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Effectiveness of Inquiry-based Learning (IbL) on Improving Students' Conceptual Understanding in Science and Mathematics: A Meta-Analysis

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Abstract

This meta-analysis evaluated the effectiveness of inquiry-based learning (IBL) on improving students' conceptual understanding in science and mathematics. The study systematically reviewed 12 empirical studies with 14 effect sizes involving 786 students across various countries, educational levels, and disciplines. These studies were selected using the PRISMA (2020) guidelines and the developed inclusion and exclusion criteria based on publication years (2014–2024), levels of IBL employed, and measures of students' conceptual understanding in science and mathematics. The results showed that IBL had a significant positive effect size (g = 0.913) on improving students' conceptual understanding, particularly in senior high school (g=1.176) and mathematics (g=1.191). Open inquiry had the greatest effect size (g=1.530), emphasizing the importance of student autonomy in learning. The findings support the broader implementation of IBL in educational curricula and teachers' training programs to foster a more student-centered learning environment that encourages inquiry, critical thinking, and deeper conceptual understanding in science and mathematics, which are essential for success in the 21st century. Recommendations include customizing IBL to students' needs and further research on diverse IBL strategies and their impact on student outcomes.

Introduction

The current state of education demands a focus on enhancing the quality of science and mathematics education (Engein et al., 2013). Inquiry-based learning (IBL) has been recognized as a promising approach for achieving these improvements (Rocard et al., 2007). Schools that have incorporated IBL have reported positive results in improving students' academic performance, prompting education authorities to explore the approach further and consider its broader adoption (SEAMEO INNOTECH, 2020). Systematic reviews of IBL highlight its strengths while also identifying areas for growth to enhance its implementation. However, critics have raised concerns that IBL may not be the best approach for students lacking foundational knowledge, suggesting that explicit instruction might be more beneficial in such cases due to the challenges posed by self-directed learning (Pedley-Smith, 2021). To address these differing perspectives, the researchers conducted a meta-analysis to thoroughly examine the effectiveness of IBL in improving students' conceptual understanding of science and mathematics.

Wale & Bishaw (2020) and Lee (2014) defines inquiry-based learning is the process of obtaining knowledge and skills by inquiring for information and are largely employed to the teaching of science and mathematics. It is a discovery method of learning in which students make observations, ask questions, examine sources, collect, analyze, interpret, and synthesize data, propose answers, explanations, and predictions, communicate findings through discussion and reflection, apply findings to real-world situations, and follow up on new questions that arise during the process. Inquiry-based learning stresses students' ability to perceive, question, and investigate multiple views and concepts in the actual world (Caswell & LaBrie, 2017). In a student-centered learning environment, the teacher encourages and scaffolds learning while also providing facts and information, allowing students to investigate, question, and explain their reality, and develop their problem solving and critical skills (Maxwell, Lambeth, & Cox, 2015).

Guido (2017) outlines seven advantages of IBL, claiming that it: (1) reinforces curricular contents, (2) heats up the brain for learning (3) encourages a greater comprehension and understanding of the concepts, (4) aids to make learning rewarding (5) promotes initiative and self-direction, (6) works in almost any classroom, and (7) provides differentiated education. In addition, Orosz et al. (2023) and Tafoya, Sunal, & Knecht (1980) classified IBL into four levels: (a) confirmation inquiry, (b) Structured, (c) guided, and (d) open inquiry. In confirmation inquiry a concept or principle is presented, and the student performs some exercise to confirm it. The student knows what is supposed to happen and the procedure has been carefully outlined for the student to follow. In structured inquiry, the student is presented with a problem but does not know the results beforehand. Procedures are outlined, and the selection of activities and materials is structured to enable the student to discover relationships and to generalize from data collected. On the other hand, in guided inquiry, only the problem to investigate is given the student. The student directs his/her own procedures and methods of collecting data from which concepts or principles are discovered and generalized. While in open inquiry, the student formulates both the problem and the procedure for solving the problem, interprets the data, and arrives at conclusions.

Understanding concepts during the learning process and applying them accurately, precisely, flexibly, and effectively in problem-solving are the goals of learning (Harun et al., 2021). The capacity to understand ideas, relationships, and procedures in mathematics and science is known as conceptual understanding (Pujiati, Kanzunnudin, & Wanabuliandari 2018). Conceptual understanding is a comprehensive and practical grasp of mathematical, scientific, or other concepts. Understanding ideas enables learners to see beyond individual facts and techniques. They grasp why a mathematical subject is vital and how it may be utilized in a variety of situations. Learning is more than just memorizing information; it's also about comprehending and organizing their relationships (University of the Potomac, 2024).

Several studies including those of Nst and Hastini (2017), and Abdi, (2014) have found that using IBL strategies has a substantial impact on improving students' understanding of science-related concepts, and the students who use IBL have a higher level of comprehension of science concepts than those who use traditional or conventional approaches. Tursinawati (2016) and Artayasa et al (2018) described science concept understanding as students' cognitive ability to comprehend and grasp science concepts through a phenomena, event, object, or action connected to the science curriculum. In addition, Rahayu (2016) believed that human require expertise in understanding science concepts in order to address today's increasingly complicated science and technology challenges.

Moreover, several researchers have already conducted meta-analysis studies on the effectiveness of IBL and IBL-related instruction and approaches including Antonio & Prudente (2024) who gave emphasis on the effects of inquiry-based approaches on students’ higher-order thinking skills in science; Ananda & Usmeldi (2023) for the effect of using IBL model on students’ competence; Nugroho et al. (2023) who studied the effectiveness of inquiry learning towards scientific argumentation skills; Purwantini et al. (2023) on the influence of the IBL model in students’ mathematics learning; Praminingsih et al. (2022) on the effect of inquiry learning model on students critical thinking skill; Kaçar et al. (2021) on the effect of IBL on academic success; Yang, Sung, & Chang (2020) on the use of meta-analysis to uncover the critical issues of mobile IBL; Heindl (2019), who studied the IBL and the pre-requisite for its use in science at school; Zheng et al. (2018) on the effectiveness of integrating mobile devices with IBL on students' learning achievements; Hasanah, Prasetyo, & Rudyatmi (2017) on their meta-analysis of inquiry-based instruction research; Lazonder & Harmsen (2016) who studied the effects of guidance on IBL; Aktamiş, Hiğde, & Özden (2016) for the effects of the IBL method on students’ achievement, science process skills and attitudes towards science; Furtak et al. (2012) who gave emphasis on the experimental and quasi-experimental studies of inquiry-based science teaching; and Wang et al. (2011) who conducted a meta-analysis of inquiry-based instruction on student learning outcomes in Taiwan.

However, despite the number of meta-analyses conducted along the effectiveness of IBL and IBL-related approaches like those mentioned above, none of them covered the effects of IBL on improving the students’ conceptual understanding in science and mathematics and how it differs across educational levels (primary, junior high school, senior high school, and tertiary), academic discipline (science and mathematics), and the level of IBL used (confirmation inquiry, structured inquiry, guided inquiry, and open inquiry).

Furthermore, several empirical research studies, comprising those by Khasawneh et al. (2023), Berhanu and Sheferaw (2022), Utaminingsih (2022), Gerhatova et al. (2021), Senyigit, Onder & Silay (2021), Mengistu (2021), Sutrisno Nanda and Widarti (2020), Annisa and Rohaeti (2018), Artayasa et al. (2017), Fan (2015), and Salim and Tiawa (2015), have examined the effectiveness of IBL on improving students' conceptual understanding through the use of various research designs and employed levels of IBL. Thus, the primary goal of this study is to conduct a meta-analysis of the results of the eligible studies in order to draw a general conclusion about the overall effectiveness of IBL on improving students' conceptual understanding in science and mathematics and how it varies across educational levels, academic disciplines, and the level of IBL employed in the intervention.

Research Questions

This study examined the effectiveness of Inquiry-based Learning (IBL) on improving students’ conceptual understanding in science and mathematics through a meta-analysis. Specifically, it answered the following questions:

1. What is the overall effect size of inquiry-based learning (IBL) on improving students' conceptual understanding in science and mathematics?
2. Is there a significant difference in the effect sizes of IBL on improving students' conceptual understanding in terms of:

    2.1 Educational levels

    2.2 Academic disciplines

    2.3 Level of IBL employed

3. What are the IBL models, approaches, or strategies used by the meta-analyzed studies on improving students' conceptual understanding in science and mathematics?

Method

Research Design

This study employed a meta-analysis research design to assess the effectiveness of IBL on improving students' conceptual understanding in science and mathematics through examining the results of selected studies on the defined variables. The researchers used systematic procedures anchored on the study's objectives to review and synthesize the quantitative findings of previous studies on IBL that were selected using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA 2020) and a set of inclusion and exclusion criteria.

Study Search Procedures

The researchers developed a set of criteria to guide the selection of studies for inclusion and exclusion. Publish or Perish software (Harzing, 2017) was used to search peer-reviewed articles published between 2015 and 2024 and indexed in Google Scholar, Crossref, Education Resources Information Center (ERIC), and Scopus.

The following keywords or terms were used for the search process: "inquiry-based learning," "inquiry-based teaching," "inquiry-based approach," "inquiry-based strategy," and similar keywords but without hyphens. Also, Boolean operator "AND" was used for the search string to connect the term "conceptual understanding," to the IBL "keywords." These words were entered into the Publish and Perish "keywords" bar, and "2015 to 2024" was entered in the "year" section. The obtained studies were then screened and evaluated using the inclusion and exclusion criteria as reflected in the PRISMA (2020) flowchart in Figure 1 (included studies for IBL on students' conceptual understanding).

Furthermore, as indicated in Figure 1, there are 12 empirical research studies that met the inclusion criteria for this meta-analysis study. These were comprised of studies from the Asian Region (n = 6) from China, Indonesia, and Malaysia; the European Region (n = 2) from Turkey and the Slovak Republic; the African Region (n = 3) from Ethiopia and Ghana; and the American Region (n = 1) from the United States of America, as shown in Figure 2.

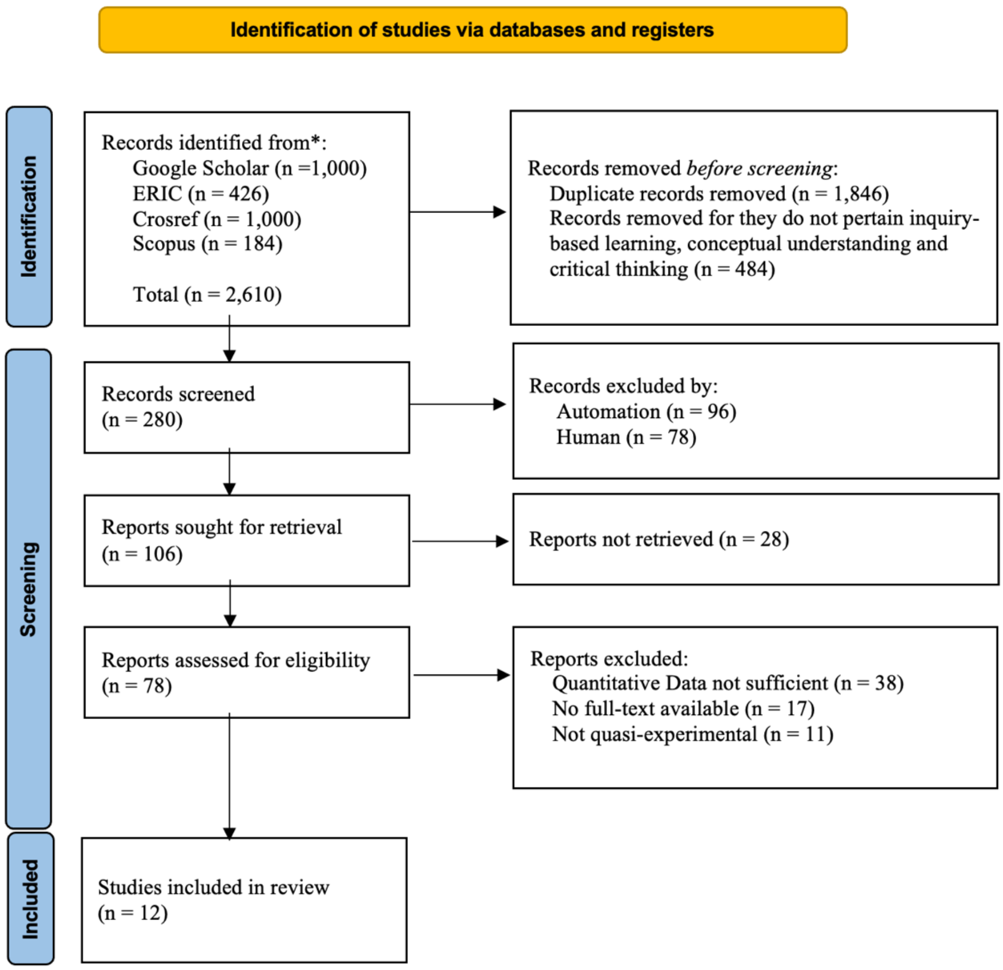

Figure 1. PRISMA (2020) Flowchart and Search Strategy Results on the Effectiveness of Inquiry-based Learning on Students' Conceptual Understanding

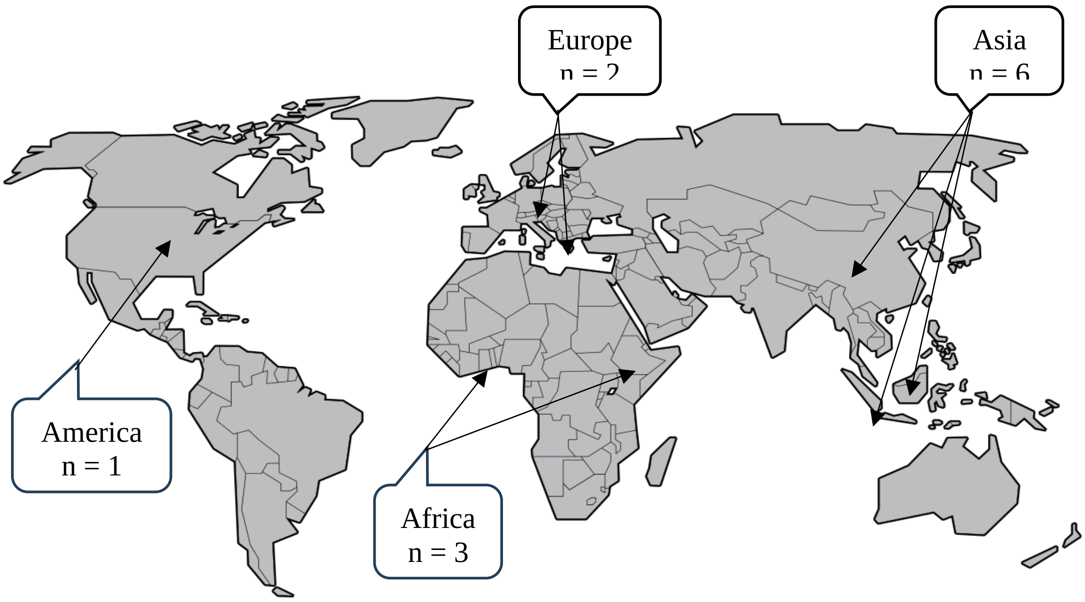

Figure 2. Origin of Included Studies

Inclusion and Exclusion Criteria

To investigate the effects of IBL on students' conceptual understanding, the researcher looked at articles that used a quantitative research strategy within a 10-year period (2015–2024). Specifically, the following inclusion criteria were set forth: (a) must be published in a peer-reviewed journal between 2014 and 2024; (b) must include a clear and specific reference to inquiry-based learning and the level of IBL employed; (c) must use a measure of conceptual understanding in science or mathematics as dependent variables; (d) must be conducted at any educational level; (e) must contain data on post-test results for the controlled and experimental groups; and (f) must provide appropriate quantitative data, such as sample size (n), post-test mean (M), and standard deviation (SD), to allow effect size computations. On the other hand, if the SD is not provided but the standard error (SE) is available together with the mean and sample size, then the SD can be calculated by the researchers by multiplying the SE by the square root of the sample size (Tuovila, 2024).

In addition, studies that measured the effects of IBL on students conceptual understanding and other variables were included in the set of studies examined, as long as appropriate quantitative data are presented or provided for the students' conceptual understanding and other variables separately. Likewise, studies that measured the effects of IBL on students' conceptual understanding at multiple IBL levels were also included as long as they were compared to traditional or conventional methods, and a separate set of quantitative data on the results were provided per level and on the traditional or conventional method and were considered as individual results.

Moreover, studies that did not explicitly mention or specify the level of IBL used but have met the other inclusion criteria were still considered; however, the level of IBL employed were interpreted by the researchers based on the definition and description of the four levels of IBL by Orosz et al. (2023) and Tafoya, Sunal, & Knecht (1980), classified as (a) confirmation inquiry, (b) structured inquiry, (c) guided inquiry, and (d) open inquiry. Furthermore, the researcher used the PRISMA search strategy flowchart in Figure 1 to filter the acquired articles based on the inclusion criteria specified.

Coding Procedures

Included studies from eligible peer-reviewed journals were coded as follows: (a) study labels (author's last name); (b) year of publication; (c) country of origin; (d) educational level where the study was conducted or implemented; (e) academic discipline; (f) level of IBL employed; (f) outcome measure characteristics (sample size, mean, and standard deviation).

Effect Size Calculation

The researcher utilized Hedges g to determine the effect size of the gathered data. According to the National Institute of Standards and Technology (2017), the Hedge's g statistic is used to measure the effect size of the difference between means. In addition, Hedge's g statistic is generally preferred to Cohen's d statistic because it has better small sample properties and has better properties when the sample sizes are significantly different.

Also, Hedges and Olkin (1985) and Ellis (2010) stated in their articles that Hedges' g outperforms Cohen's d when the sample size is very small (n<20). The number of studies included in this meta-analysis is less than 20 (n = 14). Hence, the researchers followed the recommendations of Hedges and Oiken (1985) and Ellis (2020) to use Hedges g as the effect size model estimator. Moreover, Hedge's g statistic result is interpreted as: 0.2 means small effect; 0.5 denotes medium effect; and 0.8 indicates large effect (NIST, 2017).

Furthermore, the researchers used the Jamovi Version 2.4.7.0 (2023) to compute effect sizes, generate forest plots, and assess heterogeneity and publication bias. Lastly, the researchers utilized the same method as Funa and Prudente (2021) and Ramallosa et al. (2022) to systematically perform and present the procedures on the computation of effect sizes and the identification of publication bias. This procedures include: (a) Hedges g identification for sample size less than 20, (b) Forest plot generation to visualize effect size distribution, (c) Classic Fail-Safe N analysis to verify the obtained effect and resistance to publication bias, (d) Funnel plot generation to visualize and determine outliers, (e) Begg-Mazundar test to determine publication bias, and (f) Moderator analysis to compare the effect size of the identified variables.

Results

Study Characteristics

This study examined twelve (12) research studies that satisfied the inclusion criteria. These studies included a total of 786 students of various origins who were exposed to both IBL and conventional/traditional approaches. Table 1 details the descriptive characteristics of these studies, including authors and publication years, the country where the studies are implemented, the educational level of student-participants, the scientific discipline focus, the level of IBL used, and group comparisons based on quantitative data such as post-test means, standard deviations, and sample size.

Table 1. Descriptive Characteristics of Included Studies

Study No.	Author(s)	Year of Pub.	Country of Origin	Educ. Level	Academic Discipline	Level of IBL Employed	Experimental Group			Controlled Group		
							M	SD	n	M	SD	n
1	Khasawneh et al.	2023	USA	Tertiary	Math	Guided*	78.26	11.49	23	63.11	12.76	18
2	Berhanu & Sherefaw	2022	Ethiopia	JHS	Science	Guided	6.8304	2.65366	28	4.3426	2.90817	27
3	Istikomah, Sri, & Sumaji	2022	Indonesia	Primary	Math	Guided	32.42	8.403	40	31.97	8.971	32

Study No.	Author(s)	Year of Pub.	Country of Origin	Educ. Level	Academic Discipline	Level of IBL Employed	Experimental Group			Controlled Group		
							M	SD	n	M	SD	n
4	Gerhatova et al.	2021	Slovak Republic	Primary	Science	Guided	20.17	7.14	30	16.27	6.89	30
5	Senyigit, Onder & Silay	2021	Turkey	Tertiary	Science	Guided	11.84	3.69	25	8.76	3.92	25
6	Mengistu	2021	Ethiopia	JHS	Science	Guided	6.8929	2.77591	28	5.33	2.8593	25
7	Sutrisno, Nanda & Widarti	2020	Indonesia	SHS	Science	Guided	83.7	11.21	36	71.79	17.39	35
8	Annisa & Rohaeti	2018	Indonesia	SHS	Science	Guided*	86.07	6.49	27	81.82	4.86	28
9	Artayasa et al.	2017	Indonesia	Tertiary	Science	Structured	54.79	17.288	41	52.23	13.38	36
						Guided	64.1	14.551	39	52.23	13.38	36
						Open	72.59	13.007	38	52.23	13.38	36
10	Mensah-Wonkyi & Adu	2016	Ghana	SHS	Math	Guided*	33.00	6.3251	41	18.65	5.4491	38
11	Fan	2015	China	JHS	Science	Guided	30.45	5.96	22	26.25	7.28	16
12	Salim & Tiawa	2015	Malaysia	JHS	Math	Structured	78.62	7.39	29	65.21	7.19	29

** Level of IBL employed by the study was interpreted by the researchers*

As depicted in Table 1, the twelve research studies (12) that were included concentrating on the effect of IBL on students' conceptual understanding in science and mathematics encompassed fourteen (14) effect sizes since the study of Artayasa et al. (2017) compared the effectiveness of IBL at multiple levels to the traditional approach. These studies were published from 2015 to 2023 and spanned Asia, Europe, Africa, and the Americas. Notably, Asia contributed to 50% of the studies, with Africa representing 25%, Europe 16.67%, and the Americas 8.33%.

In addition, the data in Table 1 revealed that the included studies were undertaken in science (n = 8) and mathematics (n = 4) subjects at all educational levels. Particularly, a large portion was implemented at the junior high school level (n = 4), followed by senior high school (n = 3), tertiary (n = 3), and at the primary level (n = 2). According to SEAMEO INNOTECH (2020), IBL and IBL-based instruction can be used not only in science but also in mathematics, language, literacy and numeracy, arts and crafts, and life skills, as they promote children's holistic development and instill critical thinking, creativity, and other 21st-century skills.

Effectiveness of IBL on Improving Students' Conceptual Understanding in Science and Mathematics

Table 2 presents the overall effect size, heterogeneity analysis, and confidence intervals based on the analysis effect model generated using the meta-analyses in Jamovi software (2023). The heterogeneity analysis was found to be significant (p-value < 0.001), and the Q-value with 13 degrees of freedom was 68.467, indicating that the studies included in the meta-analysis do not have a common effect size and are therefore significantly heterogeneous. According to Borenstein et al. (2021), when the heterogeneity is significant, the random-effects method to synthesize the studies is recommended. Thus, the random-effects model must be employed.

Table 2. Overall Effect size and Heterogeneity Analysis

	k	Estimate	SE	Z	P	CI Lower Bound	CI Upper Bound
Random	14	0.913	0.1690	5.40	< 0.001	0.582	1.245
Fixed	14	0.853	0.0729	11.7	< 0.001	0.710	0.996

Heterogeneity Statistics

Tau	Tau^2	I^2	H^2	R^2	df	Q	p
0.568	0.3225 (SE= 0.1576)	81.18%	5.314		13.000	68.467	< 0.001

The estimated average standardized mean difference based on the random-effects model was g = 0.9134 (95% CI: 0.582 to 1.245), which is interpreted as large positive effect size as per NIST (2017). However, this average outcome results also differed significantly from zero ($z = 5.40$, $p < 0.001$), and as per Q-test result, the true outcome appears to be heterogenous. Hence, a 95% prediction interval for the true outcomes is given by -0.2480 to 2.0747. This further implies that although the average outcome is estimated to be positive, in some studies the true outcome may in fact be negative.

Table 3. Effect Size Distribution of Included Studies

Study Label	Hedges g	SE	SE^2	LL	UL	p-value
Khasawneh et al. (2023)	1.23	0.46	0.21	0.56	1.90	<0.0018
Berhanu and Sheferaw (2022)	0.88	0.34	0.11	0.33	1.44	0.002*
Utaminingsih (2022)	0.05	0.24	0.06	-0.41	0.52	0.828
Gerhatova et al. (2021)	0.55	0.29	0.08	0.03	1.06	0.036*
Senyigit, Onder, Silay (2021)	0.80	0.34	0.11	0.22	1.37	0.006*

Study Label	Hedges g	SE	SE^2	LL	UL	p-value
Mengistu (2021)	0.55	0.31	0.09	0.00	1.10	0.049*
Sutrisno, Nanda, Widarti (2020)	0.81	0.29	0.08	0.32	1.29	0.001*
Annisa and Rohaeti (2018)	0.73	0.32	0.10	0.19	1.28	0.009*
Artayasa et al. (2017)	0.16	0.23	0.05	-0.29	0.61	0.467
Artayasa et al. (2017)	0.84	0.28	0.08	0.37	1.31	<0.001*
Artayasa et al. (2017)	1.53	0.37	0.14	1.01	2.05	<0.001*
Mensah-Wonkyi & Adu (2016)	2.40	0.50	0.25	1.82	2.98	<0.001*
Fan (2015)	0.63	0.39	0.15	-0.03	1.29	0.069
Salim and Tiawa (2015)	1.81	0.47	0.22	1.20	2.43	<0.001*

* *p-value < alpha = 0.05*

Furthermore, an examination of the studentized residuals and Cook's distance were run through Jamovi to determine if there are any potential outlier in the data set. Results revealed that one study (Mensah-Wonkyi and Adu (2016)) had a value larger than ± 2.9137 and may be a potential outlier in the context of this model (Viechtbauer, 2010). Studentized residual is an efficient method for identifying outliers and evaluating the equal variance assumption (Multiple Regression Residual Analysis and Outliers, n.d.). Also, result from Cook's distances proved that none of the studies could be overly influential. According to Thieme (2021), Cook's distance is a method that is frequently applied in regression analysis to identify influential outliers in a set of predictor variables.

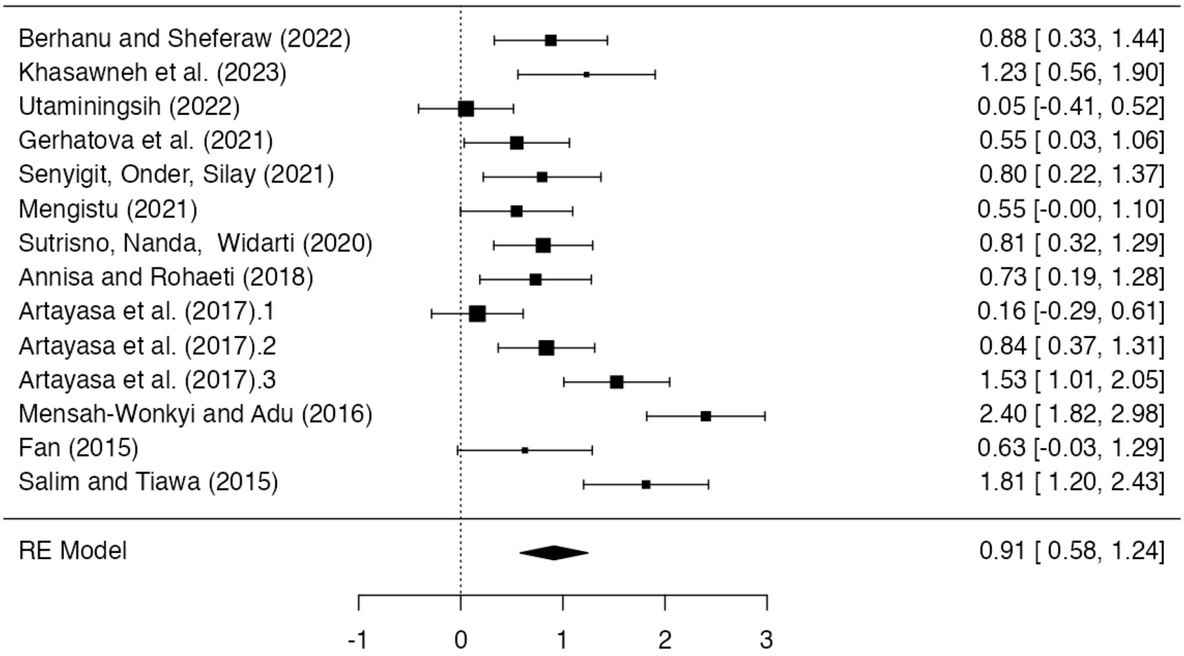

Figure 3. Forest Plot of the Included Studies

Lastly, to further validate the obtained effect sizes of IBL on students' conceptual understanding, the researchers conducted the Classic Fail-Safe N analysis to verify publication bias. Table 4 shows the results of the Classic Fail-Safe N analysis.

Table 4. Publication Bias Assessment

Test Name	**value**	**p**
Fail-Safe N	747.000	< .001
Begg and Mazumdar Rank Correlation	0.385	0.062
Trim and Fill Number of Studies	0.000	.

Note: Fail-safe N Calculation Using the Rosenthal Approach

Results on Classic Fail-Safe N as shown in Table 4 demonstrate that the 12 empirical studies and 14 effect sizes that make up this study are sufficient, valid for meta-analysis. Furthermore, the funnel plot is not a certain way to screen for publication bias, particularly in meta-analyses with limited number of articles (Harbord et al., 2009). Furthermore, according to Janhavi and Anwaya (2017), the Begg-Mazumdar test has poor power with less than 25 studies but is quite powerful for meta-analyses with more than or equivalent to 75 trials. In order to ascertain the substantial variation in effect sizes between groups (educational levels, focused discipline, and levels of IBL employed), the researchers took into account the findings of Classic Fail-Safe N and proceeded straight to the moderator analysis.

Table 5 outlines the moderator analysis results, which assess variations in effect sizes related to students' educational levels, academic disciplines, and the degree of inquiry-based learning (IBL) implemented. Significant and positive effect sizes were noted for students from junior high to tertiary levels, highlighting the benefits of IBL in improving conceptual understanding. Notably, senior high school students experienced the highest improvement (g = 1.176) compared to primary, junior high, and tertiary levels. The significant heterogeneity (p < 0.001) suggests that effect sizes differ across educational levels, pointing to the diverse impact of IBL.

Table 5. Moderator Analysis

Moderator	**Subgroups**	**k**	**Hedges g**	**95% CI**		**p-value**	**Test of Heterogeneity p-value**
				LL	**UL**		
Educational Level	Primary	2	0.289	-0.433	1.01	0.433	<0.001*
	Junior High School	4	0.908	0.336	1.48	0.002*	
	Senior High School	3	1.176	0.522	1.83	<0.001*	

Moderator	Subgroups	k	Hedges g	95% CI		p-value	Test of Heterogeneity p-value
				LL	UL		
Academic Discipline	Tertiary	5	0.850	0.360	1.34	<0.001*	0.197
	Science	10	0.727	0.580	1.80	<0.001*	
	Mathematics	4	1.191	0.376	1.08	<0.001*	
Level of IBL Employed	Guided	11	0.786	0.4642	1.11	<0.001*	<0.001*
	Structured	2	0.772	0.0143	1.53	0.046*	
	Open	1	1.530	1.01	2.05	0.001*	

*Radom-effects Model, *p < alpha = 0.05*

The results presented in Table 6 demonstrate the wide range of IBL models, approaches, and strategies that have been applied in the studies that were subjected to meta-analysis. These include more structured and methodical techniques like the OE3R approach (Orientation-Exploration-Explanation-Elaboration-Reflection) as well as well-known models like the 5E's learning model, which follows the steps of Engage, Explore, Explain, Elaborate, and Evaluate.

Table 6. IBL Model, Approaches or Strategies used by the Included Studies

Author(s)	Year of Publication	IBL Models, Approaches, and Strategies Used
Khasawneh et al.	2023	IBL Model supplemented by textbook and Pearson Education's MyMathLab
Berhanu and Sheferaw	2022	5Es Learning Model Approach (Engagement-Exploration-Explanation-Elaboration-Evaluation)
Utaminingsih	2022	Guided IBL Model (Formulating Problems-Developing Hypotheses-Collecting Evidence-Testing Hypotheses-Drawing Conclusions)
Gerhatova et al.	2021	Interactive Education Strategy–Integrated e-Learning (INTe-L). The strategy was built on the role of interactive simulations and experimenting at the knowledge acquisition. The following INTe-L components were used: (a) on-site and remote experiments, (b) interactive simulations and (c) electronic study materials.

Author(s)	Year of Publication	IBL Models, Approaches, and Strategies Used
Senyigit, Onder, Silay	2021	Simulation-supported IBL using Capacitor Lab and Capacitor Lab Basic simulations in PhET Interactive Simulations
Mengistu	2021	5Es Learning Model Approach (Engagement-Exploration-Explanation-Elaboration-Evaluation)
Sutrisno, Nanda, Widarti	2020	OE3R Approach (Orientation-Exploration-Explanation-Elaboration-Reflection)
Annisa and Rohaeti	2018	IBL Model (Orientation-Formulate the Problem-Submitting Hypothesis-Collecting Data-Testing the Hypothesis-Formulate Conclusions)
Artayasa et al.	2017	IBL Cycle (Inquisition-Acquisition-Supposition-Implementation-Summation-Exhibition)
Mensah-Wonkyi & Adu	2016	IBL Model (Ask Questions-Investigate Solutions-Add New Knowledge-Discuss Experience-Reflect on New Ideas)
Fan	2015	Interactive Simulation Using 5 Steps: (1) Elicitation and Clarification; (2) Prediction and Implication; (3) Testing with Interactive Simulations; (4) Elucidation and Linking; and 5) Metacognitive Evaluation and Further Testing.
Salim and Tiawa	2015	Structured IBL Model (Promotion of students active involvement in searching for, examining, formulating concepts and principles, and encourage students intellectual and skills development)

Discussion

The result on the characteristics of the meta-analyzed studies along educational levels may imply that the prevalent application of IBL in junior high schools maybe due to its explicit incorporation into the science and science-related curriculum such as mathematics for secondary levels, like for example in the educational curriculum in the Philippines. This may also indicate IBL is a flexible approach that can be used across educational levels. Subsequently, this result could also suggest that science and mathematics teachers at all levels, from elementary to tertiary, may effectively use IBL to teach concepts in science and mathematics.

Also, it was observed that the included studies employed varying levels of IBL. Most studies used guided inquiry (n = 11), while structured inquiry (n = 2) and open inquiry (n = 1) were less common. Artayasa et al. (2017) contributed data for three effect sizes, examining the impact of employing three levels of IBL on students' conceptual understanding compared to traditional teaching methods. Conversely, researchers were unable to locate or identify studies that used the confirmation inquiry level. The various levels of IBL used in the included studies may indicate that educators and researchers are experimenting with diverse ways to determine the most effective level of IBL for improving students' conceptual understanding. The prevalence of guided inquiry may indicate that it is viewed as a balanced method, providing structure while encouraging student discovery and critical thinking. According to Kirschner et al. (2006), guided inquiry is relatively prevalent since it accommodates to a wide range of student competency and autonomy while promoting a balance of possibilities between planned learning and individual discovery. On the other hand, the lack of studies applying confirmation inquiry may imply a research gap in this specific technique, providing an opportunity for future studies to explore its possible advantages or limits in educational contexts.

The results on the effectiveness of IbL may imply how it significantly improves students' conceptual understanding in science and mathematics. This backs up the use of IBL as a successful teaching and learning method in a range of educational settings. IBL may significantly increase students' understanding of difficult ideas, as seen by the large effect size, which may lead to improved conceptual understanding and perhaps academic achievement and a greater appreciation for the subjects. Therefore, to improve learning outcomes, educational institutions and policymakers can think about incorporating IBL more widely into curriculum and teacher preparation programs.

In addition, the result of I^2 of 81.18% suggests the significance of subgroup, hence, moderator analysis is valuable (Borenstein et al., 2021). The effect sizes of Hedges' g for each individual study were calculated, displayed, and depicted in the forest plot (Figure 3) and effect size distribution of the included studies (Table 3), all within a 95% confidence interval.

Moreover, the observed standardized mean differences (Hedges g) as shown in Table 3 ranged from 0.05 to 2.40, with most estimates being positive (100%), which implies that majority of the studies favored the experimental group (IBL) over the controlled group (conventional approaches) as evident in the forest plot (Figure 3). The estimated average standardized mean difference based on the random-effects model was g = 0.9134 (95% CI: 0.582 to 1.245). Therefore, the average outcome differed significantly from zero ($z = 5.40$, $p < 0.001$).

Subsequently, IBL also demonstrated a large positive effect on students' understanding of mathematics (g = 1.191), while its application in science subjects yielded a medium effect size (g = 0.727). Despite these variations, the heterogeneity analysis ($p > 0.05$) indicates no significant difference between the disciplines, suggesting that IBL can be effectively applied in both science and mathematics. Additionally, the level of IBL employed played a crucial role in student outcomes ($p < 0.001$); open inquiry achieved a large effect size (g = 1.530), whereas structured (g = 0.772) and guided inquiry (g = 0.786) achieved medium effect sizes. This underscores the importance of the specific level of IBL applied to improving students' conceptual understanding.

According to Ferguson (2010), IBL-based mathematics instruction significantly improves mathematics achievement; hence, he recommended that mathematics teachers utilize an inquiry-based teaching and learning method from junior through tertiary levels and urged curriculum experts to use IBL-based mathematics teaching to improve students' conceptual understanding of the subject. This somehow implies that he did not support the use of IBL at the primary level.

Similarly, comparable results were also obtained in other studies, such as those conducted by Crawford & Snider (2000) and Riordan & Noyce (2001), where they found out that students who were taught through IBL performed better than the group that was taught using the conventional approach. This suggests that students have far better comprehension when IBL is applied than their traditional group counterparts. Conversely, Ramadhani & Aprilianingsih (2020), found out in their study that students who use the guided inquiry learning can comprehend mathematical concepts more effectively than those who are under the traditional learning method.

Likewise, individual studies for SHS and tertiary ($p < 0.001$) and JHS ($p < 0.05$); academic disciplines in science ($p < 0.001$) and mathematics ($p < 0.001$); and as well as the level of IBL employed with guided inquiry ($p < 0.001$), and structured and open inquiry ($p < 0.05$) revealed significant differences. These results could be associated with the differences among the various IBL models, approaches or strategies involved in each study.

Furthermore, the range of methodologies and models used in IBL throughout the research demonstrates how flexible and adaptive IBL is to various topic subjects and situations. For example, the IBL cycle—which includes phases of inquisition, acquisition, supposition, implementation, summation, and exhibition —has been adopted by certain studies, enabling students to take charge of their educational path. Because it can be adjusted to match a variety of themes and difficulty levels, the IBL cycle is a well-liked option. Additional innovative methods include interactive simulation and simulation-supported IBL, in which students interact with intricate scenarios in a virtual setting to foster a better comprehension of the material through hands-on experience. These methods encourage a more immersive learning process by giving students the chance to experiment and see the results of various decisions in a controlled environment.

Lastly, Pearson Education's integration of technology in the form of MyMathLab demonstrates how IBL may be supplemented by digital resources, which facilitate students' access to individualized learning experiences and instant feedback. This strategy fits in nicely with the current wave of remote learning and digital education. Lastly, the need of tailoring IBL to the unique requirements and objectives of various educational contexts is emphasized by the structured IBL model and other comparable approaches, which differ in their methods and processes of implementation. Because of its adaptability, teachers may choose from a variety of IBL strategies to create the best possible learning opportunities for their students.

Empirically, the many ways that IBL has been implemented in research point to a good link with student knowledge and engagement since students are often more engaged and driven when they are actively involved in their education. However, depending on the environment in which they are used and the assistance that teachers offer, the effectiveness of these strategies may differ. Hence, finding the IBL models, approaches or strategies that best fits the needs of the students in a particular setting and the learning objectives is crucial.

Conclusions

The meta-analysis shows that inquiry-based learning (IBL) significantly enhances students' conceptual understanding in science and mathematics across educational levels, particularly benefiting senior high school students and the mathematics discipline. Open inquiry yielded the largest effect size, emphasizing the importance of student autonomy in learning. To ensure improvement in students' academic achievement in science and mathematics, educators and policymakers should consider broader integration of IBL in curricula and teacher training programs. Employing various IBL models and approaches can tailor instruction to students' needs and promote deeper engagement. Further research is needed to explore the impact of different IBL strategies on student outcomes in diverse educational contexts.

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