demonstrating to what degree this approach can still be encouraged for effective science teaching and learning. The findings revealed by this paper can then be an input for further researchers to develop and disseminate this approach extensively. Moreover, despite the relatively mature approach within the century of our knowledge development, we cannot neglect if scientific inquiry is one of the milestones achieved by educational scholars within the lens of the constructivist paradigm.

RESEARCH METHOD

This paper aims to extract our general understanding regarding the effect of the scientific inquiry approach on science education. Quantitative research was categorical in this paper using post hoc studies. The data gathered for the study was analyzed using the meta-analysis method. According to Retnawati et al., (2018), effect size is a common form that statistical data from several studies must be converted into. Effect sizes were extracted from each study based on the participant title, sample size (presence of traditional and inquiry science education), quantitative data (r, t, F, and X2 statistics), p values, or mean and standard deviation. The computations make use of both fixed effects and random effects models. However, in the social sciences, random effects models are recommended (Cumming, 2013). We used Q and I2 statistics to assess the heterogeneity of the impact sizes. The meta-analytic process was carried out once more on the moderator subgroup in cases where these statistics showed a lack of homogeneity. Thus, the impact size classification system created by Cohen, (1992) was applied in this investigation. Classification coefficients help interpret effect estimates in meta-analyses. According to this classification, an effect size is considered minor if it falls between 0.20 and 0.50. It is referred to as a medium effect size if it falls between 0.50 and 0.80 and a large effect size if it exceeds 0.80. Microsoft Excel was used in this work to calculate effect size and ultimate effect; JASP 0.16 was used for random effect estimates, funnel plots, and publication bias. The effect was estimated using a measure of effect size calculated based on research results (mean, sample size, and standard deviation) reported by the research papers in this study. The inclusion criteria for eligible research papers that would be selected as our dataset should consider the following requirements.

1. Publication year. Research papers published between 2004 and 2022 were selected in our dataset of meta-analysis of this study.
2. Indexing database. Merely published articles that Scopus and Web of Science database indexed.
3. Subgroup data. Various learning outcomes and educational environments from various educational levels were included as subgroup data. Scholars from Asia and non-Asian countries authored this data.
4. Keyword used. In the literature search process, we maintained several keywords; thus, readers could re-check our dataset for the further challenge of replicability. Our keywords comprised "inquiry learning" AND "scientific inquiry" AND "science achievement" OR "scientific literacy" OR "inquiry ability measurement" AND "science education" AND "preschool" OR "secondary school" OR "elementary school level" OR "higher education."

Following data collection based on relevant selection criteria, data was tabulated based on the author's name, year of writing, subgroup level, and quantitative data findings. The data selection procedure was then carried out, as illustrated in Figure 1.

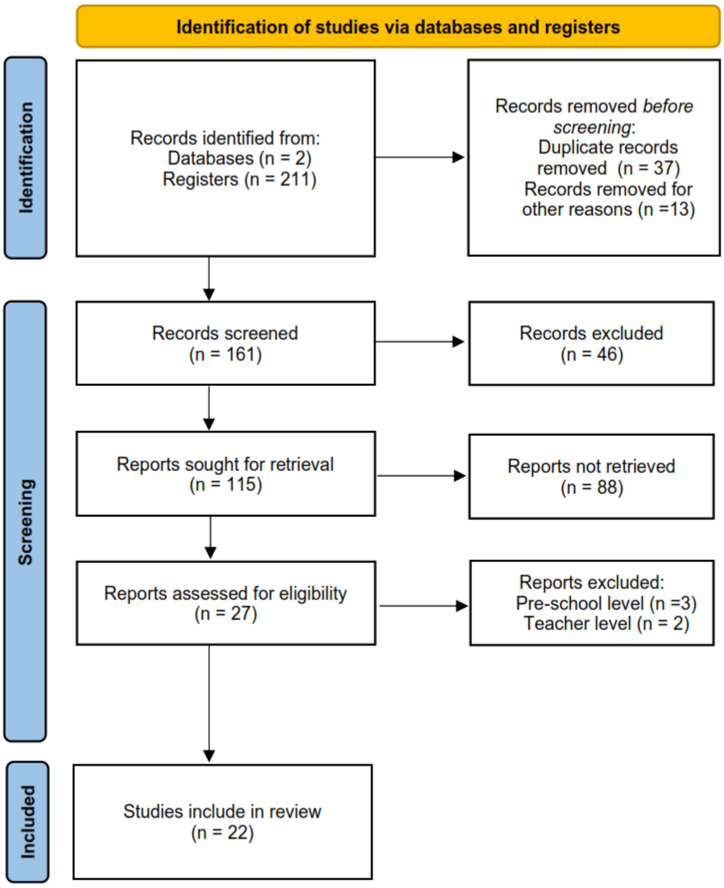

Figure 1. PRISMA to select research studies

RESULTS AND DISCUSSION

After filtering reference lists from two database sources—Scopus and Web of Science—based on specific criteria, 211 research studies were found through the search. After deleting references for various reasons, 37 were eliminated for duplicate data, leaving 161 data points after duplication was removed. Forty-six studies were eliminated after duplicates were eliminated, and 115 studies underwent full-text screening. Eighty-eight of these were omitted. Twenty-seven studies fulfilled the requirements for the measurement effect calculation component; however, five studies were excluded from the feasibility study because they were deemed not to meet the components (teacher and preschool level). Consequently, they were disqualified from the feasibility study, leaving the 22 remaining studies to complete the measurement effect calculation, compute effect sizes, and determine conclusion effects. Studies that meet the criteria for meta-analysis are listed in Table 1, along with an overview of their estimated impacts.

Table 1. Studies included in the review

Studies Reported	Author	Education level	Continent Level	N	X	SD	SE	ES
1	(Effendi-Hasibuan et al., 2019)	SHS	Asian	99	26,7	8,1	0,814	26,7
2	(Arief & Utari, 2015)	JHS	Asian	35	50,88	4,04	0,683	50,88
3	(van der Graaf et al., 2019)	JHS	non-Asian	301	48,3	24,2	1,395	48,3
4	(Fu-Pei Hsieh, 2017)	SHS	Asian	230	41,3	1,94	0,128	41,3
5	(Wenning, 2007)	SHS	non-Asian	425	23,7	24,62	1,194	23,7
6	(Lou et al., 2015)	JHS	non-Asian	630	17,02	6,03	0,240	17,02
7	(Ješková et al., 2021)	SHS	non-Asian	6675	30,62	18,59	0,228	30,62
8	(van Schijndel et al., 2018)	EleS	non-Asian	139	19,387	4,832	0,410	19,387
9	(van Schijndel et al., 2018)	EleS	non-Asian	139	17,332	5,641	0,478	17,332
10	(Huang, 2022)	Univ	non-Asian	773	39,1	6,5	0,234	39,1
11	(Kolovou & Kim, 2020)	JHS	non-Asian	42	35,57	36,06	5,564	35,57
12	(Schmid & Bogner, 2015)	JHS	non-Asian	126	23,6	7,21	0,642	23,6
13	(Arnold et al., 2021)	JHS	non-Asian	64	44,2	8,3	1,038	44,2
14	(Ganajová et al., 2021)	JHS	non-Asian	198	66,47	12,68	0,901	66,47
15	(J. Wang et al., 2015)	Univ	Asian	27	15,63	7,632	1,469	15,63
16	(Seeratan et al., 2020)	JHS	non-Asian	754	11,59	4,16	0,151	11,59
17	(Cairns, 2019)	JHS	Asian	514119	20,3	9,1	0,013	20,3
18	(Van Katwijk et al., 2021)	Univ	non-Asian	236	46	8,5	0,553	46
19	(Parmin et al., 2016)	Univ	Asian	36	23,812	8,328	1,388	23,812
20	(Connolly et al., 2022)	Univ	non-Asian	33	81	3,9	0,679	81
21	(Korkman & Metin, 2021)	SHS	Asian	128	22,59	6,116	0,541	22,59
22	(Katrancı & Şengül, 2020)	SMA	Asian	217	35,5	6,9	0,468	35,5

Eight papers from Asian countries and fourteen from non-Asian countries comprised the 22 that met the meta-analysis requirements. Eight Asian studies were conducted in the United Arab Emirates, China, Taiwan, Indonesia, and Turkey. The eight non-Asiatic research nations were the Netherlands, America, Slovakia, the Greek Islands, Germany, Israel, Ghana, and Ireland. In this investigation, sample sizes ranging from 27 to 514119 were used. Numerous studies have been founded on methods and findings from scientific studies published in prestigious international journals. The chosen study year's range of criteria is from 2007 to 2022.

Table 2. displays the findings of a meta-analysis of the availability of scientific capabilities based on a scientific method of inquiry using a random effect model. This meta-analysis revealed that the use of scientific inquiry approaches has a significant impact on the availability of scientific capabilities, as reflected in the measures of the effects produced and the confidence intervals calculated.

Table 2. Results analysis meta-model random effect

Model Type	N	Z	Q	Estimates	Standard Error	p	95% Confidence Interval	
							Lower	Upper
Random Effect Model	22	9.0039	55332.7346	33.6543	3.7378	<.001	26.3284	40.9802

Homogeneity tests are used in meta-analyses to determine effect measurements. A homogeneous effect scale impacts the application of a fixed effect model; however, a random effect model may be appropriate in cases where the effect measurement is heterogeneous (Ellis, 2010). In order to test the zero hypothesis which states that every study in the meta-analysis has the same impact—the homogeneity test is carried out by examining the statistical findings of the Q test (Borenstein et al., 2009, 2013). The Zero Hypothesis is accepted on a Q test result if the value is insignificant with p>0,05 (at a 95% confidence gap), indicating that the effect is measured heterogeneously. Conversely, if the test statistics of Q are significant with p<0.05 (at the 95% confidence interval), the impact size is homogenous. Table 2 indicates a homogeneous effect with a statistical Q value of 55332.7346 and p < 0.001, supporting using a random effect model with a standard error of 3.7378.

The meta-analysis provided a positive study result, with a significant effect estimate of 33.6543, a lower limit of 26.3284, and an upper limit of 40.9802; the forest plot in Figure 2 highlights this issue by illustrating that 22 studies are on the right side of the aggregate line.

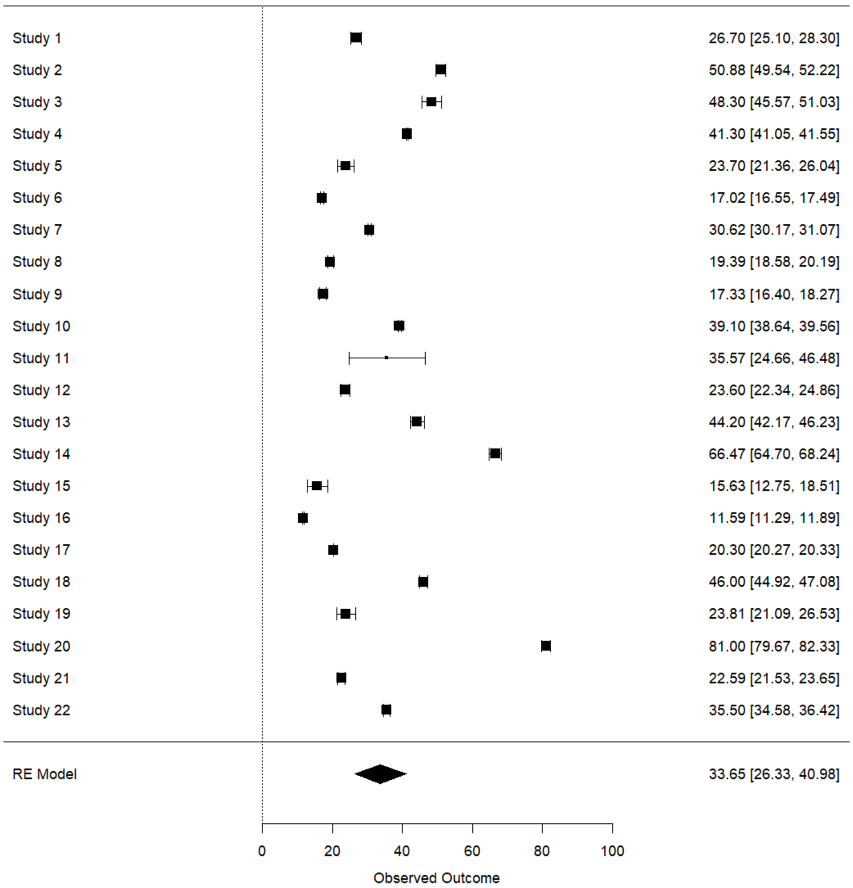

Figure 2. Forest Plot

The effect size of 33.6543 in this meta-analysis was calculated based on the pooling of effect measures from 22 studies analyzed using a random effects model, which takes into account the inter-study variation (heterogeneity) measured through a significant Q value (55332.7346, p < 0.001). This measure of effect reflects the magnitude of the impact of the scientific inquiry approach on the availability of students' scientific abilities. The estimate of 33.6543 is considered substantial because it is well above the zero value, with a narrow 95% confidence interval (26.3284 to 40.9802), suggesting that the effect is significant and consistent across the studies analyzed. This indicates that the use of scientific inquiry methods has a positive and strong effect on science learning, as depicted in the Forest Plot where the entire study is located on the right side of the aggregate line, reinforcing the conclusion that the impact is positive overall.

The majority of studies with positive statistical significance and statistics report publication bias. Studies have employed File-Safe N Orwin to regulate the impact of publication bias on the plot effect size. A plot funnel is a graph used to measure bias in publications. This displays the magnitude of the effect on the X-axis and the standard error of the study on the Y-axis. Studies towards the effect size line and at the top of the cork showed more minor error standards (Dinçer, 2020) because the variance in studies with lower sampling rates is higher than the predicted effect size.

A funnel plot against 22 studies included in the meta-analysis is depicted in Figure 3, with the majority of standard study errors indicating relatively small results, as indicated by the accumulation of plot pins near the effect size and at the top of the cork. The study's scattering, which gathers at the upper portion of the cork and is close to the effect size line, further suggests that the study forms a symmetrical plot.

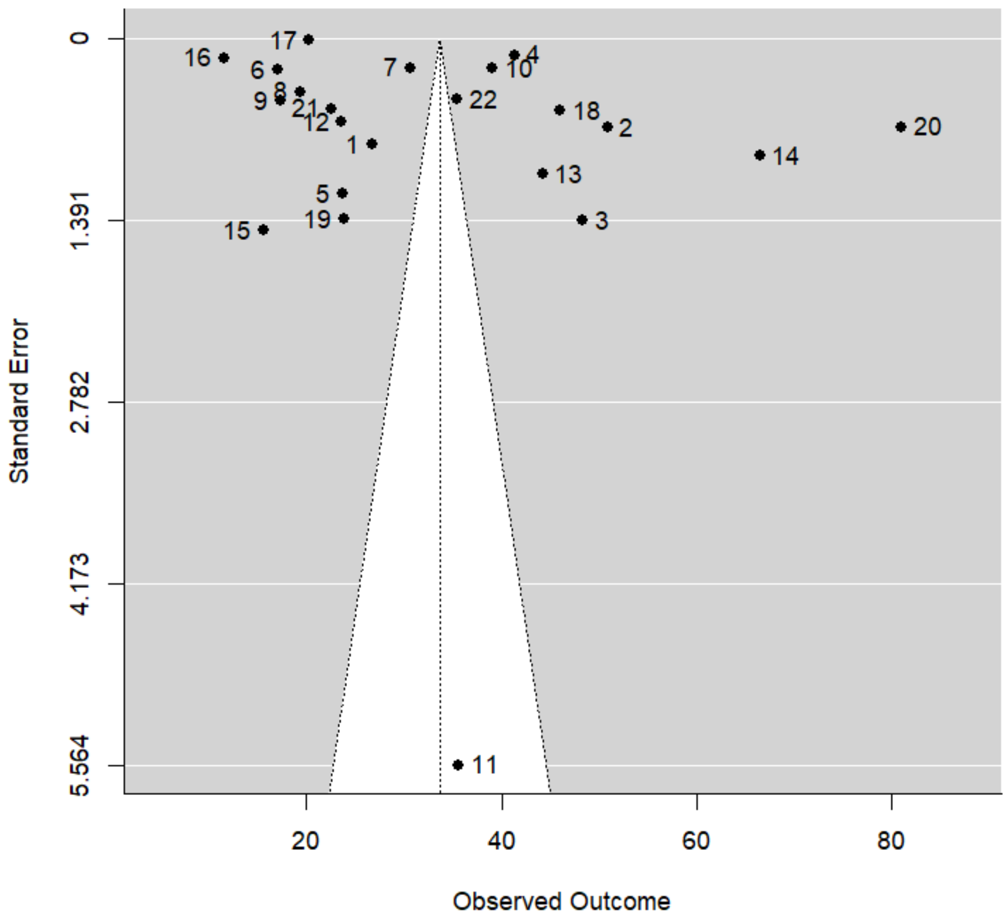

Figure 3. Funnel Plot

Information about the rank correlation test for funnel plot asymmetry is provided in Table 3. Kendall's T column illustrates the strength of the correlation between effect size and variance (Thalheimer & Cook, 2002). The p-value is contrasted with the 0.05 α value to evaluate the causal relationship between the two. We must reject the asymmetric funnel plot or the null hypothesis (funnel plot symmetry) if the p-value is less than α = 0.05. In contrast, we are inclined to concede a null hypothesis or non-indicated publication bias if p-value ≥ α = 0.05.

Table 3. Kendall's Test Result

	Kendall's τ	p
Rank test	0.00130	0.9556

Examining the Eiger test results in Table 4 is yet another approach to getting biased publication data. Table 4 of the Eiger test results provided a p-value of 0.7586, which equated to a p-valued value of ≥ α = 0.05. This signifies that the null hypothesis is accepted and the conclusion has no publication bias.

Table 4. Eiger test result

Regression test for Funnel plot asymmetry ("Egger's test")		
	z	p
Sei	0.3124	0.7586

Plenty of studies have revealed that scientific inquiry approaches affect students' access to scientific literacy skills (Babaci-Wilhite, 2017; Aulia et al., 2018; Chun et al., 2018; Kang, 2020; Takda et al., 2022) as well as their access to science skills (Abdi, 2014; Cairns, 2019; H. H. Wang et al., 2019; Chou et al., 2022; Toma, 2022). By engaging students to view themselves as researchers who can rediscover lessons and define activities in everyday life, such as biology, inquiry-based education helps students feel more empowered (Firman et al., 2019). According to research by Wang et al., (2015), students' scientific query skills were more effectively developed by inquiry-based learning models than by traditional methods, with significant improvements in process skills performance, comprehensive skills, learning attitudes, communication skills, and reflective skills. It has also been determined that inquiry learning enhances students' critical thinking and query-accessing abilities when combined with authentic assessment within an IPA module. (Ergul et al., 2011; Hairida, 2016) studied the effects of inquiry-based science learning on students' attitudes toward science and science process skills in elementary school students. They concluded that inquiry-based science learning significantly affects these attributes.

The findings of 22 research studies from Asian and non-Asian continents that were chosen according to predetermined standards and underwent several phases of meta-analysis reveal that applying scientific inquiry techniques improves access to scientific capabilities. Information from forest plot observations supported this, indicating a significant impact estimate of 33,6543 with a lower limit of 26,3284 and an upper limit of 40,9802, indicating that research demonstrating scientific inquiry approaches had a noteworthy positive influence on science capabilities accessibility. Based on Table 2's computations, which revealed a statistic Q value of 55332.7346 and p < 0.001, indicating a homogeneous effect, the analysis's results also included a model of random effects. The measurements of 33.6543, the standard error of 3.7378 (relatively small because less than 5%), the Z value of 9.0039 with a value of p< 0.001 (significant at the confidence interval of 99%), and the lower and upper limits of measures of effects on the real side of 5% are 26.3284 and 40.9802, respectively, were also obtained based on the measurements of effects in Table 2. The zero hypothesis is rejected when Z >1.96 and p<0.05 are noted, indicating that investigating how scientific methods are used in the inquiry affects students' access to science skills in science classes. The results of the Eiger test (Table 4) and Kendall test (Table 3) that display p-value values ≥ α = 0.05 provide information about publication bias and allow the null hypothesis to be accepted while yielding conclusions not supported by publication biases.

In this meta-analysis, regional differences in effectiveness and significance related to scientific inquiry approaches also emerged as important findings. Studies from Asia showed more significant results compared to studies from non-Asian regions, especially in terms of improving students' science process skills and accessibility of scientific abilities. This can be due to differences in curricula and educational approaches in different countries, where Asian countries are more likely to implement structured and systematic learning strategies, including a scientific inquiry approach to science learning. On the other hand, studies from non-Asian regions have also shown positive impacts, but in some cases, the effects are more moderate. Factors such as cultural background, educational resources, and the implementation of different science education policies in each region contribute to this variation in effectiveness. These findings confirm that while scientific inquiry approaches are generally effective in improving the accessibility of science capabilities, regional contexts play an important role in determining their level of effectiveness, so it is important to consider curriculum adaptations that suit local needs and characteristics.

The meta-analysis results show strong evidence that the scientific inquiry approach significantly improves students' access to science abilities. An estimated overall effect size of 33.6543, with a 95% confidence interval ranging from 26.3284 to 40.9802, indicates a substantial positive impact of inquiry-based learning methods on students' science skills. These positive results are consistent across the studies included in the analysis, suggesting that this approach is effective in a variety of educational settings and among diverse demographics of students. The observed homogeneous effects, as shown by the Q and p-value statistics, support the reliability of the findings and justify the use of a random effects model to account for potential variability between studies.

Further examination of the geographical distribution of these studies reveals interesting insights. Both Asian and non-Asian contexts benefit from a scientific inquiry approach, albeit with some variation. Studies that included Asian countries, such as the United Arab Emirates, China, Taiwan, Indonesia, and Turkey, as well as non-Asian countries such as the Netherlands, America, Slovakia, Greece, Germany, Israel, Ghana, and Ireland, demonstrated the global applicability of this educational method. Positive impacts across different cultural and educational systems underscore the universal value of inquiry-based learning in promoting science literacy and skills (Greenleaf et al., 2018; Fitzgerald et al., 2019)

Including Indonesian and non-Indonesian studies in this meta-analysis is crucial because it provides a broader and holistic understanding of the effectiveness of scientific inquiry approaches in different global contexts (Shadiqi et al., 2019; Ariyatun et al., 2023). The study from Indonesia, which reflects the educational background in developing countries with unique resource and accessibility challenges, provides valuable insights into how inquiry approaches can be adapted to address these limitations. The results of research in Indonesia show that the scientific inquiry approach can significantly improve science literacy skills and student engagement, especially in an environment with limited laboratory facilities and educational resources (Scogin & Stuessy, 2015).

In contrast, studies from non-Indonesian countries, particularly from developed countries, offer a different perspective, where educational infrastructure is more established and inquiry approaches are often supported by more advanced technology and greater resources (Effendi-Hasibuan et al., 2019). By combining studies from these two contexts, this analysis is able to identify more general patterns of effectiveness while also appreciating existing regional variations. It also helps to understand how the scientific inquiry approach can be applied at different levels of economics and education, which is particularly relevant for promoting inclusive and equitable science education globally (Wilson et al., 2010). Thus, including studies from Indonesia and non-Indonesia not only enriches the external validity of these findings but also offers a more comprehensive roadmap for educators and policymakers in different countries to adopt scientific inquiry methods in science learning.

The overall results are positive, but some limitations must be acknowledged. There are a few limitations to this study compared to the numerous meta-analyses that have been carried out in the past: (1) studies that used a scientific research approach to limit the field of study in science education, meaning that study information from other fields is not included; (2) the number of studies that are worth conducting meta-analysis calculations after the selection and selection have access restrictions in the scope of the study with several relevant studies are still minimal; it is preferable to select on studies with a tremendous amount of coverage; and (3) this research restricts the use of scientific inquiry approaches on the accessibility of science capabilities, which is a global focus of accessibility in science learning. The scope of studies is limited to the field of science education, excluding relevant studies from other disciplines. In addition, the relatively small number of studies that met the rigorous criteria for inclusion in the meta-analysis suggests that broader research is needed to strengthen the evidence base. Limitations on studies that use scientific inquiry approaches also mean that other effective teaching methods are not considered, which could provide a more comprehensive understanding of how different teaching strategies impact science education outcomes. The results of this study's meta-analysis generally suggest that the scientific method of inquiry directly influences learning outcomes by providing access to science skills. It explains how educators at all levels primary, middle, and higher are strongly urged to use a scientific approach to science instruction because Asian and Non-Asian studies have demonstrated its beneficial effects.

CONCLUSION

The studies that comprise our dataset for a systematic review and synthesis of the scientific inquiry approach's summary impact on science education have yielded positive results from random effect meta-analysis. Additionally, we expand the analysis's scope to investigate publication bias and its effects on different kinds of learning outcomes in science education practices. Based on the literature review of a respectable international journal that has been examined, the meta-analysis of 22 carefully chosen and chosen studies offered information on random effect modeling that demonstrated favorable summary affect access to the right. The acquisition of a symmetrical plot funnel with a standard description of the study error approaching the upper corner with a spread that is close to the line of access to science capabilities further demonstrated that the bias of publication in the studied studies did not indicate bias from Kendall’s and Eiger’s tests, as per the results of the meta-analysis. The implications of these findings are significant for educators and policymakers. The demonstrated effectiveness of the scientific inquiry approach in improving science skills shows that educators at all levels should consider integrating inquiry-based learning into teaching practice. Consistent positive impacts observed across different levels of education and geographic regions highlight the potential for inquiry-based learning to foster critical thinking, problem-solving skills, and a deeper understanding of scientific concepts. Therefore, this research supports wider adoption and support for inquiry-based science education to improve student learning outcomes globally.

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AUTHOR CONTRIBUTIONS

Mobinta Kusuma and Purwoko Haryadi Santoso conceived the study. Heri Retnawati contributed to the conception and design of the study. Mobinta Kusuma organized the dataset and performed the meta-analysis. Insih Wilujeng, Purwo Susongko, and Chokchai Yuenyong supervised and overviewed the data collection, validation, analysis, and interpretation. Purwoko Haryadi Santoso wrote the drafting of the manuscript. Ariyatun Editing or reviewing, supervision. All authors contributed to the revision, reading, and approval of the final version of the manuscript.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

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