www.ijemst.net

Effects of Inquiry-Based Approaches on Students' Higher-Order Thinking Skills in Science: A Meta-Analysis

Ronilo Palle Antonio
Bulacan State University & De La Salle University, Philippines

Maricar Sison Prudente
De La Salle University, Philippines

To cite this article:

Antonio, R.P. & Prudente M.S. (2024). Effects of inquiry-based approaches on students' higher-order thinking skills in science: A meta-analysis. *International Journal of Education in Mathematics, Science, and Technology (IJEMST), 12*(1), 251-281. https://doi.org/10.46328/ijemst.3216

International Journal of Education in Mathematics, Science and Technology

2024, Vol. 12, No. 1, 251-281 https://doi.org/10.46328/ijemst.3216

Effects of Inquiry-Based Approaches on Students' Higher-Order Thinking Skills in Science: A Meta-Analysis

Ronilo Palle Antonio, Maricar Sison Prudente

Article Info

Article History

Received:
22 January 2023
Accepted:
01 September 2023

Keywords

Inquiry-based approach
Higher-order thinking skills
Science education
Meta-analysis

Abstract

Demonstrating higher-order thinking skills is crucial for thriving in a volatile, uncertain, complex, and ambiguous (VUCA) environment. In science education, inquiry-based learning has increasingly been recognized as a potent approach to stimulate students' higher-order thinking skills. While prior research has shown evidence of its positive impact on student achievement, no study has critically synthesized its effect on students' higher-order thinking skills in the context of science learning. Thus, this study conducted a meta-analysis following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol. The study extracted twenty-six (26) effect sizes from twenty (20) studies, involving 1,349 students exposed to both inquiry-based and conventional approaches. Using the Comprehensive Meta-analysis Software, effect size (Hedges g) was calculated to determine the magnitude of the effectiveness of inquiry-based approaches. The overall weighted effect size of g = 0.893 demonstrates that inquiry-based approaches have a significantly large and positive impact on students' higher-order thinking skills. Moderator analysis suggests that regardless of students' educational level, scientific discipline, or level of inquiry, the use of the inquiry-based approach in teaching scientific concepts maximizes students' higher-order thinking skills. Although various inquiry-based approaches were effective when combined with other instructional strategies for teaching scientific concepts, only a few studies integrated technology into the implementation of inquiry-based approaches in science. Given the positive findings of this meta-analysis, science teachers are further encouraged to adapt inquiry-based approaches to enhance their teaching practices and support students in strengthening their higher-order thinking skills.

Introduction

The 21st century is characterized by a volatile, uncertain, complex, and ambiguous (VUCA) environment. It is marked by the rapid and dynamic progress of technology, shifting societal norms, and intricate global challenges (Jerald, 2009; Valtonen et al., 2021). To adeptly navigate the multifaceted changes, individuals must be able to develop higher-order thinking skills, enabling them to make informed decisions and contribute meaningfully as responsible members of society (Kurniawati, 2021; Miterianifa et al., 2021; Saavedra & Opfer, 2012). In science education, teachers play a pivotal role in fostering and nurturing students' higher-order thinking skills through effective pedagogical approaches (Barak & Shakman, 2008). Emerging from the constructivist perspective on learning, the inquiry-based approach has increasingly been recognized as a potent pedagogy for stimulating students' higher-order thinking skills. Although existing research has demonstrated its potential effectiveness in improving students’ learning outcomes (Heindl, 2019; Kaçar et al., 2021; Oztürk et al., 2022), the impact of inquiry-based learning on students' higher-order thinking skills in the context of science learning remains unexplored. Hence, the objective of this meta-analysis was to examine the effectiveness of inquiry-based approaches in developing students' higher-order thinking skills. It aimed to generate valuable insights on the current state of literature about inquiry-based approach and students’ higher-order thinking skills in science learning.

Despite the unprecedented challenges posed by the COVID-19 pandemic, the primary objective of science education remains the promotion of scientific literacy. Scientific literacy encompasses a broad spectrum of knowledge and skills, including understanding scientific phenomena, cultivating positive attitudes towards scientific knowledge, and honing process skills such as formulating and exploring scientific inquiries and drawing inferences from evidence (American Association for the Advancement of Science, 1993; K to 12 Science Curriculum, 2016). Achieving scientific literacy is crucial for individuals to participate effectively in a rapidly evolving society. Thus, science education curricula must focus on educating individuals toward this goal (Özdem et al., 2010). These elements of scientific literacy should be cultivated through lived experiences where students engage in problem-solving, investigations, and project development (Hurd, 1998). To achieve this end, science teachers should be able to adhere to sound and evidence-based pedagogies that can lead students towards the promotion of scientific literacy.

Central to scientific literacy is the development of higher-order thinking skills. In the past decades, relevant researches in science education have long concentrated on higher-order thinking (HOT) skills and emphasized their significant role in the process of science learning (Sun et al., 2022). Teachers aim to foster these cognitive aspects of science learning among students. Thinking skills encompass a wide array of concepts, including information evaluation, reasoning, problem-solving, argument analysis, decision-making, and self-regulated learning (Schraw & Robinson, 2011). Within the realm of thinking skills, two primary tiers exist: higher-order thinking skills (HOTs) and lower-order thinking skills (LOTS). LOTS pertain to a lower level of knowledge that relies solely on memorization, retrieval, and comprehension, whereas HOTs involve the application, analysis, evaluation, and creation processes. The latter entails activities such as applying learned concepts, analyzing situations, evaluating arguments, and generating new ideas (Silitonga et al., 2020). Higher-order thinking skills play a critical role in knowledge construction and academic achievement (Tanujaya et al., 2017). Both critical and creative thinking are part of these skills, eliciting active engagement from learners. Active learning occurs when students analyze, evaluate, and create. Critical thinking involves logical contemplation and avoiding hasty conclusions, leading to systematic analysis and reflective learning (Scriven & Paul, 1987). Students exhibiting higher-order thinking can apply their knowledge, synthesize information, and evaluate scientific ideas and hypotheses (Hurd, 1999). Critical and creative thinking enrich cognitive prowess (Conklin, 2011), necessary for success in daily life challenges (Prayitno & Titikusumawati, 2018). Taking all of these into account, teachers are encouraged to instill higher-order thinking skills among their students, moving beyond surface-level understanding (Sulaiman et al., 2017) and shifting from rote memorization (ŽivkoviĿ, 2016).

In the pursuit of developing students' higher-order thinking skills, several challenges have been encountered by teachers. Studies by Barak and Shakman (2008) and Halim et al., (2020) found that some teachers utilized teaching strategies that hinder students' development as independent thinkers. Some teachers may attempt to foster higher-order thinking skills but primarily view it as a means to convey subject content effectively. Additionally, only a minority of teachers consider the development of higher-order thinking as an essential goal in Physics learning. Furthermore, challenges arise from the lack of support, training, and available learning materials, the excessive emphasis on content assessment, and the misconception, difficulty, and time-consuming nature of approaches that support students' higher-order thinking skills (Gutierez, 2015). To continuously enhance teaching and learning practices, especially in the post-pandemic period, science teachers must demonstrate a comprehensive understanding of evidence-based instructional strategies that they can adapt to nurture students' higher-order thinking skills.

Numerous approaches and strategies have been employed to assist students in enhancing their higher-order thinking skills. Anchored on the constructivist educational philosophy, inquiry-based learning approach has been utilized to nurture students' scientific thought processes (Artika & Nurmaliah, 2023). Inquiry-based learning puts a premium on acquiring knowledge through inquiry and problem-solving, underpinned by critical and creative thinking (Ismail & Alias, 2006). Within the classroom context, inquiry-based learning motivates students to emulate the practices of scientists (Keselman, 2003; Pedaste et al., 2015). It empowers students to meticulously observe the natural world, question their observations, and seek evidence to address these inquiries. Throughout this iterative process, students are expected to employ and refine their inquiry skills, which encompass activities such as making observations, posing inquiries, formulating hypotheses, designing research methodologies, deriving evidence-backed conclusions, and effectively communicating findings (National Research Council [NRC], 2000). Involvement in scientific inquiry activities assists students in cultivating critical thinking abilities and honing their skills in knowledge construction (Schneider & Krajcik, 2002).

Learning science by doing science in the classroom setting involves four progressively intricate levels: limited inquiry, structured inquiry, guided inquiry, and open inquiry. In the context of open inquiry, students explore questions they formulate themselves, following the procedures they have designed. For instance, Abaniel (2020) implemented an open inquiry model in Physics, where students crafted questions for their experimental investigation. Collaborating within groups, they devised and carried out experimental procedures stemming from their queries, leading them to insightful conclusions. Subsequent to conducting experiments, students presented their laboratory reports and shared their experimental designs, findings, and conclusions with their peers. Guided inquiry, on the other hand, involves students investigating questions presented by the teacher, while utilizing procedures they have designed or chosen. Ural (2016) exemplifies this, as students were presented with semi-structured Chemistry problems and encouraged to devise experimental approaches using provided materials. An essential aspect was the justification of conclusions drawn from observations and experimental outcomes. In structured inquiry, students delve into teacher-posed questions following prescribed procedures. In limited inquiry, students verify principles through activities where results are predetermined (Banchi & Bell, 2008; Duran & Dokme, 2016). A meta-analysis conducted by Lazonder and Harmsen (2018) demonstrates the pivotal role of guidance in successful inquiry-based learning. Students who receive guidance of some form develop greater skillfulness during tasks, achieve more success in acquiring information through investigative practices, and attain higher scores on tests assessing learning outcomes. Moreover, Sadeh and Zion (2011) suggest that teachers should provide students increased opportunities for greater involvement in open inquiry-based projects, allowing them to have greater autonomy, improved higher-order thinking skills, and a deeper understanding of science concepts.

Inquiry-based learning has gained increasing recognition within science curricula, international research initiatives, and classroom instruction. The application and impact of inquiry-based approach across various subjects have been extensively investigated (Pedaste et al., 2015). Consequently, meta-analyses have been conducted to synthesize findings from individual studies on inquiry-based learning. For instance, Kaçar et al., (2021) conducted a meta-analysis on the effects of inquiry-based learning concerning students' academic achievement across different grade levels and publication types. This study revealed that inquiry-based learning enhances academic performance across grade levels. Notably, it exhibits greater efficacy at the high school level compared to other educational level, with effect sizes showing no significant variation by publication type (i.e., articles and theses). Meanwhile, Aktamiş et al., (2016) found that inquiry-based science education enhances academic performance and aids in honing science process skills and attitudes, though its impact on student achievement is more pronounced. Zheng et al., (2018) also explored the effectiveness of combining mobile devices with inquiry-based learning, discovering a substantial positive effect on students' learning outcomes. Heindl (2019) showcased a positive effect size for the consistent application of inquiry-based learning in primary and secondary schools. Finally, a second-order meta-analysis was conducted by Öztürk et al., (2022), demonstrating that inquiry-based learning moderately enhances students’ learning outcomes.

Despite the favorable evidences obtained from previous meta-analyses, the impact of inquiry-based learning on students' higher-order thinking skills remains unexplored. Prior meta-analyses did not exclusively concentrate on science classroom instruction and its effect on students' higher-order thinking abilities (Kaçar et al., 2021; Zheng et al., 2018). Additionally, previous meta-analyses revealed that the outcomes of inquiry-based approaches could be influenced by moderating variables. Oztürk et al.,'s (2022) comprehensive second-order meta-analysis incorporated moderating variables such as the type of inquiry employed (Lazonder & Harmsen, 2016; Çakır, 2017; Sarı & Şaşmaz- Ören, 2020), content domains (Zheng et al., 2018; Çakır & Güven, 2019), and grade levels (Armagan et al., 2017; Kaçar et al., 2021). However, when scrutinizing prior meta-analyses, other potentially influential variables like country of study, specific scientific disciplines, level of inquiry, and duration of implementation were not taken into account. To the best of the researchers' knowledge, no quantitative meta-analysis has delved into these specific aspects. Therefore, the objective of this meta-analysis was to analyze the efficacy of inquiry-based approaches in enhancing students' higher-order thinking skills within the realm of science education. Moreover, a moderator analysis was conducted, incorporating the aforementioned variables to yield significant insights into the effectiveness of inquiry-based approaches. The outcomes of this meta-analysis are deemed valuable in providing useful insights that can equip teachers’ understanding, skills, and confidence when designing and implementing inquiry-based learning experiences in their science classrooms, fostering the development of higher-order thinking skills among students.

Research Questions

The main objective of this study is to examine the effectiveness of inquiry-based approaches on students’ higher-order thinking skills in science learning using a meta-analysis. Specifically, this study aimed to answer the following questions:

1. How effective are inquiry-based approaches in maximizing students’ higher-order thinking skills?
2. How do the effectiveness of inquiry-based approaches vary according to the:
    2.1. students’ higher-order thinking skills;
    2.2. students’ education level;
    2.3. scientific discipline;
    2.4. duration of the implementation;
    2.5. inquiry level?
3. What were the inquiry-based approaches that have been employed to improve students’ higher-order thinking skills?

Method

Research Design

A systematic review was employed in this study, utilizing explicit and systematic methods to critically synthesize the findings of individual studies that address a clearly formulated question (Higgins et al., 2019). In this context, the impact of the inquiry-based approach on students' higher-order thinking skills was examined through the analysis of existing empirical studies. More specifically, a meta-analysis was employed for this purpose, involving the application of a set of statistical analyses and the synthesis of quantitative findings from multiple studies that are comparable (Cohen, 1988; Pigott & Polanin, 2020). The utilization of meta-analysis facilitated the examination and synthesis of the existing literature on inquiry-based learning and students’ higher-order thinking skills in a manner that follows logical, transparent, and analytical procedures (Gough et al., 2017). The goal of meta-analysis is to propose a new direction for future research and seeks to draw broad conclusions about the current state of the literature (Cohen et al., 2007; Creswell, 2013).

Literature Search Procedures

As depicted in Figure 1, the selection of relevant studies was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol (Moher et al., 2009; Antonio, 2022). For the identification of research articles, six (6) meta-search engines, namely Google Scholar, SCOPUS, ERIC, Semantic Scholar, PubMed, and OpenAlex, were utilized. Furthermore, a manual search was conducted to comprehensively survey the literature and minimize potential biases by manually seeking potential research articles that might not have been captured in the initial search (Vassar et al., 2016). Using Harzing's Publish or Perish (PoP) software in the literature search, empirical studies published from January 2017 until the third quarter of 2022 were intentionally sought. The meta-search engines were strategically queried using keywords such as ‘inquiry-based learning’, ‘effects’, ‘effectiveness’, and ‘thinking skills’, with certain adjustments made to accommodate specific retrieval sources. Additionally, search terms related to distinct forms of inquiry-based approaches (e.g., Argument-Driven Inquiry) were also employed in the search engines to achieve a comprehensive analysis of the inquiry-based learning approaches.

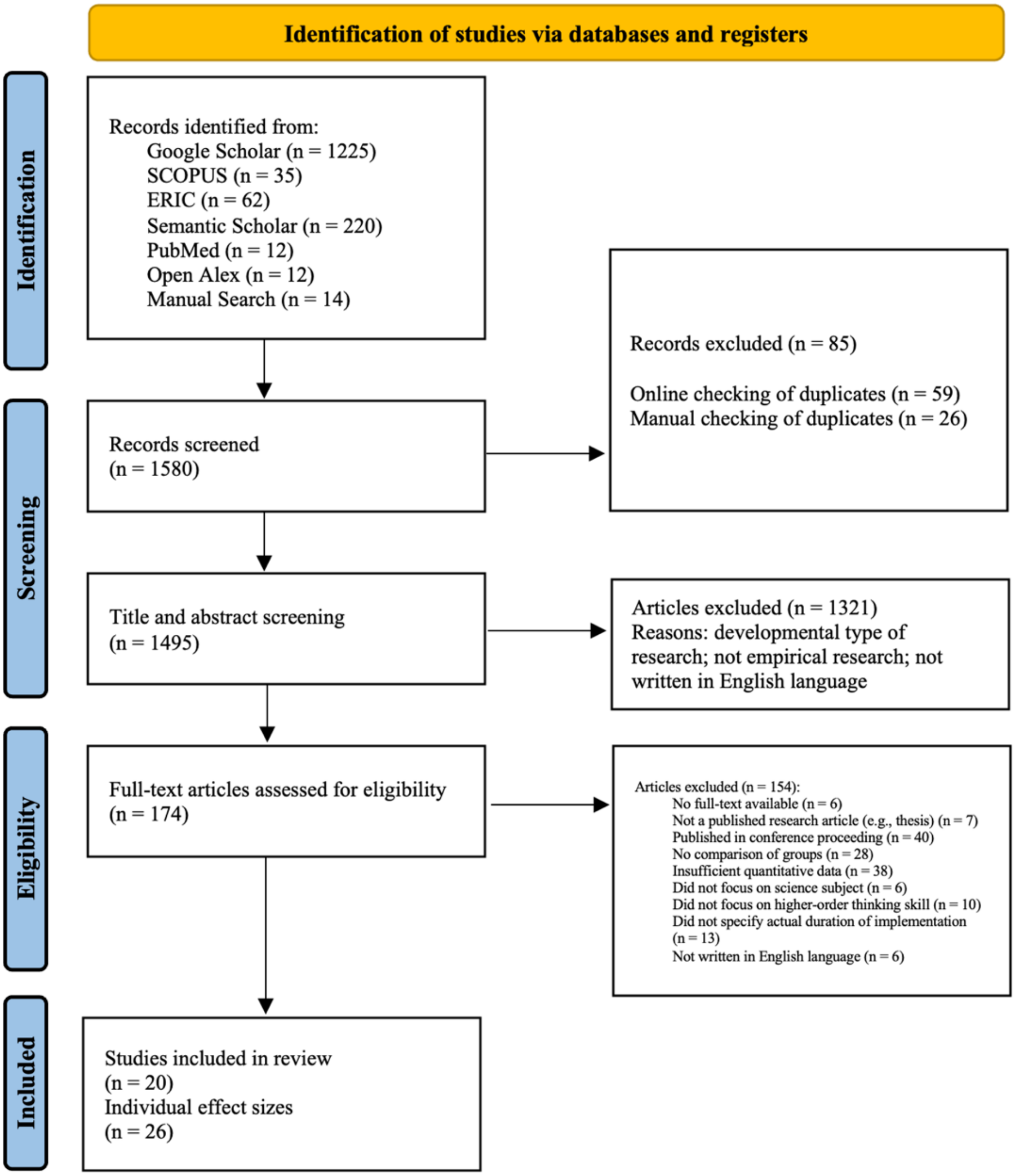


Figure 1. Flow Diagram of the Literature Search Using PRISMA Protocol

The flow diagram of the literature search conducted through the PRISMA protocol is shown in Figure 1. Over the period spanning from January 2017 to September 2022, a total of 1,580 research articles were retrieved by various meta-search engines during the initial literature search. Employing a data cleanup tool, fifty-nine (59) duplicates were removed. Nonetheless, due to differences in formatting, including variations in wording and numerical presentation, certain duplicates went undetected by the online tool, necessitating manual verification and removal (n=26). After the abstracts were meticulously screened, a remaining pool of 174 articles underwent evaluation based on the predetermined inclusion and exclusion criteria.

Inclusion and Exclusion Criteria

Purposively, only research articles relevant to the scope of this study were investigated and analyzed. The inclusion criteria for article selection were established by the researchers, encompassing the following aspects:

a) availability of the full text copy of the article online;

b) manuscript being written in the English language;

c) classification as an empirical study;

d) date of publication falling between 01 January 2017 and 30 September 2022;

e) evident inclusion of explicit reference to an inquiry-based approach in the article's title or abstract;

f) utilization of experimental and/or quasi-experimental methods;

g) provision of sufficient statistical or quantitative data (e.g., posttest means, standard deviations);

h) utilization of higher-order thinking skills as the primary learning outcome;

i) conduct of research in a K–12 or higher education setting, and;

j) focus on any scientific disciplines.

Out of the initial pool of 174 research articles, 154 studies were excluded for the following reasons: a) unavailability of full-text: 6; b) not a published research (e.g., thesis): 7; c) publication in a conference proceeding: 40; d) absence of comparison group: 28; e) insufficient quantitative data: 38; f) lack of focus on science subject: 6; g) absence of focus on thinking skills: 10; h) failure to specify actual duration: 13; i) not written in the English language: 6. Subsequent to the exclusion of the aforementioned 154 research articles, twenty (20) research articles were identified as eligible for inclusion in the meta-analysis. Given that five (5) studies investigated multiple higher-order thinking skills (Al-Balushi et al., 2017; Deniş-Çelikere & Dere, 2022; Lu et al., 2020; Ping et al., 2020), twenty-six (26) effect sizes were extracted from the 20 research articles to quantify the magnitude of the effect of the inquiry-based approach on students' higher-order thinking skills. All of the twenty (20) included studies have been designated with an asterisk (*) in the reference list.

Coding Procedures

The twenty (20) research articles were subjected to critical analysis by the researchers, and numerous relevant pieces of information were analyzed and coded. These descriptive features were carefully noted by the researchers: a) the authors and the year of publication; b) the country in which the study was conducted; c) the specific higher-order thinking skill under investigation; d) the educational level of the student-participants; e) the scientific discipline to which the study pertained; f) the particular inquiry-based approach employed; g) the level of inquiry associated with the approach; h) the duration of implementation; i) the comparison of groups, including statistical data such as posttest means, standard deviations, and sample size. These data were subsequently documented within Google Sheets. The coding procedures were conducted by the first author under the direct supervision of the second author. The latter then verified the coded data to ensure its accuracy and reliability. Both authors arrived at a consensus regarding the finality of the coded data.

Effect Size Calculation

To assess the effectiveness of the inquiry-based approaches in enhancing students' higher-order thinking skills, the researchers calculated the effect sizes, denoted as Hedges' g, for the 20 studies employing the Comprehensive Meta-Analysis Version 4 software (Borenstein et al., 2022). Effect sizes quantify the disparity between the control and experimental groups (D'Angelo et al., 2014). Hedges' g, representing the standardized mean difference, was adopted, wherein it is equivalent to the mean difference between the experimental and control groups divided by the standard deviation (Hedges & Olkin, 1985). The preference for Hedges' g over Cohen's d stemmed from its greater capacity to correct for bias emerging from small sample sizes (Borenstein et al., 2009). Effect size magnitude was classified according to Cohen's (1988) criteria: large ($g \geq 0.80$), medium ($0.50 \leq g \leq 0.79$), small ($0.20 \leq g \leq 0.49$), and no effect ($g < 0.19$). A positive effect size indicates the superiority of the group exposed to the inquiry-based approach in comparison to the control group receiving conventional instruction. Furthermore, mixed effects analysis was employed to ascertain potential variations in the effectiveness of the inquiry-based strategy across categories such as country, students' higher-order thinking skills, students' level of education, scientific discipline studied, duration of implementation, and level of inquiry. To quantify and visualize publication bias, the Begg-Mazumdar test was employed (Begg & Mazumdar, 1994). All tests were accompanied by 95% confidence intervals, and p-values below 0.05 were deemed to have statistical significance.

Results and Discussion

The following sections present the results and discussion of the study, comprising of three main sections. Firstly, the descriptive features of the included studies are elucidated, followed by the presentation and discussion of the effectiveness of the inquiry-based approach through meta-analysis. Finally, the various inquiry-based approaches employed in the included studies are thoroughly examined in the latter part of the paper.

General Study Characteristics

This meta-analysis encompasses the analysis of twenty (20) research studies that met the inclusion criteria. Collectively, these studies involved a total of 1,349 students of different nationalities who were exposed to both inquiry-based and conventional approaches. The descriptive features of these studies, including authors and publication years, the country of implementation, the specific higher-order thinking skill under investigation, the educational level of student-participants, the scientific discipline focus, the particular inquiry-based approach employed, the level of inquiry associated with the approach, the duration of implementation, and group comparisons consisting of statistical data such as posttest means, standard deviations, and sample size, are presented in detail in Table 1.

Table 1. Descriptive Features of the Included Studies

Study No.	**Author/s**	**Country**	**HOTS Investigated**	**Educational Level/Discipline**	**Inquiry-based Strategy**	**Inquiry Level**	**Duration**	**Control**			**Experimental**		
								M	**SD**	**n**	**M**	**SD**	**n**
1	Afifa et al., (2021)	Indonesia	creative thinking	Secondary (Earth Science)	argument-driven inquiry	guided inquiry	1-3 weeks	49.52	19.47	21	60.38	17.57	21
2	Al-Balushi et al., (2017a)	Oman	spatial thinking	Secondary (Chemistry)	inquiry-based learning with virtual simulation	structured inquiry	7-9 weeks	107.1	39.22	28	124	23.5	32
	Al-Balushi et al., (2017b)	Oman	scientific reasoning	Secondary (Chemistry)	inquiry-based learning with virtual simulation	structured inquiry	7-9 weeks	8.64	3.95	28	8.84	3.13	32
3	Deniş-Çelikere and Dere (2022a)	Indonesia	inquiry skills	Secondary (Physics)	problem-based learning	guided inquiry	4-6 weeks	82.09	7.06	22	98.52	8.28	21
	Deniş-Çelikere and Dere (2022b)	Indonesia	reflective thinking	Secondary (Physics)	problem-based learning	guided inquiry	4-6 weeks	57.09	6.92	22	59.8	7.21	21
4	Deprem et al., (2022)	Turkey	metacognitive thinking	Secondary (Physics)	argument-driven inquiry	open inquiry	13-15 weeks	3.87	4.24	29	4.37	2.6	31
5	Eymur (2018)	Turkey	inquiry skills	Secondary (Chemistry)	argument-driven Inquiry	guided inquiry	7-9 weeks	28	6.19	32	32.5	3.75	32
6	Farah and Ayoubi (2020)	Lebanon	critical thinking	Secondary (Chemistry)	inquiry-based learning and reflection	guided inquiry	7-9 weeks	10.59	1.734	19	18.37	3.419	19
7	Idul and Caro (2022)	Philippines	process skills	Secondary (Earth Science and Chemistry)	process-oriented guided inquiry learning	guided inquiry	22-24 weeks	5.99	1.54	45	6.68	1.36	45

Study No.	Author/s	Country	HOTS Investigated	Educational Level/Discipline	Inquiry-based Strategy	Inquiry Level	Duration	Control			Experimental		
								M	SD	n	M	SD	n
8	Işıker and Emre (2021)	Turkey	process skills	Elementary (Chemistry)	argumentation-based instruction	guided inquiry	4-6 weeks	14.54	4.52	22	16.44	5.02	25
9	Kamarudin et al., (2017)	Malaysia	higher-order thinking	Secondary (Biology)	practice laboratory and routine teaching	structured inquiry	7-9 weeks	9.21	2.587	28	13.08	5.46	36
10	Karakas and Sarikaya (2020)	Turkey	critical thinking	Tertiary (Earth Science)	argumentation-based instruction	guided inquiry	10-12 weeks	65.88	5.07	44	69.9	6.66	44
11	Kırıcı and Bakırcı (2021)	Turkey	creative thinking	Secondary (Physics)	science, technology, engineering and mathematics (STEM) supported research-inquiry-based learning	open inquiry	4-6 weeks	19.26	4.85	35	32.79	3.17	29
12	Kuvac and Koc (2018)	Turkey	metacognitive thinking	Tertiary (Earth Science)	problem-based learning	guided inquiry	10-12 weeks	3.89	0.5	27	4.1	0.35	24
13	Lin et al., (2021)	China	problem-solving	Elementary (Physics)	inquiry-based science and engineering program	guided inquiry	10-12 weeks	1.12	0.44	59	1.49	0.58	59
14	Lu et al., (2020a)	Taiwan	critical thinking	Elementary (Physics)	critique-driven inquiry	guided inquiry	19-21 weeks	71.14	13.72	28	82.68	6.41	25
	Lu et al., (2020b)	Taiwan	inquiry skills	Elementary (Physics)	critique-driven inquiry	guided inquiry	19-21 weeks	24.18	3.24	28	26.44	2.14	25
	Lu et al., (2020c)	Taiwan	critical thinking	Secondary (Physics)	critique-driven inquiry	guided inquiry	19-21 weeks	71.5	9.72	30	85	6	28

Study No.	Author/s	Country	HOTS Investigated	Educational Level/Discipline	Inquiry-based Strategy	Inquiry Level	Duration	Control			Experimental		
								M	SD	n	M	SD	n
	Lu et al., (2020d)	Taiwan	inquiry skills	Secondary (Physics)	critique-driven inquiry	guided inquiry	19-21 weeks	25.4	2.84	30	26.6	1.71	28
15	Ping et al., (2020a)	Malaysia	argumentative skills	Secondary (Biology)	modified argument-driven inquiry	guided inquiry	7-9 weeks	15.68	8.532	40	41.73	11.97	30
	Ping et al., (2020b)	Malaysia	process skills	Secondary (Biology)	modified argument-driven inquiry	guided inquiry	7-9 weeks	57.1	13.48	40	70.93	11.71	30
16	Ramirez and Monterola (2019)	Philippines	logical thinking	Secondary (Earth Science)	computer-supported collaborative learning with scripting activity	structured inquiry	7-9 weeks	5.462	2.113	39	7.18	2.258	39
17	Songsil (2019)	Thailand	argumentative skills	Secondary (Biology)	revised argument-driven inquiry using socio-scientific issues	guided inquiry	16-18 weeks	27.69	2.841	48	31.76	2.651	48
18	Tan et al., (2020)	Philippines	process skills	Secondary (Biology)	flipped inquiry-based learning	structured inquiry	7-9 weeks	20.55	5.32	22	18.29	6.72	21
19	Ural and Dadli (2020)	Turkey	reflective thinking	Secondary (Biology)	authentic problem-based learning	guided inquiry	4-6 weeks	52	8.72	27	54.69	10.24	26
20	Ural and Gençoğ (2020)	Turkey	process skills	Secondary (Chemistry)	argumentation-based instruction	guided inquiry	7-9 weeks	40.83	15.01	35	43.76	12.45	34

Note: HOTS = Higher-order thinking skills; M = Mean; SD = Standard Deviation; n = Number of students

A total of twenty (20) research studies with twenty-six (26) extracted effect sizes were included in the meta-analysis. Interestingly, all of these studies, which investigated the effects of inquiry-based teaching approaches on students' higher-order thinking skills, were conducted in Asia. More specifically, Turkey accounted for 40% of the included studies, followed by the Philippines (15%), Malaysia (10%), and Indonesia (10%). Meanwhile, 5% of the studies was conducted in China, Lebanon, Taiwan, Thailand, and Oman. Kaçar et al., (2021) conducted a meta-analysis of studies in Turkey and found that the inquiry-based approach positively influences students' academic success. This suggests that in Turkey, there is a growing acknowledgment of the effectiveness of this approach, as reflected in the growing literature. Aside from Turkey, these findings indicate that inquiry-based learning appears to have gained traction in the Asian region, where it is widely promoted as an instructional approach in science classrooms. In Asia, a shift toward an inquiry-based curriculum was observed, following the global trends in science education reform (Ramnarain, 2018).

Additionally, it was found that such studies were conducted across all levels of education. Specifically, students at the secondary level constituted the majority of the studies (75%), followed by those at the elementary level (15%) and tertiary level (10%). Existing studies on inquiry-based learning were noted to be most frequently used at the secondary level. This is potentially due to the fact that such an approach has been explicitly encouraged in the curriculum in the secondary level, particularly in the Philippines (K to 12 Science Curriculum, 2016). The findings further suggest the applicability of the inquiry-based approach across levels of education. Science teachers, whether at the elementary or tertiary level, can employ this approach to teach scientific concepts by designing and implementing inquiry learning experiences adapted to the students' levels of interests and abilities.

Moreover, it was observed that the included studies investigated a variety of higher-order thinking skills. In particular, the effectiveness of inquiry-based approaches in improving students' process skills was investigated in 20% of the studies, while critical thinking was explored in 15%. On the other hand, 10% of the studies examined students' argumentative, inquiry, metacognitive, and creative thinking skills. Meanwhile, 5% of the studies focused on students' spatial thinking, scientific reasoning, problem-solving, logical thinking, and overall higher-order thinking. Since process skills play a crucial role in science learning, several studies have aimed to improve these skills among students, which are essential when performing inquiry-based investigations. Moreover, the inclusion of critical thinking apart from developing students' content knowledge implies that science education has become more relevant in the twenty-first century. Teachers and science education researchers have increasingly recognized the development of students' higher-order thinking skills as a potent mechanism to prepare them for coping with the demands of the 21st century.

Furthermore, when examining the specific inquiry-based approaches, it was determined that the included studies adhered to various levels of inquiry to stimulate students' higher-order thinking skills. Seventy-five (75%) of the included studies utilized guided inquiry, 20% used structured inquiry, and 10% employed open inquiry. Given the crucial role of teachers as instructional facilitators, most teachers used and implemented an inquiry-based approach at the guided inquiry level to provide adequate scaffolding to their students while conducting scientific investigations (Zion et al., 2007). The use of guided inquiry creates a balance of opportunities between structured learning and independent exploration, catering to varying levels of student autonomy and competence (Kirschner et al., 2006).

Additionally, not all students may be able to engage in higher levels of inquiry, particularly open inquiry, due to the need for prior experience and a lack of necessary knowledge and abilities. These findings align with the meta-analysis conducted by Lazonder and Harmsen (2018), which demonstrated the pivotal role of guidance in successful inquiry-based learning. Students who receive guidance of some form develop greater skillfulness during tasks, achieve more success in acquiring information through investigative practices, and attain higher scores on tests assessing learning outcomes. However, given the limited number of studies that adhered to open inquiry in the present-meta-analysis, Sadeh and Zion (2011) suggest that teachers should offer students increased opportunities for greater involvement in open inquiry-based projects. This would ultimately grant students more autonomy, promote higher-order thinking, and foster a deeper understanding of science concepts.

Regarding scientific disciplines, the inquiry-based approach was most frequently used (25%) in the fields of Physics, Biology, and Chemistry. On the other hand, Earth Science was taught using an inquiry-based approach in 20% of the included studies, while 5% utilized this approach to teach combined Earth Science and Chemistry concepts, as noted in a single study. This indicates that various scientific concepts can be effectively taught using an inquiry-based approach, which can actively engage students in the processes and nature of science while learning scientific concepts (Cairns & Areepattamannil, 2017).

Finally, in terms of the duration of implementation, the majority of studies (40%) implemented the inquiry-based approach for 7-9 weeks, 20% used it for 4-6 weeks, 15% used it for 10-12 weeks, and 5% of the studies used it for 1-3 weeks and 13-21 weeks. Different duration lengths were observed in the implementation of inquiry-based approaches. Several literature points to the time-consuming nature of inquiry-based approach (Demaria et al., 2019; Wilson, 2020) because they require students to possess extensive knowledge and skills to address scientific inquiries; thus, studies lasting up to 24 weeks have been conducted. The nature of the inquiry-based approach used and the time allotted for the unit in which it was implemented may also influence the duration length.

Effectiveness of Inquiry-based Approach in Improving Students' Higher Order Thinking Skills

Table 2 presents the heterogeneity value, average effect size, and confidence intervals based on the analysis effect model. The heterogeneity analysis was found to be significant (p < .05), and the Q-Value with 25 degrees of freedom was 171.315, indicating that the studies included in the meta-analysis do not have a common effect size and are therefore significantly heterogeneous (Borenstein et al., 2009). Thus, the random-effects model must be employed (Ellis, 2010). Additionally, I_2 yielded a value of 85.407%, indicating high heterogeneity and suggesting that moderator analysis can be conducted (Higgins & Thompson, 2002). The calculated effect sizes for the random-effects model range between 0.622 (lower limit) and 1.164 (upper limit) at a 95% confidence level.

Table 2. Overall Effect Size and Heterogeneity Analysis

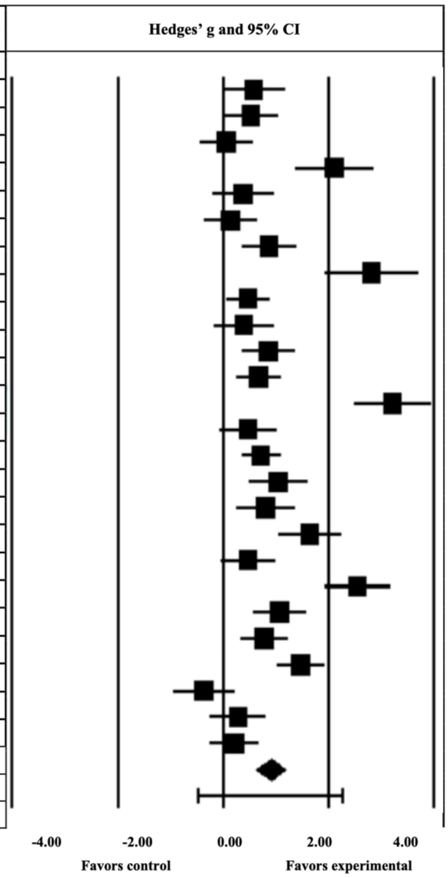
Model	Effect size and 95% confidence interval						Test of null (2-Tailed)		Heterogeneity statistics			
	k	Hedges' g	Std. error	Variance	Lower Limit	Upper Limit	z-value	*p*-value	Q-value	df	*p-value*	I^2
Fixed	26	0.785	0.052	0.003	0.683	0.888	15.035	0.000*	171.32	25	0.000*	85.41
Random	26	0.893	0.138	0.019	0.622	1.164	6.464	0.000*				

*Note: k = no. of effect sizes; Std.=standard error; Q=Homogeneity Value; df=degrees of freedom; *Significant at p < .05*

As revealed by the overall weighted effect size of g = 0.893, inquiry-based approaches have a significant, positive, and substantial impact on students' higher-order thinking skills (Cohen, 1988). The effect sizes of Hedges' g for the individual studies were computed and presented within a 95% confidence interval, which were then visualized in the forest plot (Table 3). A forest plot is a graphical representation that presents the effect size and its precision for each study, along with the cumulative effect. It adds a visual dimension to the analysis, revealing whether the combined effect relies on a limited number or an extensive array of studies, as well as whether the effect size maintains consistency or exhibits variation (Borenstein, 2022). As can be gleaned in Table 3, the distribution of effect sizes in the forest plot revealed that the majority of the studies favored the experimental (inquiry-based approach) group over the conventional approaches. However, these studies exhibited varying effect sizes and degrees of effectiveness. When examining the individual studies, the maximum effect size was g = 3.201 (Kırıcı & Bakırcı, 2021), while the minimum effect size was g = -0.367 (Tan et al., 2020). Additionally, the lower and upper limits of the effect sizes in the studies ranged between g = -0.959 (Tan et al., 2020) and g = 3.938 (Kırıcı & Bakırcı, 2021).

Table 3. Effect Sizes Distribution and Forest Plot of Studies that used Inquiry-based Approach

	Hedges' g	SE	Variance	Lower Limit	Upper Limit	Z-value	p-Value
Afifa et al., (2021)	0.575	0.309	0.096	-0.031	1.181	1.858	0.063
Al-Balushi et al., (2017a)	0.524	0.260	0.068	0.015	1.034	2.017	0.044*
Al-Balushi et al., (2017b)	0.056	0.255	0.065	-0.445	0.557	0.219	0.827
Deniş-Çelikere and Dere (2022a)	2.100	0.375	0.141	1.364	2.836	5.594	0.000*
Deniş-Çelikere and Dere (2022b)	0.377	0.302	0.091	-0.216	0.969	1.246	0.213
Deprem et al., (2022)	0.141	0.255	0.065	-0.359	0.642	0.554	0.580
Eymur (2018)	0.869	0.259	0.067	0.362	1.376	3.359	0.001*
Farah and Ayoubi (2020)	2.810	0.453	0.205	1.923	3.697	6.209	0.000*
Idul and Caro (2022)	0.471	0.212	0.045	0.055	0.886	2.222	0.026*
Işıker and Emre (2021)	0.390	0.290	0.084	-0.179	0.959	1.343	0.179
Kamarudin et al., (2017)	0.861	0.260	0.068	0.351	1.371	3.307	0.001*
Karakas and Sarikaya (2020)	0.673	0.217	0.047	0.247	1.099	3.098	0.002*
Kırıcı and Bakırcı (2021)	3.201	0.376	0.142	2.463	3.938	8.507	0.000*
Kuvac and Koc (2018)	0.474	0.280	0.079	-0.075	1.023	1.692	0.091
Lin et al., (2021)	0.714	0.189	0.036	0.344	1.084	3.784	0.000*
Lu et al., (2020a)	1.042	0.289	0.084	0.475	1.609	3.602	0.000*
Lu et al., (2020b)	0.802	0.282	0.80	0.248	0.355	2.843	0.004*
Lu et al., (2020c)	1.637	0.301	0.099	1.048	2.226	5.448	0.000*
Lu et al., (2020d)	0.476	0.266	0.069	-0.040	0.991	1.809	0.070
Ping et al., (2020a)	2.541	0.321	0.103	1.911	3.170	7.911	0.000*
Ping et al., (2020b)	1.072	0.255	0.065	0.572	1.573	4.198	0.000*
Ramirez and Monterola (2019)	0.778	0.233	0.054	0.322	1.234	3.343	0.001*
Songsil (2019)	1.469	0.229	0.053	1.021	1.917	6.428	0.000*
Tan et al., (2020)	-0.367	0.302	0.091	-0.959	0.225	-1.215	0.224
Ural and Dadli (2020)	0.279	0.272	0.074	-0.254	0.812	1.026	0.305
Ural and Gençoğ (2020)	0.210	0.239	0.057	-0.258	0.678	0.881	0.379
Pooled	0.893	0.138	0.019	0.622	1.164	6.464	0.000*
Prediction Interval	0.893			-0.470	2.247		



*Note: *p < 0.05*

Out of the 26 effect sizes extracted from the 20 studies, 16 effect sizes found statistically significant p-values, indicating notable differences (p < .05) in the posttest mean scores between the experimental and control groups concerning students' higher-order thinking skills. This reflects that students exposed to the inquiry-based approach had increased opportunities for hands-on and minds-on learning, enhancing their thinking skills compared to students exposed to the conventional approach. However, 10 effect sizes found no significant differences (p > .05) in students' higher-order thinking skills based on the posttest mean scores between the experimental and control groups. This lack of significance could be attributed to a variety of factors, including the instructional strategy employed in the control group. Some of the included studies incorporated inquiry-based activities in the control group by integrating concept mapping, problem-solving, group discussions, and brainstorming into their existing curricula (Al-Balushi et al., 2017b; Afifa et al., 2021; Deniş-elikere & Dere, 2022b), which could have potentially increased the performance of the students in the control group.

Given the positive and large overall weighted effect size of g = 0.893, these findings of the present meta-analysis are consistent with previous studies that established the potential of inquiry-based learning in fostering students' thinking skills (Duran & Dökme, 2016; Oztürk et al., 2022; Rahmi et al., 2019; Thaiposria & Wannapiroon, 2015). This positive outcome can be associated with the inherent constructivist nature of the inquiry-based approach, falling within the realm of inductive teaching approaches. This approach empowers students to engage in exploration and interpretation of a range of a set of observations or data, or a complex real-world problem (Prince & Felder, 2006). It is a learner-centered approach to teaching, emphasizing student learning over the mere transmission of content or knowledge (Kember, 1997). The scientific processes afforded by inquiry-based approach underscore vital facets of scientific thinking (Pedaste et al., 2015). It creates opportunities to spark students' curiosity through scientific inquiry; enable students to gather evidence for formulating explanations related to scientific questions; evaluate their explanations, potentially including alternative interpretations rooted in scientific comprehension; and effectively communicate and substantiate proposed explanations (National Research Council, 2000). These processes allow students to effectively harness their higher-order thinking skills, enabling them to adeptly fulfill assigned tasks.

Moderator Analysis of the Included Studies Using Inquiry-based Approach

Considering the significant heterogeneity analysis, inquiry-based approaches were found to have a varied impact on students' higher-order thinking skills based on the included studies (p < .05). Thus, moderator analysis was conducted using the following variables: the country of study, the specific higher-order thinking skill under investigation, the educational level of student-participants, the scientific discipline focus, the level of inquiry associated, and the duration of implementation. Table 4 presents the results of the moderator and subgroup analyses of studies that investigated the effect of inquiry-based approach on students' higher-order thinking skills. The effect sizes (Hedges' g) of the subgroups are arranged in descending magnitude, starting from the largest effect size down to the smallest effect sizes.

Table 4. Moderator and Subgroup Analyses of Studies that investigated the Effect of Inquiry-based Approach

Moderator	**Subgroups**	**k**	**Test for Effect**			**Test for Heterogeneity**	
			Hedges' g	95% CI		Q-value	p-value
				LL	**UL**		
Country	Lebanon	1	2.81	1.923	3.697	37.253	0.000*
	Malaysia	3	1.474	0.52	2.428		

	Thailand	1	1.469	1.021	1.917		
	Indonesia	3	0.995	0.004	1.986		
	Taiwan	4	0.976	0.499	1.453		
	Turkey	8	0.745	0.217	1.273		
	China	1	0.714	0.344	1.084		
	Philippines	3	0.323	-0.274	0.921		
	Oman	2	0.288	-0.171	0.747		
Higher-order thinking Skill	argumentative thinking	2	1.981	0.932	3.03	26.530	0.005*
	creative thinking	2	1.879	-0.695	4.452		
	critical thinking	4	1.472	0.695	2.249		
	inquiry skills	4	1.016	0.426	1.607		
	higher-order thinking	1	0.861	0.351	1.371		
	logical thinking	1	0.778	0.322	1.234		
	problem-solving	1	0.714	0.344	1.084		
	spatial thinking	1	0.524	0.015	1.034		
	process skills	5	0.371	-0.052	0.793		
	reflective thinking	2	0.323	-0.074	0.719		
	metacognitive thinking	2	0.292	-0.077	0.662		
	scientific reasoning	1	0.056	-0.445	0.557		
Educational Level	Secondary	20	0.969	0.611	1.327	2.234	0.327
	Elementary	4	0.732	0.488	0.976		
	Tertiary	2	0.598	0.262	0.935		
Scientific Discipline	Physics	9	1.131	0.591	1.671	4.366	0.359
	Biology	6	0.974	0.257	1.691		
	Chemistry	6	0.734	0.162	1.306		
	Earth Science	4	0.647	0.4	0.894		
	Earth Science and Chemistry	1	0.471	0.055	0.886		
Inquiry Level	open inquiry	2	1.659	-1.339	4.657	5.008	0.082
	guided inquiry	19	0.957	0.674	1.240		
	structured inquiry	5	0.388	-0.043	0.818		
Duration	16-18 weeks	1	1.469	1.021	1.917	20.247	0.005*
	4-6 weeks	5	1.248	0.182	2.313		
	19-21 weeks	4	0.976	0.499	1.453		
	7-9 weeks	10	0.897	0.389	1.404		
	10-12 weeks	3	0.651	0.402	0.9		
	1-3 weeks	1	0.575	-0.031	1.181		
	22-24 weeks	1	0.471	0.055	0.886		
	13-15 weeks	1	0.141	-0.359	0.642		

*Random-effects model, *p < 0.05;*

In terms of the country of implementation, the study conducted in Lebanon (n = 1) yielded the largest effect size on students' higher-order thinking skills (g = 2.81), followed by studies in Malaysia (g = 1.474), Thailand (g = 1.469), Indonesia (g = 0.995), and Taiwan (g = 0.976). Medium effect sizes were found in studies from China (g

= 0.714) and Turkey (g = 0.745). The studies in the Philippines (g = 0.323) and Oman (g = 0.288) produced small effect sizes. The heterogeneity test indicates that the effect sizes of the included studies differ significantly when grouped by country of implementation (Q_b = 37.253; $p < .05$). These results are inconclusive given the limited number of studies included in each subgroup. Despite the heterogeneity, these studies showed positive effects in favor of the inquiry-based approach.

The varying degrees of effectiveness revealed in the results could be attributed to the science education curriculum followed by these countries, students' cultural backgrounds, and the type of inquiry-based approach and its actual implementation. For instance, Malaysia's science curriculum encourages explicit teaching of science process skills, utilizing practical work through inquiry as a strategy to enhance students' science process skills (Ping et al., 2020). In Thailand, strategies were found ineffective in promoting argumentative expression; hence, the implementation of an argument-driven inquiry approach resulted in large effect sizes for students' higher-order thinking skills (Songsil et al., 2019). While the Philippine curriculum promotes inquiry-based learning, students may lack the necessary knowledge and experience in conducting scientific inquiry investigations, crucial for developing higher-order thinking skills. Notably, studies in the Philippines and Oman focused on developing students' process skills and spatial logical thinking, which require longer exposure to yield significant results or larger effect sizes (Fischer, 2009; Schwartz & Fischer, 2006).

When the studies were grouped by the higher-order thinking skill examined, it was found that using an inquiry-based approach had the most significant impact on enhancing students' argumentative thinking (g = 1.981), followed by creative thinking (g = 1.879), critical thinking (g = 1.472), inquiry skills (g = 1.016), and overall higher-order thinking (g = 0.861). Students' logical thinking (g = 0.778), problem-solving (g = 0.714), and spatial thinking (g = 0.524) showed medium effects. Meanwhile, process skills, reflective thinking, and metacognitive thinking displayed marginal effects (g = 0.371, g = 0.323, and g = 0.292, respectively). However, students' scientific reasoning showed no significant effect (g = 0.056). Taken together, a significant difference was found when studies were grouped based on different higher-order thinking skill outcomes (Q_b = 26.530; $p < .05$).

In studies by Ping et al., (2020) and Songsil (2019), the argument-driven inquiry approach was used as the primary instructional approach, which likely contributed to the largest effect sizes seen in students' argumentative thinking. Encouraging students to develop and defend scientific arguments based on their inquiry-based investigations provided opportunities for students to actively engage in scientific argumentation, thus maximizing their argumentative thinking skills. For example, Ping et al., (2020) utilized the 7E inquiry approach, embedding argument-driven inquiry in data analysis and argumentation phases. In the study by Songsil (2019), socioscientific issues (SSI) were used during argumentation sessions, possibly explaining the large effect sizes obtained. Altogether, these findings add to the growing body of literature on the effectiveness of scientific argumentation in developing students' higher order thinking skills (Giri & Paily, 2020; Foutz, 2018; Hasançebi et al., 2021; Sari & Islami, 2020).

Conversely, small effect sizes were observed in students' process skills, reflective thinking, and metacognitive thinking. According to Chen et al., (2019), developing higher-order thinking skills, including reflective thinking skills, requires time and consistent exposure to inquiry experiences that put a premium on metacognitive and reflective thinking (Antonio, 2020; Fischer, 2009; Schwartz & Fischer, 2006). Some studies lacked clear learning opportunities for the development of these skills; for instance, Deniş-Çelikere and Dere (2022) combined problem-based learning with experiments, where students completed assessments but had limited chances for reflection. It is therefore important for teachers to incorporate reflective learning opportunities during inquiry-based learning experiences among students. Integrating metacognition and reflection during inquiry-based learning has the potential to enhance students' learning outcomes (Antonio, 2020; Farah & Ayoubi, 2020; Seraphin et al., 2012). Recent studies highlight that metacognition, involving the understanding and regulation of one's thinking, can lead students towards authentic engagement and thoughtful learning (Akben, 2020; Stanton et al., 2022). Employing metacognitive strategies, such as metacognitive scaffolding and prompts, can effectively support students in accomplishing their inquiry-based tasks (Kalemkus & Bulut-Ozek, 2022).

As regards the educational level, the inquiry-based approach most significantly benefited students at the secondary level ($g = 0.969$), followed by those at the elementary ($g = 0.732$) and tertiary ($g = 0.598$) levels, resulting in medium effects. The effect sizes across the included studies did not significantly differ from one another ($Q_b = 2.234$; $p > .05$). This outcome further establishes that the effectiveness of the inquiry-based approach in enhancing students' higher-order thinking skills did not vary based on students' educational levels. Regardless of the educational level, the use of inquiry approaches seems to consistently yield positive results on students' higher-order thinking skills; hence, science teachers are encouraged to employ it in teaching scientific concepts, either at elementary or tertiary level. Interestingly, a greater effect was observed among secondary students, which might be attributed to their heightened curiosity and interest in scientific investigations during their adolescent years. Furthermore, the popularity of inquiry-based learning in secondary schools could have contributed to its greater impact among these students.

Concerning scientific disciplines, the inquiry-based approach had the most pronounced impact on enhancing students' higher-order thinking skills in Biology ($g = 0.974$) and Physics ($g = 1.131$). Earth science ($g = 0.647$) and Chemistry ($g = 0.734$) both showed medium effect sizes, while a smaller effect size was found in Chemistry and Earth Science ($g = 0.471$). Overall, no significant differences were observed among the effect sizes of the included studies when grouped by scientific discipline investigated ($Q_b = 4.366$; $p > .05$). The larger effect sizes in Biology and Physics could be attributed to the inherent nature of these disciplines. The abstract and complex nature of Biology and the hands-on experiences required in Physics align well with the inquiry-based approach. Given that no significant differences were observed among the effect sizes when the scientific discipline was taken into account, these findings underscore that inquiry-based learning can be successfully applied to teach a diverse range of scientific concepts, leading to improved scientific learning and enhanced higher-order thinking skills.

Finally, when examining the inquiry-based approaches in terms of inquiry level, open inquiry-based approaches had the most substantial effect size ($g = 1.659$), followed by guided inquiry ($g = 0.957$), whereas structured inquiry yielded a small effect size ($g = 0.388$). However, no significant difference was found across the different inquiry levels ($Q_b = 5.008$; $p > .05$). Notably, open inquiry is often considered the most challenging level of inquiry-based learning. In here, the teacher presents a context while students select their own inquiry questions, design their experiments, and draw conclusions (Abaniel, 2021).

The largest effect size noted in open inquiry level can be linked to its affordances, including the provision of greater autonomy, promotion of higher-order thinking, and fostering a deeper understanding of science concepts (Sadeh & Zion, 2011). Meanwhile, guided inquiry involves the teacher providing research questions, with students designing experiments to answer them. While structured inquiry focuses on hands-on investigations through teacher-provided questions and procedures, higher levels of inquiry, particularly guided and open inquiry, better enhanced students' higher-order thinking skills.

Hence, this could be the probable reason of the larger effect size obtained for guided and open inquiry levels. Literature showed that structured inquiry is insufficient for developing critical thinking skills (Berg et al., 2003). Nonetheless, the findings suggest that students' higher-order thinking skills can be developed regardless of the inquiry level. Therefore, it is encouraged for teachers to continue employing inquiry-based approach across various levels of inquiry in teaching scientific concepts to cultivate students' higher-order thinking skills.

Moreover, regarding the implementation duration of the inquiry-based approach, it's worth noting that positive effect sizes were calculated albeit varying durations. The study that utilized the inquiry-based approach over 16-18 weeks yielded the largest effect size of $g = 1.469$. This was followed by five studies with an inquiry-based approach lasting 4-6 weeks ($g = 1.248$), four studies lasting 19-21 weeks ($g = 0.976$), and ten studies lasting 7-9 weeks ($g = 0.897$).

Studies lasting 10-12 weeks ($g = 0.651$) and 1-3 weeks ($g = 0.575$) showed medium effect sizes, while studies spanning 22-24 weeks ($g = 0.471$) yielded small effect sizes. No effect was observed in studies spanning 13-15 weeks. The heterogeneity test indicates significant differences in effect sizes when considering implementation duration ($Q_b = 20.247$; $p < 0.05$). The novelty effect, leading to positive results when introducing an inquiry-based approach, might explain the diminished effect over time (Clark, 1983). While positive effect sizes were achieved, these results emphasize the importance of considering the implementation duration of the inquiry-based approach in teaching. Hence, teachers should vary instructional approaches to sustain students' learning motivation and engagement.

Inquiry-based Approaches employed in the Included Studies

The inquiry-based instructional approaches employed in the included studies were also identified to generate valuable information on the current state of literature about inquiry-based learning and students' higher-order thinking skills in science learning. Figure 2 illustrates the effect sizes of these approaches, organized in descending order of magnitude.

The present meta-analysis revealed the diverse inquiry-based approaches employed by the individual studies to improve students' higher-order thinking skills within the context of science learning. Specifically, out of the 20 included studies, 15 distinct inquiry-based approaches were identified and applied in teaching various scientific concepts across different educational levels. Argument-driven inquiry emerged as a prominent approach, featured in multiple studies (Afifa et al., 2021; Deprem et al., 2022; Eymur, 2018; Işıker & Emre, 2021; Karakas & Sarikaya, 2020; Ural & Gençoğ, 2020). This approach encourages students to formulate and defend scientific arguments based on their inquiry-based investigations (Antonio & Prudente, 2021).

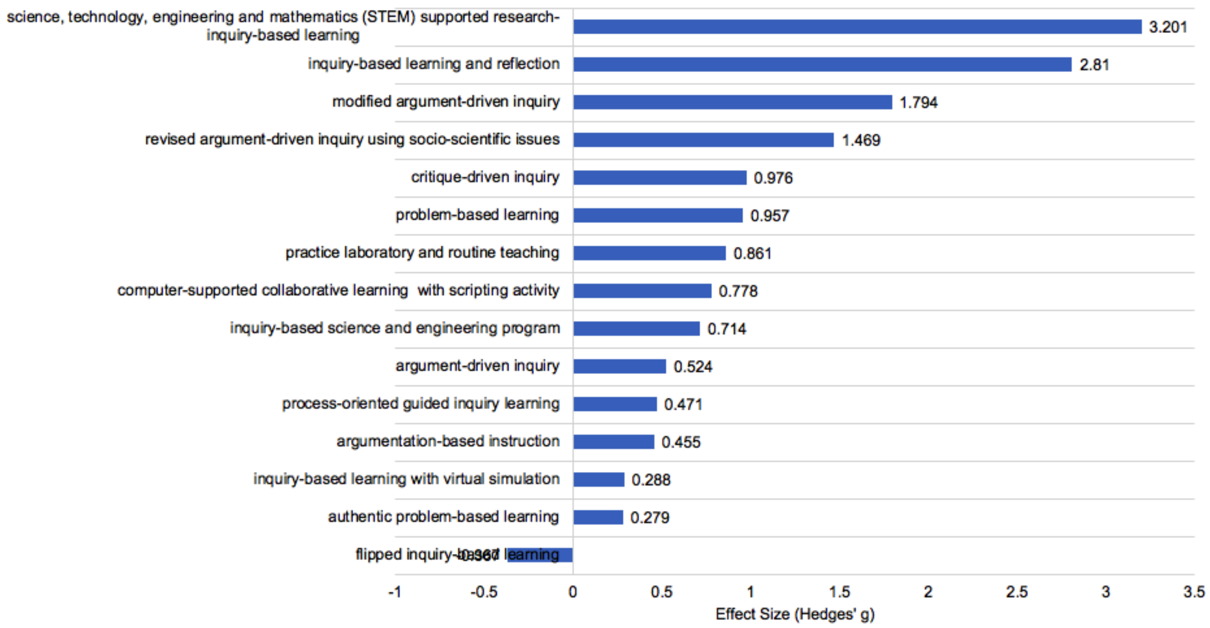


Figure 2. Inquiry-based Approaches employed in the Included Studies

Note: Effect size magnitude was classified according to Cohen's (1988) criteria: large (g ≥ 0.80), medium (0.50 ≤ g ≤ 0.79), small (0.20 ≤ g ≤ 0.49), and no effect (g < 0.19).

Additionally, variations of this approach were found, such as the modified argument-driven inquiry (Lu et al., 2020), critique-driven inquiry (Ping et al., 2020), and revised argument-driven inquiry using socio-scientific issues (Songsil, 2019), highlighting the adaptability of the approach to cater to different educational contexts and respond to societal issues. On the other hand, problem-based learning was seen to be another widely adopted strategy (Deniş-Çelikere & Dere, 2022; Kuvac & Koc, 2018; Ural & Dadli, 2020). This student-centered approach involves challenging students with authentic and complex problems to solve, fostering their problem-solving skills, and encouraging deeper understanding and engagement with the subject matter (Funa & Prudente, 2021). Meanwhile, inquiry-based learning, both in its standard form and combined with virtual simulations, was adapted by several studies (Al-Balushi et al., 2017). The incorporation of virtual simulations allows students to explore concepts in a controlled yet immersive digital environment, promoting hands-on and minds-on experiences (Antonio & Castro, 2023).

Furthermore, modifications have been made to improve inquiry-based instruction in the form of flipped inquiry-based learning (Tan et al., 2020) and process-oriented guided inquiry learning (Idul & Caro, 2022), proving its applicability in various learning modalities. Moreover, the inclusion of interdisciplinary approaches was evident, such as the integration of STEM (science, technology, engineering, and mathematics) components within research-inquiry-based learning (Kırıcı and Bakırcı, 2021; Lin et al., 2021), underscoring the value of interdisciplinary connections in fostering a deeper comprehension of scientific concepts. Several studies underscored the importance of critical reflection and collaborative learning. Furthermore, Farah and Ayoubi (2020) integrated reflection into inquiry-based learning, enhancing metacognition and fostering a deeper understanding. Similarly, Ramirez and Monterola (2019) implemented collaborative learning with scripting activities to facilitate collaborative problem-solving, highlighting the social nature of scientific inquiry. The emphasis on reflection and collaborative learning reinforces the need to nurture metacognitive thinking and interpersonal skills alongside subject-specific knowledge during inquiry-based learning.

Employing Cohen's (1998) criteria, seven (7) of these approaches exhibited effect sizes that could be categorized as having a positive and large impact on students' higher-order thinking skills. These approaches, listed in decreasing order of effect size magnitude in Figure 2, are as follows: science, technology, engineering, and mathematics (STEM)-supported research-inquiry-based learning, inquiry-based learning and reflection, modified argument-driven inquiry, revised argument-driven inquiry using socio-scientific issues, critique-driven inquiry, problem-based learning, and practice laboratory and routine teaching.

Upon closer examination, it becomes apparent that inquiry-based approaches have been integrated with other teaching approaches to enhance students' scientific learning and higher-order thinking abilities. The identification of various approaches used in the studies included in the meta-analysis is indicative of the continuous improvement of teaching practices. Science teachers are innovating inquiry-based learning approach by integrating multiple strategies in their science classrooms to cultivate students' higher-order thinking skills. For example, Kirc and Bakrc (2021) integrated STEM activities and inquiry-based learning to teach secondary students about force and energy, resulting in the highest effect size of g = 3.201. In this study, students formulated questions, designed and conducted experiments to find answers, demonstrating an open inquiry level. Contextualization and interdisciplinary learning were evident due to the incorporation of relevant force and energy issues, potentially contributing to the development of higher-order thinking skills. Similarly, Dongsil et al., (2019) introduced socio-scientific issues in a Grade 10 science unit to contextualize students' argument-driven inquiry learning (g = 1.469). This approach, involving interdisciplinary contextualization and inquiry-based methods, aligns with existing literature indicating students' development of scientific knowledge, higher-order thinking skills, and mindset to innovate for real-world problems (Acut & Antonio, 2023).

Medium effect sizes were obtained for the following inquiry-based approaches: computer-supported collaborative learning with scripting activity (g = 0.778), inquiry-based science and engineering programs (g = 0.714), and argument-driven inquiry (g = 0.524). Ramirez and Monterola (2019) utilized computer-supported collaborative learning (CSCL) with scripting activity, where ideas were encapsulated within a worksheet acting as a script. This structured inquiry approach likely contributed to the medium effect size. Similarly, Lin et al., (2021) implemented an inquiry-based science and engineering program for kindergarten pupils, with the medium effect size possibly reflecting the extensive scaffolding required for young learners to develop higher-order thinking skills.

Additionally, small effect sizes were observed for process-oriented guided inquiry learning (g = 0.471), argumentation-based instruction (g = 0.455), inquiry-based learning with virtual simulation (g = 0.288), and authentic problem-based learning (g = 0.279). Idul and Caro (2022) utilized process-oriented guided inquiry worksheets focused on concept exploration, development, and application. The small effect size could partly be attributed to the novelty effect, given the exposure to POGIL-based activities for two quarters. Social loafing can could have also occurred during collaborative tasks such as POGIL, impacting group effort. On a different note, Tan et al., (2020) reported a negative effect size (g = -0.367) while comparing the effectiveness of inquiry-based and flipped inquiry-based classrooms on science process skills, based on posttest mean scores. Notwithstanding this observation, Tan et al., (2020) explained that the findings from the independent samples t-test revealed that there was no significant difference between the flipped inquiry and non-flipped inquiry groups for each science process skill.

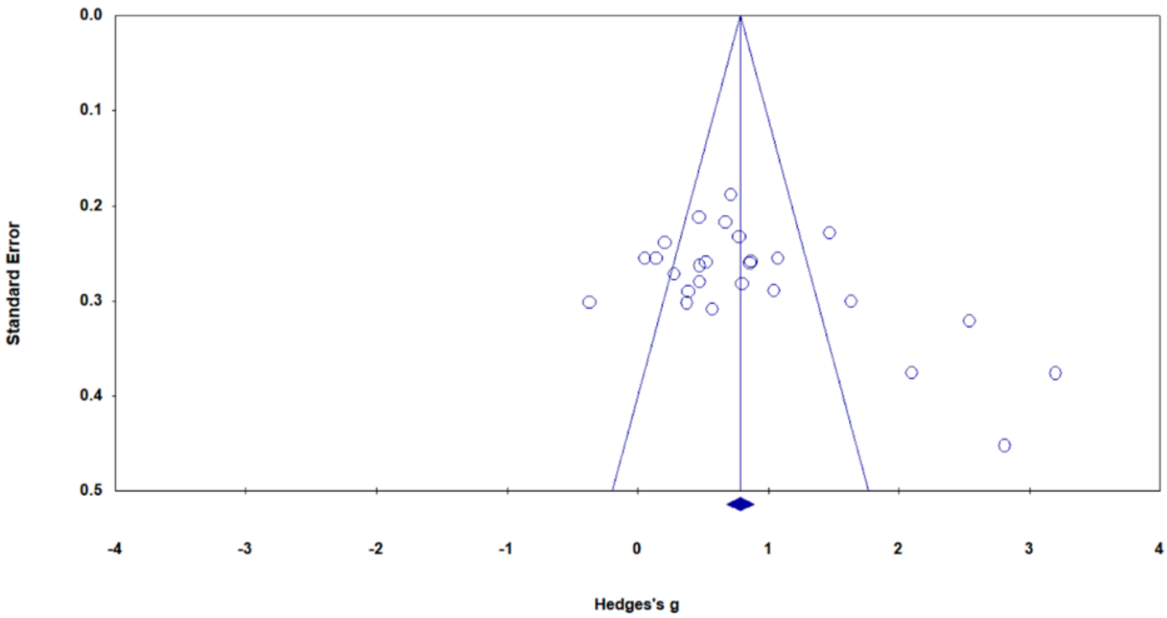
Additionally, results showed that the post-test mean scores of these groups were significantly higher than their respective pretest mean scores. These findings suggest that while a flipped learning environment provides flexibility, in-class sessions can deliver heightened social interaction and learning activities (Abate, 2004; Antonio & Prudente, 2021) that align well with an inquiry-based approach. However, due to the limited number of studies examining this variable in the meta-analysis, conclusive results regarding the effectiveness of the inquiry-based approach on students' process skills remain elusive.

In recent times, technology has evolved into an indispensable tool for enhancing the delivery of a more profound scientific learning experience among students. This advancement presents the potential to offer students novel avenues through which they can enhance their problem-solving, critical thinking, and communication skills (Saavedra & Opfer, 2012). Chan and Yang (2018) underscored the importance of technology integration in guiding students towards actively participating in inquiry practices akin to those employed by scientists. This facilitates a deeper comprehension of science and the acquisition of meaningful scientific learning experiences. Consequently, students not only improve their scientific knowledge but also develop essential 21st-century skills and competencies. In the present meta-analysis, however, when the presence of technology integration in the included studies was examined, it was found that only 15% of the studies utilized technology to deliver an inquiry-based approach aimed at enhancing students' higher-order thinking skills.

For instance, Al-Balushi et al., (2017) employed virtual simulations to enhance students' spatial thinking. These virtual simulations served multiple purposes, including: (1) introducing the topic— students viewed animations to construct fundamental ideas about the subject; (2) serving as the main activity during the lesson— students watched animations and completed formative learning worksheets to aid comprehension and reflection on the animation content; and (3) acting as a summative activity—students engaged with the animation by performing the simulation part of the package, if feasible. On the other hand, Ramirez and Monterola (2019) allowed students to utilize earth science courseware as a collaborative learning environment. In this teaching approach, each group accomplished various subtasks that contributed to the completion of the designated courseware module. Given this consideration, it is recommended that teachers and researchers in science education integrate educational technology into the implementation of inquiry-based learning. The influence of technology-enhanced inquiry on students' learning outcomes, with a particular focus on higher-order thinking skills, may also be examined.

Publication Bias

The potential for publication bias was assessed by examining the funnel plot. As depicted in Figure 3, the funnel plot analysis visually displayed an asymmetrical funnel, resulting from an uneven distribution around the average effect sizes.



Hedges' *g*

Z-value for observed studies	15.9407	Tails	2.000000	Number of missing studies that would bring p-value to > alpha	1694.000
P-value for observed studies	0.000000	Z for alpha	1.959960		
Alpha	0.050000	Number of observed studies	26.00000		

Figure 3. Standard Error Funnel Plot of Publication Bias

To verify this observation, Begg-Mazumdar rank correlation and fail-safe N tests were conducted. The Begg-Mazumdar rank correlation calculated Kendall's tau as 0.24 ($p > 0.05$). Moreover, the results of the classical fail-safe N tests indicated that in order to nullify the overall effect size and render the p-value non-significant ($p > .05$), an additional 1,694 studies would need to be included in this meta-analysis. Based on the Begg-Mazumdar rank results, it can be concluded that there is no evidence of publication bias in the meta-analysis.

Conclusion

The objective of this meta-analysis was to examine the effectiveness of inquiry-based approaches in developing students' higher-order thinking skills within the context of science learning, spanning the timeframe from January 2017 to September 2022. The meta-analysis of twenty (20) studies that examined the effectiveness of inquiry-based approaches resulted in a positive and large effect on students' higher-order thinking skills. In comparison to students who received conventional instructional approaches, those who engaged in inquiry-based learning demonstrated superior higher-level thinking abilities. Through moderator analysis, existing researches on the effects of inquiry-based approach on students' higher-order thinking skills yielded varying results across countries.

Significant differences were also found when the effect sizes of the individual studies were grouped according to students' higher-order thinking skill and implementation duration; however, there were no discernible differences in the students' educational level, scientific discipline, and inquiry level. These findings suggest that regardless of students' educational level, scientific discipline, or level of inquiry, the use of inquiry-based approach in teaching scientific concepts has the potential to maximize students' higher-order thinking skills.

Moreover, several inquiry-based approaches have been used to improve students' higher-order thinking skills, including STEM-supported research-inquiry, inquiry-based learning and reflection, argument-driven inquiry, socio-scientific issues, and problem-based learning. The integration of inquiry-based approaches with other instructional strategies to enhance students' higher-order thinking skills has become evident based on the included studies. The identification of various approaches is indicative of the continuous improvement of teaching practices. Science teachers are innovating inquiry-based learning approach by integrating multiple strategies in their science classrooms to cultivate students' higher-order thinking skills. Few studies, however, have integrated technology in the form of virtual simulations and courseware into an inquiry-based approach to foster students' higher-order thinking skills.

Recommendations

Science teachers at all levels of education are encouraged to use inquiry-based approaches to teach scientific concepts and to assist their students develop higher-order thinking skills. Professional development training programs on inquiry-based approaches could be developed and implemented to assist in-service teachers further improve their instructional practices resulting in students' improved higher-order thinking skills. Greater emphasis must be placed on developing teachers' technological and pedagogical knowledge of inquiry-based approaches adaptive in the blended learning environment. Equal importance must also be placed on developing preservice science teachers' self-efficacy, understanding, and competencies in designing and implementing inquiry-based learning experiences. Future research could investigate the effectiveness of other innovative inquiry-based approaches with technology integration in developing students' higher-order thinking skills, particularly process skills, scientific reasoning, reflective and metacognitive thinking.

Acknowledgements

The authors would like to express their sincerest gratitude to the Department of Science and Technology – Science Education Institute, National Research Council of the Philippines, De La Salle University, and Bulacan State University for the support given in this study.

References

***Included studies in the meta-analysis**

Abaniel, A. (2021). Enhanced conceptual understanding, 21st century skills and learning attitudes through an open inquiry learning model in Physics. *JOTSE*, *11*(1), 30-43.

Abate, L. M. (2004). Blended model in the elementary classroom. TeachLearning. (11.12.2014). Retrieved from http://www.techlearning.com/story/showArticle/jhtml?articleID= 5200

Acut, D., & Antonio, R. (2023). Effectiveness of Science-Technology-Society (STS) approach on students' learning outcomes in science education: Evidence from a meta-analysis. *JOTSE*, *13*(3), 718-739.

*****Afifa, I. N., Hasnunidah, N., & Maulina, D. (2021). Effectiveness of argument-driven inquiry (ADI) learning model on students' creative thinking skill: Environmental pollution. *Biosfer: Jurnal Pendidikan Biologi*, *14*(1), 1-12.

Akben, N. (2020). Effects of the problem-posing approach on students' problem solving skills and metacognitive awareness in science education. *Research in Science Education*, *50*(3), 1143-1165. https://doi.org/10.1007/s11165-018-9726-7

Aktamiş, H., Hiğde, E., & Özden, B. (2016). Effects of the Inquiry-Based Learning Method on Students' Achievement, Science Process Skills and Attitudes towards Science: A Meta-Analysis Science. *Journal of Turkish Science Education (TUSED)*, 13(4).

*****Al-Balushi, S. M., Al-Musawi, A. S., Ambusaidi, A. K., & Al-Hajri, F. H. (2017). The effectiveness of interacting with scientific animations in chemistry using mobile devices on grade 12 students' spatial ability and scientific reasoning skills. *Journal of Science Education and Technology*, *26*(1), 70-81.

American Association for the Advancement of Science. (1993). *Benchmarks for scientific literacy*. New York: Oxford University Press.

Antonio, R. P. (2022). Effectiveness of Blended Instructional Approach in Improving Students' Scientific Learning Outcomes: A Meta-Analysis. *Journal of Higher Education Theory and Practice*, 22(5), 221-239.

Antonio, R. P., & Prudente, M. S. (2021). Metacognitive argument-driven inquiry in teaching antimicrobial resistance: Effects on students' conceptual understanding and argumentation skills. *Journal of Turkish Science Education*, *18*(2), 192-217.

Antonio, R. P. (2020). Developing Students' Reflective Thinking Skills in a Metacognitive and Argument-Driven Learning Environment. *International Journal of Research in Education and Science*, *6*(3), 467-483.

Armagan, F.Ö., Keskin, M.Ö., & Akin, B.S. (2017). Effectiveness of conceptual change texts: A meta-analysis. *European Journal of Science and Mathematics Education*, 5(3), 343-354.

Artika, W., & Nurmaliah, C. (2023). Improving critical thinking skills through higher order thinking skills (hots)-based science. *International Journal of Instruction*, *16*(4).

Banchi, H., & Bell, R. (2008). The many levels of inquiry. *Science and children*, *46(*2), 26.

Barak, M., & Shakhman, L. (2008). Fostering higher-order thinking in science class: teachers' reflections. *Teachers and Teaching: theory and practice*, *14*(3), 191-208.

Berg, C. A. R., Bergendahl, V. C. B., Lundberg, B., & Tibell, L. (2003). Benefiting from an open-ended experiment? A comparison of attitudes to, and outcomes of, an expository versus an open-inquiry version of the same experiment. *International journal of science education*, *25*(3), 351-372.

Begg, C. B., & Mazumdar, M. (1994). Operating characteristics of a rank correlation test for publication bias. *Biometrics*, 1088-1101.

Borenstein, M. (2022). Comprehensive meta-analysis software. *Systematic Reviews in Health Research: Meta-Analysis in Context*, 535-548.

Borenstein, M., Cooper, H., Hedges, L., & Valentine, J. (2009). Effect sizes for continuous data. *The handbook of research synthesis and meta-analysis, 2*, 221-235.

Cairns, D., & Areepattamannil, S. (2019). Exploring the relations of inquiry-based teaching to science achievement and dispositions in 54 countries. *Research in science education*, *49*, 1-23.

Çakır, N. K., & Güven, G. (2019). Effect of 5E learning model on academic achievement and attitude towards the science course: A meta-analysis study. *Cukurova University Faculty of Education Journal*, *48*(2), 1111-1140. https://doi.org/10.14812/cufej.544825

Clark, R. E. (1983). Reconsidering research on learning from media. *Review of educational research*, *53*(4), 445–459.

Chan, C. K., & Yang, Y. (2018). Developing scientific inquiry in technology-enhanced learning environments.

Journal: Handbook of Comparative Studies on Community Colleges and Global Counterparts *Springer International Handbooks of Education,* 1-20

Chen, M. R. A., Hwang, G. J., & Chang, Y. Y. (2019). A reflective thinking-promoting approach to enhancinggraduate students' flipped learning engagement, participation behaviors, reflective thinking and project learning outcomes. *British Journal of Educational Technology*, *50*(5), 2288-2307.

Cohen, L., Manion, L., & Morrison, K. (2007). Research Methods in Education, 6th ed. *Routledge: Taylor and Francis Group.* 272-289. https://doi.org/10.4324/9780203029053

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd edition). Hillsdale, NJ: Lawrence Erlbaum. https://doi.org/10.4324/9780203771587

Conklin, W. (2011). *Higher-order thinking skills to develop 21st century learners.* Teacher Created Materials.

Creswell, J. (2013). Research design: Qualitative, quantitative, and mixed methods approach. 4th edition. *SAGE Publications, Inc.* http://doi.org/10.1002/nha3.20258

D'Angelo, C., Harris, C., & Rutstein, D. (2013). Systematic review and meta-analysis of STEM simulations. *Computer-Supported Collaborative Learning Conference (CSCL),* (2), 239-240.

*****Deniş-Çeliker, H., & Dere, S. The Effects of The Problem-Based Learnıng Supported by Experiments in Science Course: Students' Inquiry Learning and Reflective Thinking Skills. *Journal of Science Learning*, *5*(1).

Demaria, M., Barry, A., & Murphy, K. (2019). Using inquiry-based learning to enhance immunology laboratory skills. *Frontiers in immunology*, *10*, 2510.

*Deprem, S. T., Çakıroğlu, J., Öztekin, C., & Kıngır, S. (2022). Effectiveness of Argument-Based Inquiry Approach on Grade 8 Students’ Science Content Achievement, Metacognition, and Epistemological Beliefs. *International Journal of Science and Mathematics Education*, 1-23.

Duran, M., & Dökme, I. (2016). The effect of the inquiry-based learning approach on student's critical-thinking skills. *Eurasia Journal of Mathematics Science and Technology Education*, *12*(12).

Ellis, P. D. (2010). The essential guide to effect sizes. Statistical power, meta-analysis, and the interpretation of research result. New York: Cambridge University Press.

*****Eymur, G. (2018). Developing high school students’ self-efficacy and perceptions about inquiry and laboratory skills through argument-driven inquiry. *Journal of Chemical Education*, *95*(5), 709-715.

*****Farah, N., & Ayoubi, Z. (2020). Enhancing the critical thinking skills of grade 8 chemistry students using an inquiry and reflection teaching method. *Journal of Education in Science Environment and Health*, *6*(3), 207-219.

Fischer, K. W. (2009). Mind, brain, and education: Building a scientific groundwork for learning and teaching. *Mind, Brain, and Education*, *3*(1), 3–16.

Foutz, T. L. (2018). Using argumentation as a learning strategy to improve student performance in engineering Statics. *European Journal of Engineering Education*, 1-18.

Giri, V., & Paily, M. U. (2020). Effect of scientific argumentation on the development of critical thinking. *Science& Education*, *29*(3), 673-690.

Hasançebi, F., Güner, Ö., Kutru, C., & Hasancebi, M. (2021). Impact of Stem Integrated Argumentation Based Inquiry Applications on Students' Academic Success, Reflective Thinking and Creative Thinking Skills. *Participatory Educational Research*, *8*(4), 274-296.

Hurd, P. D. (1998). Scientific literacy: New minds for a changing world. *Science education*, *82*(3), 407-416.

Gough, D., Oliver, S., & Thomas, J. (Eds.). (2017). *An introduction to systematic reviews*. Sage.

Gutierez, S. B. (2015). Collaborative professional learning through lesson study: Identifying the challenges of inquiry-based teaching. *Issues in Educational Research*, *25*(2), 118-134.

Halim, A. S., Osman, K., Aziz, M. M., Ibrahim, M. F., & Ahmad, A. A. K. (2021, February). The competency of science teachers in integrating higher order thinking skills in teaching and learning. In *Journal of Physics: Conference Series* (Vol. 1793, No. 1, p. 012005). IOP Publishing.

Hedges, L., & Olkin, I. (1985). Statistical methods for meta-analysis. London: Academic Press.

Heindl, M. (2019). Inquiry-based learning and the pre-requisite for its use in science at school: A meta-analysis. *Journal of Pedagogical Research*, 3(2), 52-61.

Higgins, J. P., & Thompson, S. G. (2002). Quantifying heterogeneity in a meta-analysis. Statistics in medicine, 21(11), 1539-1558. http://www.centerforpubliceducation.org/Main-Menu/Policies/21st-Century/

Higgins, J.P.T., Thomas, J., & Chandler, J. (2019). *Cochrane Handbook for Systematic Reviews of Interventions: Version 6.0. Cochrane*. Available from https://training.cochrane.org/handbook.

*****Idul, J. J. A., & Caro, V. B. (2022). Does process-oriented guided inquiry learning (POGIL) improve students' science academic performance and process skills? *International Journal of Science Education*, *44*(12), 1994-2014.

*****Işiker, Y., & İrfan, E. M. R. E. The İmpact of Argumentation-Based İnstruction on Academic Achievements and Scientific Process Skills of Primary School Students and Their Attitudes towards the Science Course. *International Journal of Scholars in Education*, *4*(1), 1-14.

Ismail, N., Alias, S., & Albakri, I. (2006). Inquiry based learning: A new approach to classroom learning. *English Language Journal*, *2*(1), 13-24.

Jerald, C. D. (2009). *Defining a 21st Century Education. Center for Public Education*. http://www.centerforpubliceducation.org/Learn-About/21st-Century/Defining-a-21st-Century-Education-Full-Report-PDF.pdf

K to 12 Science Curriculum Guide (2016). *K to 12 Curriculum Guide Science (Grade 3 to Grade 10).* Retrieved from http://www.deped.gov.ph

Kaçar, T., Terzi, R., Arıkan, İ., & Kırıkçı, A. C. (2021). The Effect of Inquiry-Based Learning on Academic Success: A Meta-Analysis Study. *International Journal of Education and Literacy Studies*, *9*(2), 15-23.

Kalemkuş, F., & Bulut-Özek, M. (2022). The effect of online project-based learning on metacognitive awareness of middle school students. *Interactive Learning Environments*, 1-19.

*Kamarudin, N., TzeJiun, L., Talib, O., & Hassan, A. (2017). Enhancing higher order thinking skills via inquiry-based laboratory practices among science students. *Man In India*, *97*(17), 185-194.

*Karakaş, H., & Sarıkaya, R. (2020). The effect of argumentation-based teaching performed for environment-energy issues on critical thinking of prospective classroom teachers. Ilkogretim Online, 19(1), 366-383.

Kember D. (1997). A reconceptualisation of the research into university academics' conceptions of teaching. *Learning and Instruction*, *7*(3), 255–276.

Keselman, A. (2003). Supporting inquiry learning by promoting normative understanding of multivariable causality. *Journal of Research in Science Teaching*, *40*(9), 898-921.

*Kırıcı, M. G., & Bakırcı, H. (2021). The effect of STEM supported research-inquiry-based learning approach on the scientific creativity of 7th grade students. *Journal of Pedagogical Research*, *5*(2), 19-35.

Kirschner P., Sweller J. and Clark R., (2006), Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching, *Educ. Psychol.*, *41*(2), 75–86.

Kurniawati, T. (2021, November). Student's Higher Order Thinking Skilll's on Economics in The VUCA Era. In *Seventh Padang International Conference On Economics Education, Economics, Business and Management, Accounting and Entrepreneurship (PICEEBA 2021)* (pp. 253-256). Atlantis Press.

*Kuvac, M., & Koc, I. (2019). The effect of problem-based learning on the metacognitive awareness of pre-service science teachers. *Educational Studies*, *45*(5), 646-666.

Lazonder, A. W., & Harmsen, R. (2016). Meta-analysis of inquiry-based learning: Effects of guidance. *Review of educational research*, *86*(3), 681-718.

*Lin, X., Yang, W., Wu, L., Zhu, L., Wu, D., & Li, H. (2021). Using an inquiry-based science and engineering program to promote science knowledge, problem-solving skills and approaches to learning in preschool children. *Early Education and Development*, *32*(5), 695-713.

*Lu, Y. Y., Lin, H. S., Smith, T. J., Hong, Z. R., & Hsu, W. Y. (2020). The Effects of Critique Driven Inquiry Intervention on Students' Critical Thinking and Scientific Inquiry Competency. *Journal of Baltic Science Education*, *19*(6), 954-971.

Miterianifa, M., Ashadi, A., Saputro, S., & Suciati, S. (2021, January). Higher order thinking skills in the 21st century: critical thinking. In *Proceedings of the 1st International Conference on Social Science, Humanities, Education and Society Development, ICONS 2020, 30 November, Tegal, Indonesia*.

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Journal of Clinical Epidemiology*, *62*(10), 1006–1012. https://doi.org/10.1016/j.jclinepi.2009.06.005.

National Research Council. (2000). Inquiry and the National Science Standards. Washington, DC: National Academy Press.

Öztürk, B., Kaya, M., & Demir, M. (2022). Does inquiry-based learning model improve learning outcomes? A second-order meta-analysis. *Journal of Pedagogical Research*, 6(4), 201-216.

Pedaste, M., Mäeots, M., Siiman, L. A., De Jong, T., Van Riesen, S. A., Kamp, E. T., ... & Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational research review*, 14, 47-61.

Pigott, T. D., & Polanin, J. R. (2020). Methodological guidance paper: High-quality meta-analysis in a systematic review. *Review of Educational Research*, *90*(1), 24-46.

*Ping, I. L. L., Halim, L., & Osman, K. (2020). Explicit Teaching of Scientific Argumentation as an Approachin Developing Argumentation Skills, Science Process Skills and Biology Understanding. *Journal of Baltic Science Education*, *19*(2), 276-288.

Prayitno, B. A., & Titikusumawati, E. (2018). Enhancing Students' Higher Order Thinking Skills in Science through INSTAD Strategy. *Journal of Baltic Science Education*, *17*(6), 1046-1055.

Prince, M. J., & Felder, R. M. (2006). Inductive teaching and learning methods: Definitions, comparisons, and research bases. *Journal of engineering education*, *95*(2), 123-138.

Rahmi, Y. L., Alberida, H., & Astuti, M. Y. (2019, October). Enhancing students' critical thinking skills through inquiry-based learning model. *In Journal of Physics: Conference Series* (Vol. 1317, No. 1, p. 012193). IOP Publishing.

*****Ramirez, H. J. M., & Monterola, S. L. C. (2022). Co-creating scripts in computer-supported collaborative learning and its effects on students' logical thinking in earth science. *Interactive Learning Environments*, *30*(5), 908-921.

Ramnarain, U. (2018). Scientific literacy in East Asia: Shifting toward an inquiry-informed learning perspective. *Primary Science Education in East Asia: A Critical Comparison of Systems and Strategies*, 201-213.

Saavedra, A. R., & Opfer, V. D. (2012). Teaching and learning 21st century skills: Lessons from the learning sciences. *A Global Cities Education Network Report. New York, Asia Society*, *10*.

Sadeh, I., & Zion, M. (2012). Which type of inquiry project do high school biology students prefer: Open or guided?. *Research in Science Education*, *42*, 831-848.

Sari, I. J., & El Islami, R. A. Z. (2020). The Effectiveness of Scientific Argumentation Strategy towards the Various Learning Outcomes and Educational Levels Five Over the Years in Science Education. *Journal of Innovation in Educational and Cultural Research*, *1*(2), 52-57.

Sarı, K., & Şaşmaz Ören, F. (2020). The effect of inquiry-based learning strategy on the students' academic achievements: a meta-analysis study. *Hacettepe University Journal of Education*, *35*(3), 540-555. http://doi.org/10.16986/huje.2019052510

Şaşmaz Ören F., & Tezcan, R. (2009). The effectiveness of the learning cycle approach on learners' attitude toward science in seventh grade science classes of elementary school. *Elementary Education Online*, *8(*1), 103-118.

Schneider, R. M., & Krajcik, J. (2002). Supporting science teacher learning: The role of educative curriculum materials. *Journal of science teacher education*, *13*(3), 221-245.

Schraw, G., & Robinson, D. R. (2011). Assessment of higher order thinking skills. Charlotte: NC.

Schwartz, M. S., & Fischer, K. W. (2006). Useful metaphors for tackling problems in teaching and learning. *About Campus*, *11*(1), 2–9.

Scriven, M., & Paul, R. (1987, March). Critical thinking. In *The 8th Annual International Conference on Critical Thinking and Education Reform*, CA (Vol. 7, No. 9).

Seraphin, K. D., Philippoff, J., Kaupp, L., & Vallin, L. M. (2012). Metacognition as means to increase the effectiveness of inquiry-based science education. *Science Education International*, *23*(4), 366-382.

Silitonga, H. T. M., Panjaitan, M., & Supriyati, Y. (2020). Problem solving based physics learning strategy to enhance students' higher order thinking skills. *In Journal of Physics: Conference Series* (Vol. 1567, No. 4, p. 042104). IOP Publishing.

*****Songsil, W., Pongsophon, P., Boonsoong, B., & Clarke, A. (2019). Developing scientific argumentation strategies using revised argument-driven inquiry (rADI) in science classrooms in Thailand. *Asia-Pacific Science Education, 5*(1), 1-22.

Stanton, J. D., Sebesta, A. J., & Dunlosky, J. (2021). Fostering metacognition to support student learning and performance. *CBE—Life Sciences Education*, *20*(2), fe3. https://doi.org/10.1187/cbe.20-12-0289

Sulaiman, T., Muniyan, V., Madhvan, D., Hasan, R., & Rahim, S. S. A. (2017). Implementation of higher order thinking skills in teaching of science: A case study in Malaysia. *International research journal of education and sciences (IRJE*S), *1*(1), 2550-2158.

Sun, H., Xie, Y., & Lavonen, J. (2022). Exploring the structure of students' scientific higher order thinking in science education. *Thinking Skills and Creativity*, *43*, 100999.

*****Tan, R. M., Yangco, R. T., & Que, E. N. (2020). Students' Conceptual Understanding and Science Process Skills in an Inquiry-Based Flipped Classroom Environment. *Malaysian Journal of Learning and Instruction*, *17*(1), 159-184.

Tanujaya, B., Mumu, J., & Margono, G. (2017). The Relationship between Higher Order Thinking Skills and Academic Performance of Student in Mathematics Instruction. *International Education Studies*, *10*(11), 78-85.

Thaiposri, P., & Wannapiroon, P. (2015). Enhancing students' critical thinking skills through teaching and learning by inquiry-based learning activities using social network and cloud computing. *Procedia-Social and Behavioral Sciences*, *174*, 2137-2144.

Ural, E. (2016). The Effect of Guided-Inquiry Laboratory Experiments on Science Education Students' Chemistry Laboratory Attitudes, Anxiety and Achievement. *Journal of Education and Training Studies*, *4*(4), 217-227.

*Ural & Dadli, G. (2020). The effect of problem-based learning on 7th-grade students' environmental knowledge, attitudes, and reflective thinking skills in environmental education. *Journal of Education in Science Environment and Health*, *6*(3), 177-192.

*****Ural, E., & Gençoğlan, D. M. (2019). The effect of argumentation-based science teaching approach on 8th graders' learning in the subject of acids-bases, their attitudes towards science class and scientific process skills. *Interdisciplinary Journal of Environmental and Science Education, 16*(1), e02207.

Vassar M, Atakpo P, Kash MJ. Manual search approaches used by systematic reviewers in dermatology. Journal of the Medical Library Association (JMLA), *104*(4), 302-304. https://doi.org/10.5195/JMLA.2016.145

Wilson, C. (2020). The Effects of Inquiry-Based Learning and Student Achievement in the Science Classroom. *Student Research Submissions*. 370. https://scholar.umw.edu/student_research/370

Zheng, L., Li, X., Tian, L., & Cui, P. (2018). The effectiveness of integrating mobile devices with inquiry-based learning on students' learning achievements: a meta-analysis. *International Journal of Mobile Learning and Organisation*, *12*(1), 77-95.

Valtonen, T., Hoang, N., Sointu, E., Näykki, P., Virtanen, A., Pöysä-Tarhonen, J., ... & Kukkonen, J. (2021). How pre-service teachers perceive their 21st-century skills and dispositions: A longitudinal perspective. *Computers in Human Behavior*, *116*, 106643.

ŽivkoviĿ, S. (2016). A model of critical thinking as an important attribute for success in the 21st century. *Procedia-social and behavioral sciences*, *232*, 102-108.

Author Information

Ronilo Palle Antonio
https://orcid.org/0000-0002-2832-7203
De La Salle University
Taft Avenue, Manila
Bulacan State University
City of Malolos, Bulacan
Philippines
Contact e-mail: *ronilo_p_antonio@dlsu.edu.ph*

Maricar Sison Prudente
https://orcid.org/0000-0003-1156-0380
De La Salle University
Taft Avenue, Manila
Philippines