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DEVELOPING SCIENCE PROCESS SKILLS IN SCIENCE
EDUCATION: A COMPREHENSIVE SYSTEMATIC REVIEWNurashikin Muzafar¹, Nur Jahan Ahmad^{2*}¹ School of Educational Studies, Universiti Sains Malaysia, Malaysia
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Abstract:

The rapid evolution of science education necessitates innovative teaching approaches to equip students with essential scientific process skills (SPS). Despite the growing adoption of Inquiry-Based Learning (IBL), there remains a lack of comprehensive synthesis regarding its effectiveness in enhancing SPS, particularly in the context of technological integration. This systematic review aims to address this gap by (i) identifying current issues in SPS development, (ii) evaluating the objectives and methodologies of recent IBL studies, and (iii) synthesizing key findings to inform best practices. A total of 178 articles published between 2019 and 2023 were retrieved from Scopus and Web of Science databases, with 18 studies meeting the inclusion criteria through a rigorous PRISMA-based selection process. The analysis reveals that guided inquiry, supported by technology and scaffolded instruction, is the most effective IBL approach for fostering SPS among secondary school students. Key findings are categorized into three main themes: active engagement and hands-on experience, integration of modern technological tools, and structured guidance. The review highlights the importance of aligning IBL strategies with curriculum objectives, providing targeted teacher training, and addressing challenges such as resource limitations and varying student readiness. This study offers actionable recommendations for educators and policymakers to enhance SPS through effective IBL implementation and suggests future research directions to further optimize science education in a technology-driven era.

Keywords:

Active Engagement, Blended Learning, Curriculum Alignment, Digital Tools, Formative Assessment

Introduction

Science education plays a crucial role in equipping students with the skills needed to understand and interpret natural phenomena. However, concerns have been raised globally regarding students' declining interest and achievement in science subjects. For example, the Trends in International Mathematics and Science Study (TIMSS) 2019 reported that only 39% of Malaysian students achieved at least the intermediate international benchmark in science, indicating persistent challenges in science literacy and process skills (Mullis et al., 2020). Similar trends are observed in other countries, highlighting the urgent need for effective teaching approaches to enhance students' scientific competencies (OECD, 2019).

Among the various teaching approaches, Inquiry-Based Learning (IBL) has been widely recognized as an effective method for enhancing Science Process Skills (SPS). These skills, which include observing, inferring, classifying, predicting, and experimenting, are essential for fostering scientific literacy and preparing students to solve real-world problems (Kim & Hamdan Alghamdi, 2019). Unlike traditional teaching methods that emphasize rote memorization, IBL encourages active engagement, hands-on learning, and critical thinking, making it a transformative approach in science education (Hmelo-Silver et al., 2007).

While the effectiveness of IBL has been well-documented in previous reviews, these reviews often focus on general outcomes without addressing specific aspects of IBL implementation (Ananda & Usmeldi, 2023; Behera, 2023). For instance, there is limited exploration of how different types of IBL approaches such as guided, open, or structured inquiry impact the development of SPS in science educational contexts. Additionally, the rapid integration of technology into education has introduced new tools and methods, such as virtual laboratories and gamified learning platforms, which have not been comprehensively examined in relation to IBL and SPS. These gaps highlight the need for a systematic synthesis of recent studies to explore how IBL, when combined with modern technological advancements, can further enhance the development of SPS.

Science Process Skills (SPS) refer to the essential skills required to conduct scientific inquiry. In this study, SPS are operationally defined into two main categories based on the Science - A Process Approach (SAPA) curriculum between 1963 and 1974: Basic Science Process Skills (BSPS) and Integrated Science Process Skills (ISPS). Table 1 presents the classification and description of SPS:

Table 1: Classification And Description Of SPS

Science Process Skills	Description
Basic Science Process Skills (BSPS)	Observing
	Utilising one's senses of taste, smell, touch, hearing, or sight to learn more about things and phenomena.
	Measuring and Using Numbers
	To achieve an accurate measurement, perform quantitative observations utilising tools and numbers with standard units.
	Classifying
Integrated Science Process Skills (ISPS)	Relying on observations to classify things or phenomena based on similarities as well as differences.
	Inferring
Integrated Science Process Skills (ISPS)	Drawing conclusions and providing explanations for occurrences based on gathered data or prior experiences.
	Predicting
	Forecasting future events from data that has been gathered or from observations and past experiences.

Integrated Science Process Skills (ISPS)	Communicating	Explaining actions, things, or occurrences using words or visual representations like tables, diagrams, graphs, or models.
	Using Space-Time-Relationship	Detailing how parameters like mass, weight, volume, form, size, orientation, and location vary with time.
	Interpreting Data	Providing logical justifications for a thing, an occurrence, or a pattern based on data gathered.
	Defining Operationally	Providing a notion with meaning by outlining the necessary actions and observations.
	Controlling Variables	Overseeing fixed, responding, as well as manipulated variables.
	Hypothesising	Relationship between the responding and manipulated variables to explain a finding or occurrence. It is possible to test this claim or premise to see if it is valid.
	Experimenting	Organising and carrying out a controlled inquiry to verify a hypothesis, then gathering as well as analysing to draw a conclusion.

This paper addresses these gaps by conducting a systematic review of recent literature published between 2019 and 2023. While prior reviews have explored the general impacts of IBL on science education, this study builds upon these works by categorizing IBL approaches and identifying key themes, including active engagement, technology integration, and scaffolded learning. By addressing the lack of systematic reviews that examine these nuanced impacts on SPS in secondary education, this study provides fresh insights to guide educators, policymakers, and researchers in effectively integrating IBL into science curricula. The findings also contribute to the broader discourse on how innovative teaching methods can prepare students for the challenges of a rapidly evolving, technology-driven world.

Literature Review

IBL is a teaching method where students develop knowledge by applying techniques and methods similar to those used by professional scientists (Fredriksen et al., 2024; Waked et al., 2024). This approach emphasises the student's role in the learning process, which allows them to engage in activities such as questioning, investigating, reasoning, and problem-solving. IBL is rooted in constructivist theories of learning, which assert that learners develop their knowledge as well as comprehension of the world via experiences and reflecting on those experiences (Ouzzine et al., 2022).

The theoretical foundation of this study is grounded in the works of Piaget and Vygotsky, whose theories provide a lens to understand the relationship between IBL and SPS. Piaget's constructivist theory emphasizes active exploration, where learners construct knowledge through hands-on experiences, aligning with the principles of IBL. This approach fosters the development of SPS, such as observation, hypothesis formulation, and experimentation, as students engage in inquiry-based tasks. Similarly, Vygotsky's theory of social constructivism highlights the role of social interaction and scaffolding in learning. In IBL, students collaborate with peers and receive guidance from teachers, which enhances SPS such as data analysis, conclusion drawing, and communication. Together, these theoretical perspectives underpin the

systematic review conducted in this study, providing a framework to explore how IBL approaches impact the acquisition of SPS in science education.

IBL encompasses a spectrum of approaches, ranging from highly structured to open-ended, allowing educators to adapt instruction to students' needs and abilities (Lippmann, 2021; Ouzzine et al., 2022). By incorporating various types of IBL, teachers can design dynamic and stimulating learning settings that encourage students to think critically, solve problems, as well as having a deeper understanding of scientific concepts (Szalay, 2015; Dolenc & Kazanis, 2020; Ping et al., 2020; Panjaitan & Siagian, 2020).

IBL has been broadly recognised as an efficient pedagogical approach in science education, particularly for enhancing SPS among students (Ananda & Usmeldi, 2023). SPS are fundamental competencies that enable students to engage in scientific inquiry as well as gain a greater comprehension of scientific notions. Observing, inferring, measuring, communicating, predicting, managing variables, classifying, expressing theories, analysing data, as well as creating models are some of these abilities (Artayasa et al., 2023; Nurlaela, 2023; Owolade et al., 2022). The development of these skills is crucial for students' academic success and their ability to implement scientific knowledge in real-world contexts. Figure 1 illustrates the types of IBL and their descriptions, as published by the Curriculum Development Division, Ministry of Education Malaysia (CDC, MOE, 2016).

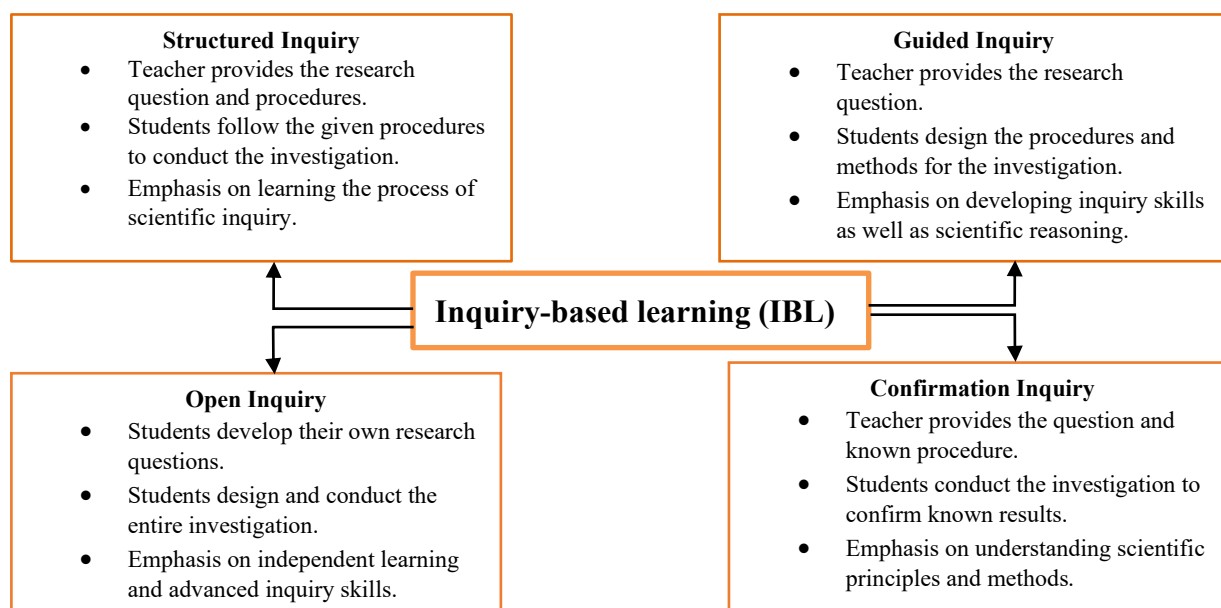


Figure 1: Types Of IBL And Their Descriptions

SPS are fundamental skills that allow students to participate in scientific inquiry as well as generate a deeper comprehension with regard to scientific concepts. These skills are essential for fostering scientific literacy and are often categorised into basic and integrated skills. A literature review uncovers substantial empirical evidence demonstrating the IBL's effectiveness in enhancing SPS among science education students.

This raises the Research Questions (RQs) below:

1. What is the effectiveness of different types of Inquiry-Based Learning (IBL) compared to non-inquiry-based approach in developing Science Process Skills (SPS) among students?
2. What is the impact of Inquiry-Based Learning (IBL) on the development of Science Process Skills (SPS) among students compared to a non-inquiry-based approach?

The first question is important because identifying the most effective types of IBL can help educators choose their teaching methods to maximise the development of students' SPS, leading to better educational outcomes. For the second question, understanding how IBL improves students' SPS is crucial for demonstrating the value of this educational approach and for refining it to enhance its effectiveness in fostering students' critical thinking as well as problem-solving abilities

Methodology

The systematic literature review process uses the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) framework, which consists of three primary phases detailed in subsections. The systematic literature review process follows the PRISMA framework, which includes three primary phases: 3.1 Identification, 3.2 Screening, and 3.3 Eligibility. Following data formulation, subsection 3.4 Data Abstraction and Analysis, details the review based on the PRISMA framework.

Identification

The systematic review process for this study involves three key stages to gather relevant research (Chin Yee Ha et al., 2023; Zainal et al., 2021). The first stage involves identifying keywords and exploring related and synonymous terms by consulting thesauri, lexicons, encyclopaedias, and previous scholarly works. Once all relevant keywords were discovered, and as Table 2 illustrates, search strings were made to query the Scopus as well as WoS databases. Scopus and WoS are chosen for their comprehensive coverage of peer-reviewed literature across various disciplines, ensuring a broad and thorough search.

These databases index high-quality journals, conference proceedings, and books, which helps maintain the credibility and reliability of the research. Both databases are widely recognised and respected in the academic community, making them standard choices for systematic reviews as well as bibliometric analyses. A total of 178 scholarly papers were successfully gathered from both databases for the years 2019 to 2023 during this first part with regard to the systematic review. In the process of conducting the search on the Web of Science (WOS) database, the search strings were applied to all publication years within the scope of this study. However, no relevant articles were identified for the years 2018 and 2019. As a result, these years are not included in Table 2. This absence reflects the unavailability of related publications during those years, rather than an intentional exclusion from the analysis.

Table 2: Search String

Database	Search String	Number Of Articles
Scopus	TITLE-ABS-KEY (("Inquiry") AND ("Science") AND ("Process") AND ("Skills") AND ("School") AND (LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR , 2023)) AND (LIMIT-TO (SUBJAREA , "SOC")) AND (LIMIT-TO (DOCTYPE , "Ar")) AND (LIMIT-TO (LANGUAGE , "English"))	103
Wos	"Inquiry" AND "Science" AND "Process" AND "Skills" AND "School" (Allfields) And 2023 Or 2022 Or 2021 Or 2020 Or 2017 (Publication Years) And Article (Document Types) And 2023 Or 2022 Or 2021 Or 2020 Or 2017 (Publication Years) And 2023 Or 2022 Or 2021 Or 2020 (Publication Years) And 2023 Or 2022 Or 2021 Or 2020 Or 2017 (Final Publication Year) And Article (Document Types) And English (Languages) And Article (Document Types)	75

Screening

Repetitive papers were excluded in the first screening stage, which led to the removal of 28 articles. Note that 178 publications were assessed in the second screening step according to precise inclusion and exclusion. The screening process involved a team of experienced researchers and academicians with expertise in science education and systematic reviews. These individuals evaluated the relevance and quality of the articles based on the inclusion and exclusion criteria. The primary criterion was the nature of the literature, with a focus on research articles for practical insights. Reviews, books, systematic reviews, meta-syntheses, meta-analyses, book series, as well as book chapters not aligned with the latest research were excluded. The selection process was limited to English-language publications from the past five years (2019 to 2023). The five-year range was selected to ensure the inclusion of the most recent and relevant studies, reflecting current trends in IBL and SPS research. These criteria led to the exclusion of 14 publications in total.

Eligibility

Correspondingly, 18 articles were gathered during the third phase, which is referred to as the eligibility evaluation. The inclusion criteria, as well as alignment with the current study objectives, were assessed by carefully analysing the titles as well as the main content of these articles. Consequently, 118 articles were excluded from the assessment for reasons such as having insignificant titles, abstracts not pertinent to the review objective, as well as being out-of-focus population. Ultimately, 18 articles remain available for re-view. Given the strict inclusion criteria and the comprehensive nature of the included studies, this sample size is considered sufficient to provide a robust understanding of the research topic. Moreover, further analysis revealed that these 18 articles collectively covered a wide range of relevant perspectives and methodologies, ensuring the comprehensiveness of the review.

Table 3: The Inclusion as well as Exclusion Criteria

Criteria	Inclusion	Exclusion
Publication timeline	2019-2023	Below 2019
Document type	Original Research Article	Conference, book chapter, proceedings, review paper
Language	English	Non-English
Source type	Journal	Non-Journal
Publication Stage	Final	In Press

Data Abstraction and Analysis

In order to guarantee a comprehensive and systematic analysis with regard to the literature on the impact of IBL on SPS in science education, the data abstraction as well as analysis procedure for this systematic literature review includes many crucial components. A standardised data extraction form was developed to ensure consistency in collecting information from each selected article, capturing details such as authors, publication year, study title, type of IBL approach used, research objectives, methodology, sample characteristics, key findings related to SPS, and any reported limitations or biases. The extracted data were then coded and categorised based on predefined categories like types of IBL, SPS outcomes, educational context, and technological integration.

A comparative analysis was conducted to compare the efficiency of different IBL approaches in enhancing SPS, highlighting variations based on educational contexts. Finally, the findings from individual studies were synthesised to provide a comprehensive understanding of how IBL influences SPS, discussing the implications for educational practice and policy, and assessing the quality and rigour of the included studies using established criteria, considering potential biases and limitations and their impact on the overall conclusions. This structured approach ensured a thorough and systematic examination of the literature on the influence of IBL on SPS in science education.

The present research made use of PRISMA. This particular investigation also employed the PRISMA flow diagram to help choose articles that were pertinent to its goal. There are four steps in the PRISMA flow diagram with regard to article selection:

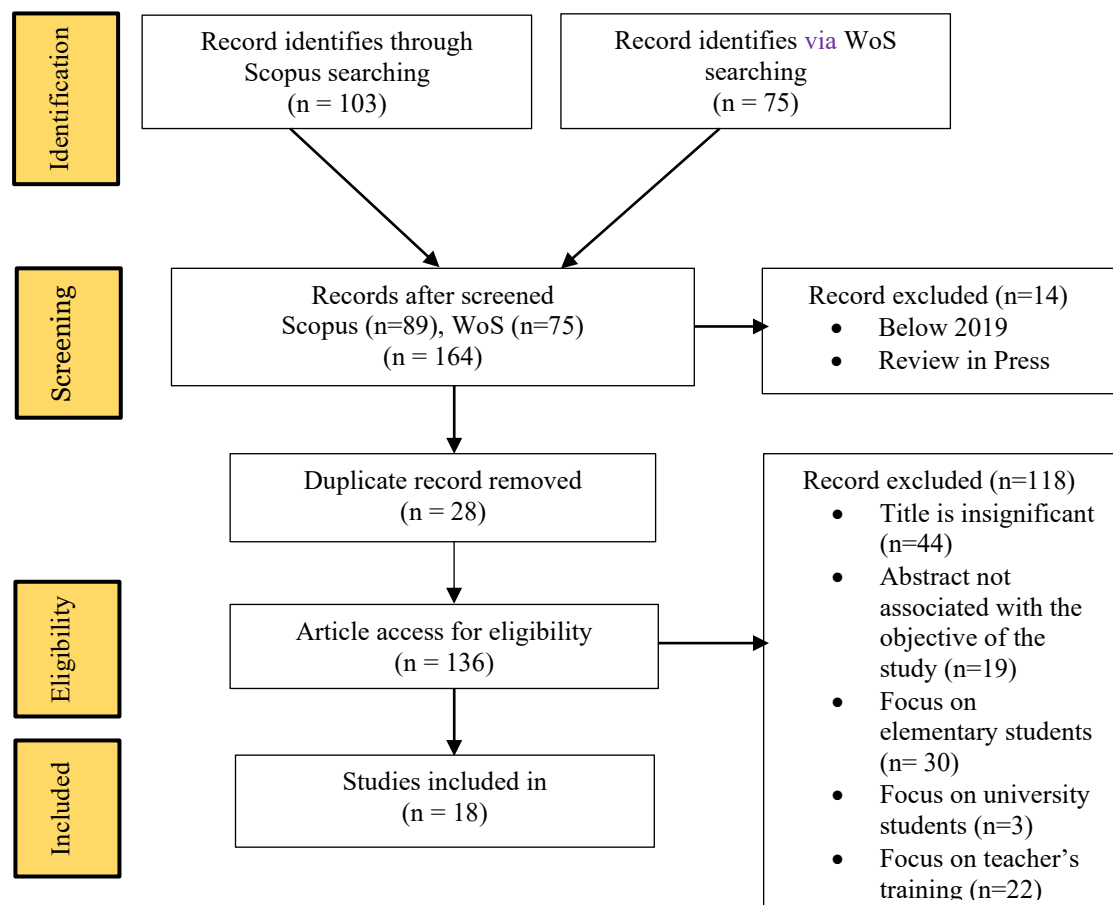


Figure 2: Flow Diagram with Regard to PRISMA 2020 To Studies Published Between 2019 And 2023

Source: Page et al. (2021)

There are two main approaches to systematic reviews: rapid and conventional. A conventional systematic review is comprehensive, involving exhaustive literature searches, dual screening, and detailed quality assessment, often taking several months to complete. In contrast, a rapid review streamlines or omits certain steps (such as limiting databases, single screening, or restricting publication years) to produce results more quickly, typically within weeks. This study adopts the conventional systematic review approach, ensuring thoroughness and rigour in article selection, data extraction, and analysis, as recommended by the PRISMA guidelines (Page et al., 2021). Several challenges were encountered during the review process, including potential publication bias due to the exclusion of non-English articles, limited access to certain full-text articles, and the possibility of missing relevant studies not indexed in Scopus or WoS. Additionally, the reliance on recent publications (2019–2023) may have excluded earlier foundational works.

Results

Several bibliometric factors or indicators, including country and year of publication, were analysed in order to ascertain the scientific significance pertaining to the sample. Subsequently, the following findings were obtained. Through an analysis of the year of publication, we can identify trends over time, such as periods of increased research activity or emerging areas of

interest. Analysing the country of origin helps to understand the geographical distribution of research contributions, highlighting which countries are leading in specific fields or topics. Therefore, the results obtained from these analyses offer insightful information about the development as well as the worldwide distribution of scientific research in the sample. Figure 3 illustrates the number of articles published on IBL and its impact on SPS in science education from 2019 to 2023. In 2019, 3 articles were published, indicating moderate interest. The number of publications surged to 4 in 2020, suggesting increased research activity. However, in 2021, there was a sharp decline to just 1 article, possibly due to shifts in research priorities or the effect with regard to the COVID-19 pandemic. The number of publications rebounded to 4 in 2022 and increased to 6 articles in 2023, indicating sustained interest and relevance.

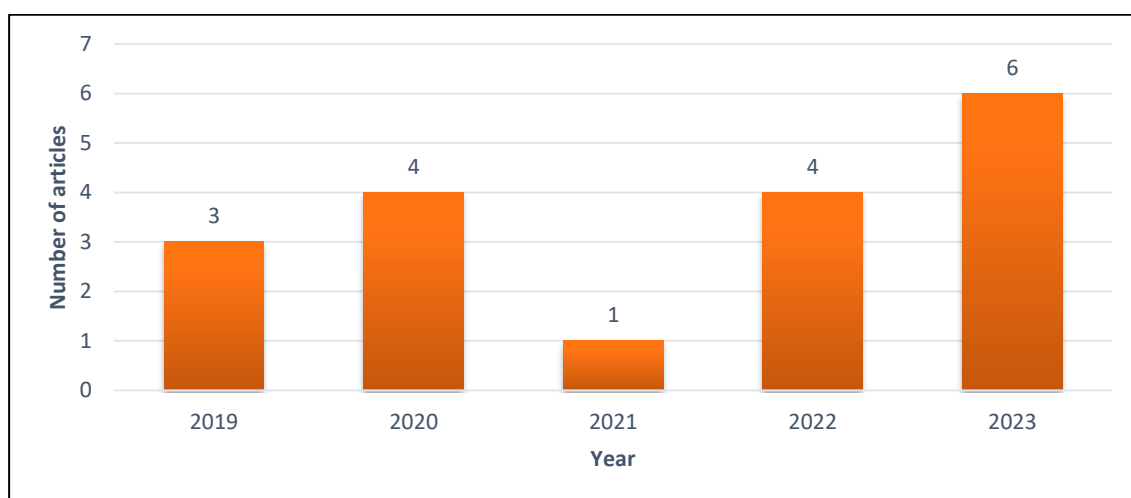


Figure 3: Publication Year and Number of Articles

The pie chart in Figure 4 illustrates the distribution of articles by country, highlighting the number and percentage of articles contributed by each nation in exploring the influence of IBL on SPS for science education. Indonesia leads with the highest contribution, accounting for 4 articles, which represents a significant 22% of the total. The United States, Philippines, Turkey, and Rwanda each contributed 2 articles, representing 11% each. Several other countries, including Switzerland, China, Ethiopia, Thailand, Malay-sia, and the United Kingdom, each contributed 1 article, accounting for 6% each. This diverse international representation underscores the global interest and research efforts in the field of IBL and its impact on science education.

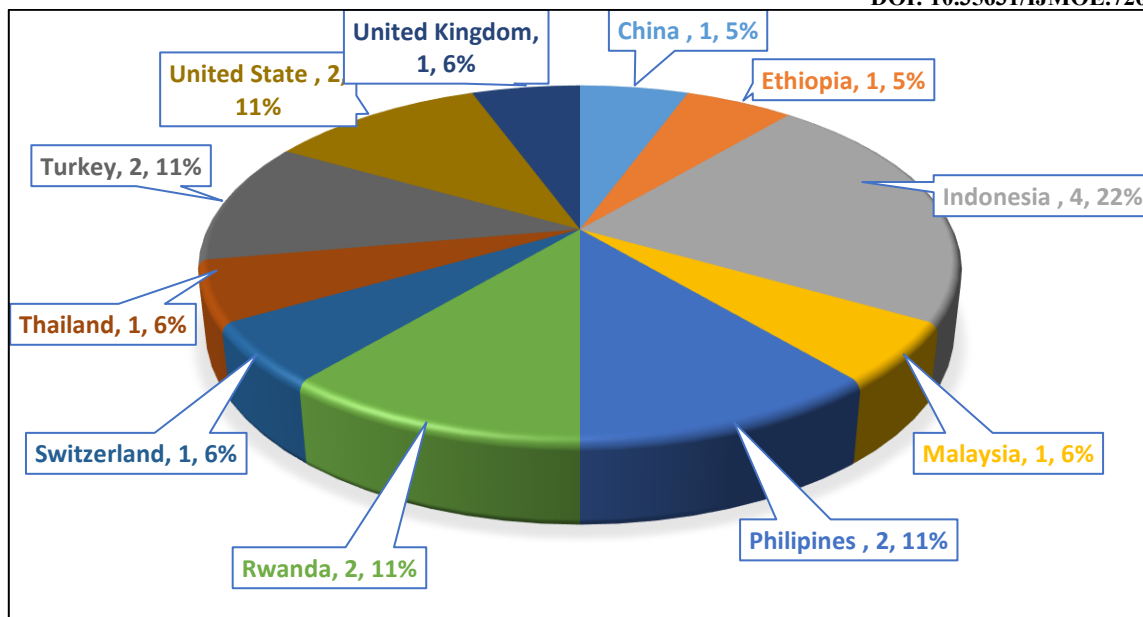


Figure 4: Countries, Number, And Percentage of Articles

RQ1: What Is the Effectiveness of Different Types of Inquiry-Based Learning (IBL) Compared to Non-Inquiry-Based Approach in Developing Science Process Skills (SPS) Among Students?

Based on the literature search on Scopus and Web of Science (WoS), a total of 18 articles were related and reviewed to answer RQ1. All of the 18 articles use IBL as the main strategy for learning to increase students' SPS, achievement, and engagement during the learning process. Table 4 shows the types of IBL used in each article and their findings.

Table 4: Types Of IBL Used in Each Article and Their Findings

No	Author, Year	Title	Type of IBL	Findings
1	Sarioğlu S. (2023)	Development of Online science process skills test for 8th-grade pupils	Guided Inquiry	Online tests for 8th-grade science skills are reliable and effective ways to measure students' abilities, improve their engagement, SPS, and accessibility, and provide valuable insights for science education.
2	Hunegnaw T.; Melesse S. (2023)	An evaluative study of the experimental tasks of the Ethiopian grade 12 chemistry textbook considering developing "science process skills"	Structured Inquiry	The Ethiopian grade 12 chemistry textbook's experimental tasks mainly focus on basic skills like observing, measuring, and communicating. However, they mostly ignore advanced skills like controlling variables, making

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|---|--|---|----------------|--|
| 3 | Idul J.J.A.;
Caro V.B.
(2022) | Does process-oriented guided inquiry learning (POGIL) improve students' science academic performance and process skills? | Guided Inquiry | hypotheses, and creating models.
Process-Oriented Guided Inquiry Learning (POGIL) significantly improves the academic performance as well as scientific skills of Grade 10 Filipino students in science compared to non-inquiry-based approach. |
| 4 | Erkacmaz, K.
B., Bakirci, H.,
& Kara, Y.
(2023) | Effect of Inquiry-based Laboratory Approach on Scientific Process Skills, Critical Thinking Skills, and Opinions of Ninth Grade Students: Cell Unit Example | Guided Inquiry | Inquiry-based laboratory approach significantly improves ninth-grade students' SPS and critical thinking dispositions. |
| 5 | Angra A.; Ng
S.L.; Onstine
A.; Spencer C.
(2020) | Trapping Fruit Flies: A Guided-Inquiry Lab Approach to Teaching Biology to Nonmajors | Guided Inquiry | A guided-inquiry lab with fruit flies effectively engages nonmajors in the scientific process, enhances their understanding of behavioural and sensory biology, and is both educational and enjoyable for students. |
| 6 | Tornee N.;
Bunterm T.;
Lee K.;
Muchimapura
S. (2019) | Examining the effectiveness of guided inquiry with problem-solving process and cognitive function training in a high school chemistry course | Guided Inquiry | Compared to conventional teaching approaches, guided inquiry with problem-solving as well as cognitive training enhanced high school student's understanding of scientific attitudes, chemistry, and science skills, along with problem-solving abilities. |
| 7 | Ping I.L.L.;
Halim L.;
Osman K.
(2020) | Explicit teaching of scientific argumentation as an approach to developing argumentation skills, science process skills, and biological understanding | Guided Inquiry | The modified Argument-Driven Inquiry approach improved students' science skills and biology understanding more effectively than the other two approaches tested. |
| 8 | Senisum M.;
Susilo H.;
Suwono H.;
Ibrohim
(2022) | GIReSiMCo: A Learning Model to Scaffold Students' Science Process Skills and | Guided Inquiry | GIReSiMCo model, a new guided inquiry approach, improved students' science skills as well as biology |

- | | | | | |
|----|--|--|----------------|--|
| | | Biology Cognitive Learning Outcomes | | learning more than other teaching methods. |
| 9 | Gunawan; Harjono A.; Hermansyah; Herayanti L. (2019) | Guided inquiry model through virtual laboratory to enhance students' science process skills on heat concept | Guided Inquiry | Guided inquiry model via virtual laboratory possessed a substantial positive effect on students' SPS, in particular with regards to hypothesising, practising, and communicating, compared to conventional learning methods. |
| 10 | Cheng M.; Su C.-Y.; Kinshuk C.-Y. (2021) | Integrating Smartphone-Controlled Paper Airplane into Gamified Science Inquiry for Junior High School Students | Guided Inquiry | Gamified mobile science inquiry improved student engagement and skills, especially for more engaged students, with no gender differences. |
| 11 | Damopolii, I; Keley, U; Rianjani, DT; Nunaki, JH; Nusantara, E; Kandowangko, NY (2020) | Potential of inquiry-based learning to train students' metacognitive and science process skill | Guided Inquiry | IBL has greater potential to train students' metacognitive and SPS compared to conventional learning. |
| 12 | Leuenberger W.; Larsen E.; Leuenberger J.; Parry D. (2019) | Predation on plasticine model caterpillars: Engaging high school students using field-based experiential learning & the scientific process | Guided Inquiry | Plasticine model caterpillars offer a hands-on way for high school students to do real science and learn about predators and prey in nature. |
| 13 | Potier D.N. (2023) | The Use of Guided Inquiry to Support Student Progress and Engagement in High School Chemistry | Guided Inquiry | Using guided inquiry to teach high school students titration improved their progress, engagement, and problem-solving skills, with students successfully designing experiments and accurately calculating results. |
| 14 | Tan R.M.; Yangco R.T.; Que E.N. (2020) | Students' conceptual understanding and science process skills in an inquiry-based flipped classroom environment | Guided Inquiry | The flipped inquiry approach generally did not outperform traditional inquiry, except in teaching non-Mendelian Genetics. |
| 15 | Beichumila F.; Bahati B. | Students' Acquisition of Science Process Skills in Chemistry through | Guided Inquiry | Students taught using computer simulations, and animations showed |

	Kafanabo E. (2022)	Computer Simulations and Animations in Secondary Schools in Tanzania		significantly better acquisition with regard to integrated SPS in learning chemistry compared to those taught using conventional materials.
16	Sachyani D.; Waxman P.T.; Sadeh I.; Herman S.; Levi Ferber M.; Yaacobi M.; Choresh O.; Link E.; Masa S.-R.; Ginsburg S.; Zion M. (2023)	Teachers' views of Open Inquiry Future-Oriented Pedagogy as part of inquiry-based molecular biology teaching in high school biology laboratories		Teachers believe that incorporating molecular biology lab work into high school IBL promotes many principles of Future-Oriented Pedagogy.
17	Kahar, MS; Susilo; Abdullah, D; Oktaviany, V (2022)	The effectiveness of the integrated inquiry guided model STEM on students' scientific literacy abilities	Guided Inquiry	When compared to non-inquiry-based approach, the STEM-integrated guided inquiry methodology significantly improved students' scientific literacy skills.
18	Nicol C.B.; Sentongo J.; Gakuba E.; Habinshuti G. (2023)	The Impact of Inquiry-Based Chemistry Experimentation on Eleventh-Grade Students' Science Inquiry Process Skills	Guided Inquiry	The 4-H Inquiry-in-Action teaching model improved students' science inquiry skills, with some skills being easier to acquire than others.

Based on the analysis of the 18 articles presented in the table, several conclusions can be drawn about the effectiveness of different types of IBL for teaching SPS. The most prevalent type of IBL used in the studies is guided inquiry, appearing in 16 out of 18 articles. This indicates that guided inquiry is a widely adopted and potentially effective approach for teaching SPS. Numerous studies employing guided inquiry reported positive outcomes in terms of improving students' SPS:

- Sarioğlu (2023) discovered that an online test based on guided inquiry effectively measured and improved students' SPS.
- Idul & Caro (2022) reported that Process-Oriented Guided Inquiry Learning (POGIL) significantly improved academic performance as well as scientific process skills.
- Tornee et al. (2019) found that guided inquiry with problem-solving as well as cognitive training improved science skills among high school students.
- Gunawan et al. (2019) reported a positive effect that is significant on students' SPS using a guided inquiry model through a virtual laboratory.

These findings suggest that guided inquiry is indeed effective for teaching SPS across various educational contexts and grade levels. Therefore, most of the studies employing guided inquiry and the consistent positive findings across these studies provide strong evidence for its efficacy in enhancing students' SPS. However, while guided inquiry appears promising, further research is needed to explore its effectiveness across different age groups, subject areas, and educational contexts to draw more definitive conclusions.

RQ2: What Is the Impact of Inquiry-Based Learning (IBL) On the Development of Science Process Skills (SPS) Among Students Compared to A Non-Inquiry-Based Approach?

Based on 18 articles filtered using the PRISMA Framework, three main themes were identified to answer RQ2, according to their findings using thematic analysis by clearly defining what each theme represents and giving them descriptive names (Braun & Clarke, 2006): (1) Active engagement and hands-on experience, (2) Technology integration and modern tools, (3) Scaffolded and guided approaches. Table 5 summarizes the main themes identified from the thematic analysis, along with their definitions, key examples, and supporting references.

Table 5: Main Themes, Definition, Key Examples and Supporting References

Main Theme	Brief Definition	Key examples/ Impacts	References
Active Engagement and Hands-on Experience	Students' active participation in authentic scientific practices through hands-on activities.	Designing experiments, collecting and analysing data, developing practical and cognitive science process skills.	Leuenberger et al., 2019; Nicol et al., 2023; Potier, 2023; Gunawan et al., 2019; Hunegnaw & Melesse, 2023; Damopolii et al., 2020; Hovardas et al., 2022
Technology Integration and Modern Tools	Utilization of modern technology to support SPS development.	Virtual labs, simulations, gamification, online platforms with instant feedback, advanced data analysis tools.	Beichumila et al., 2022; Gunawan et al., 2019; Sarioğlu, 2023; Cheng et al., 2021; Potier, 2023; Hovardas et al., 2022
Scaffolded and Guided Approaches	Structured and guided approaches that gradually build student independence.	Teacher as facilitator, guided inquiry, scaffolding, use of guiding questions, progressive support.	Basak Erkamaz et al., 2023; Idul & Caro, 2022; Senisum et al., 2022; Tornee et al., 2019; Potier, 2023; Sachyani et al., 2023; Kojo et al., 2018

Discussion

This systematic literature review examines how inquiry-based learning (IBL) influences the development of science process skills (SPS) in science education. By analysing 18 re-cent studies, this review offers a detailed synthesis of the effectiveness of different IBL approaches, with a particular emphasis on the role of technology and scaffolded methods. Unlike previous

reviews that often focus on traditional IBL strategies, this study sheds light on the growing importance of technology and innovative teaching techniques in enhancing SPS.

Among the various IBL methods, Guided Inquiry stands out as the most extensively studied and consistently effective approach. Its structured yet adaptable framework provides students with a clear pathway for conducting scientific investigations while still allowing them the freedom to explore and make discoveries. This balance between structure and independence is particularly beneficial for science students, who are at a stage of developing more advanced cognitive skills but still require guidance to navigate complex scientific concepts and processes (Angra et al., 2020; Gunawan et al., 2019; Idul & Caro, 2022; Kahar et al., 2022; Potier, 2023; Tornee et al., 2019). Guided inquiry encourages students to engage in authentic scientific practices, such as asking questions, designing experiments, and analysing data, all within a supportive environment that nurtures critical thinking and problem-solving abilities.

While guided inquiry is a dominant approach, this review also highlights the potential of other IBL methods, such as the Flipped Inquiry model explored by Tan et al. (2020). This method combines asynchronous pre-class learning with active, hands-on activities during class time, leveraging blended learning techniques to boost student engagement and comprehension. Although flipped inquiry may not outperform traditional inquiry methods in every area, it shows promise for teaching specific scientific topics, especially when supported by multimedia tools like videos and interactive texts (Macale et al., 2021). These findings suggest that different IBL approaches may be better suited to particular topics or skills, emphasizing the importance of tailoring teaching methods to specific learning goals.

One of the key insights from this review is the potential for combining IBL with emerging technologies and scaffolded approaches to further enhance SPS development. Tools such as virtual labs, simulations, and online collaborative platforms offer innovative ways to make scientific inquiry more accessible, engaging, and interactive. These technologies not only add authenticity to scientific investigations but also allow students to experiment and collaborate in ways that were previously difficult or impossible. For instance, virtual labs can replicate complex experiments that may not be feasible in a traditional classroom, while collaborative platforms enable students to work together on inquiry projects, fostering teamwork and communication skills.

The role of teachers is another critical factor in the success of IBL. Teachers with strong pedagogical content knowledge and expertise in inquiry-based strategies are better equipped to guide students and address any misconceptions that arise during inquiry activities. Therefore, professional development programs that focus on IBL strategies and the integration of technology are essential for maximizing the benefits of IBL. Additionally, scaffolding plays a crucial role in supporting students' cognitive development, particularly in helping them tackle the more challenging aspects of scientific inquiry. This review not only reaffirms the effectiveness of IBL in fostering SPS but also under-scores the importance of adopting a nuanced and context-specific approach. Integrating IBL with technology and scaffolded methods holds significant potential for improving science education, equipping students with the skills and knowledge they need to thrive in an increasingly complex and technology-driven world.

Conclusion and Recommendation

This systematic literature review emphasizes the significant impact of inquiry-based learning (IBL) on the development of science process skills (SPS) in science education. By synthesizing recent studies, this review highlights the unique contributions of IBL, particularly its emphasis on hands-on activities, scaffolded learning, and the integration of technology. Among the various IBL approaches, guided inquiry stands out as a particularly effective method, offering a balance between structure and autonomy that aligns with the cognitive development of science students.

The findings of this review have important implications for educational practice and policy. To fully harness the potential of IBL, schools should consider integrating it as a core component of science curricula, ensuring that students have regular opportunities to engage in scientific inquiry. Teachers play a pivotal role in the success of IBL, and professional development programs should be designed to equip them with the skills and knowledge needed to effectively implement IBL strategies. These programs should also emphasize the integration of technology, enabling teachers to leverage tools such as virtual labs, simulations, and collaborative platforms to enhance the IBL experience.

The integration of IBL with technology not only enriches the learning experience but also makes it more accessible to a diverse range of students. For example, virtual labs and simulations can provide students with opportunities to conduct experiments that may be limited by time, resources, or safety concerns in traditional classroom settings. Collaborative platforms can foster teamwork and communication skills, which are essential for scientific inquiry and future careers in STEM fields. These technological enhancements also encourage active and collaborative learning, which can increase student engagement and motivation.

Furthermore, this review highlights the importance of tailoring IBL approaches to specific contexts. Different IBL methods, such as guided inquiry, flipped inquiry, or open-ended inquiry, may be more effective for certain scientific concepts or skills. Educators should consider factors such as the subject matter, students' developmental levels, and available resources when selecting an IBL approach. This context-specific approach ensures that IBL is not only effective but also adaptable to the diverse needs of students and classrooms.

Future research should focus on exploring the long-term effects of IBL on SPS development, particularly through longitudinal studies that track students' progress over time. Additionally, studies should investigate the optimal combinations of IBL strategies and technologies, as well as the feasibility and scalability of successful IBL models across different educational contexts. Such research will provide valuable insights into how IBL can be implemented on a broader scale, ultimately enhancing science education for all students.

In conclusion, this review provides a comprehensive synthesis of recent studies, highlighting the role of technology and scaffolded approaches in enhancing SPS through IBL. By integrating IBL into science curricula and leveraging emerging technologies, educators can prepare students for the challenges of the 21st century, fostering the next generation of scientists, innovators, and informed citizens. Longitudinal studies should be conducted in the future to evaluate the long-term effects with regard to IBL on SPS development, explore the optimal combinations of IBL strategies and technologies, as well as investigate the feasibility and scalability of successful IBL models across different educational contexts. Such research

will provide further evidence of the benefits of IBL and guide its implementation on a broader scale, ultimately enhancing science education for all students.

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References

- Ananda, P. N., & Usmeldi, U. (2023). Meta-analysis: Effect of using inquiry-based learning (IBL) model on students' competence. *Jurnal Pendidikan Fisika*, 11(1), 86–102. doi:10.26618/jpf.v11i1.9802
- Angra, A., Ng, S. L., Onstine, A., & Spencer, C. (2020). Trapping fruit flies: A guided-inquiry lab approach to teaching biology to nonmajors. *American Biology Teacher*, 82(6), 403–408. doi:10.1525/abt.2020.82.6.403
- Artayasa, I. P., Muhlis, M., Merta, I. W., Sukarso, A., & Hadiprayitno, G. (2023). Open inquiry practicum: An effective strategy for enhancing science process skills of prospective biology teachers. *Jurnal Penelitian Pendidikan IPA*, 9(3), 1352–1359. doi:10.29303/jppipa.v9i3.3248
- Basak Erkamaz, K., Bakirci, H., & Kara, Y. (2023). Effect of inquiry-based laboratory approach on scientific process skills, critical thinking skills, and opinions of ninth grade students: Cell unit example. *Jurnal Penelitian dan Pembelajaran IPA*, 9(2), 139. doi:10.30870/jppi.v9i2.19733
- Baur, A., & Emden, M. (2021). How to open inquiry teaching? An alternative teaching scaffold to foster students' inquiry skills. *Chemistry Teacher International*, 3(1), 1–12. doi:10.1515/cti-2019-0013
- Beichumila, F., Bahati, B., & Kafanabo, E. (2022). Students' acquisition of science process skills in chemistry through computer simulations and animations in secondary schools in Tanzania. *International Journal of Learning, Teaching and Educational Research*, 21(3), 166–195. doi:10.26803/ijlter.21.3.10
- Behera, B. B. (2023). Enhancing science process skills through inquiry-based learning: A comprehensive literature review and analysis. *International Journal of Science and Research*, 12(8), 1583–1589. doi:10.21275/sr23817121415
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101. doi:10.1191/1478088706qp063oa
- Cheng, M., Su, C. Y., & Kinshuk, C. Y. (2021). Integrating smartphone-controlled paper airplane into gamified science inquiry for junior high school students. *Journal of Educational Computing Research*, 59(1), 71–94. doi:10.1177/0735633120953598
- Ha, C. Y., Khoo, T. J., & Loh, J. X. (2023). Barriers to green building implementation in Malaysia: A systematic review. *Progress in Energy and Environment*, 24(1), 11–21. doi:10.37934/progee.24.1.1121
- Čtrnáctová, H., Čtrnáctová, L., & Šmejkal, P. (2015). IBSE in chemistry education: Testing students' skills and teacher training. *LUMAT*, 3(4), [page range if available].
- Curriculum Development Division, Ministry of Education Malaysia. (2016). *Implementation guide for inquiry-based teaching and learning*. Ministry of Education Malaysia.

- Damopolii, I., Keley, U., Rianjani, D. T., Nunaki, J. H., Nusantara, E., & Kandowangko, N. Y. (2020). Potential of inquiry-based learning to train students' metacognitive and science process skills. *Jurnal Ilmiah Peuradeun*, 8(1), 83–98. doi:10.26811/peuradeun.v8i1.351
- Dolenc, N. R., & Kazanis, W. H. (2020). A potential for interest-driven learning to enhance the inquiry-based learning process. *Journal of Education*, 27(2), [page range if available].
- Fredriksen, H., Rebenda, J., Rensaa, R. J., & Pettersen, P. (2024). Inquiry-based linear algebra teaching and learning in a flipped classroom framework: A case study. *Primus*. doi:10.1080/10511970.2024.2375712
- Gunawan, Harjono, A., Hermansyah, & Herayanti, L. (2019). Guided inquiry model through virtual laboratory to enhance students' science process skills on heat concept. *Cakrawala Pendidikan*, 38(2), 259–268. doi:10.21831/cp.v38i2.23345
- Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist*, 42(2), 99–107. doi:10.1080/00461520701263368
- Hunegnaw, T., & Melesse, S. (2023). An evaluative study of the experimental tasks of the Ethiopian grade 12 chemistry textbook considering developing "science process skills." *Cogent Education*, 10(1), [page range if available]. doi:10.1080/2331186X.2023.2208944
- 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. doi:10.1080/09500693.2022.2108553
- Kahar, M. S., Susilo, Abdullah, D., & Oktaviany, V. (2022). The effectiveness of the integrated inquiry guided model STEM on students' scientific literacy abilities. *International Journal of Nonlinear Analysis and Applications*, 13(1), 1667–1672. doi:10.22075/IJNAA.2022.5782
- Kim, S. Y., & Hamdan Alghamdi, A. K. (2019). Female secondary students' and their teachers' perceptions of science learning environments within the context of science education reform in Saudi Arabia. *International Journal of Science and Mathematics Education*, 17(8), 1475–1496. doi:10.1007/s10763-018-09946-z
- Kojo, A., Laine, A., & Näveri, L. (2018). How did you solve it? – Teachers' approaches to guiding mathematics problem solving. *LUMAT*, 6(1), 22–40. doi:10.31129/LUMAT.6.1.294
- Leuenberger, W., Larsen, E., Leuenberger, J., & Parry, D. (2019). Predation on plasticine model caterpillars: Engaging high school students using field-based experiential learning and the scientific process. *American Biology Teacher*, 81(5), 334–339. doi:10.1525/abt.2019.81.5.334
- Lippmann, M. (2021). Inquiry-based learning in psychology. In *Psychology education* (pp. 1–30). Springer. doi:10.1007/978-3-030-26248-8_59-1
- Macale, A., Lacsamana, M., Quimbo, M. A., & Centeno, E. (2021). Enhancing the performance of students in chemistry through flipped classroom with peer instruction teaching strategy. *LUMAT*, 9(1), 717–747. doi:10.31129/LUMAT.9.1.1598
- Mullis, I. V. S., Martin, M. O., Foy, P., Kelly, D. L., & Hooper, M. (2020). *TIMSS 2019 international results in mathematics and science*. TIMSS & PIRLS International Study Center, Boston College. Retrieved from <https://timssandpirls.bc.edu/timss2019/international-results/>

- Nicol, C. B., Sentongo, J., Gakuba, E., & Habinshuti, G. (2023). The impact of inquiry-based chemistry experimentation on eleventh-grade students' science inquiry process skills. *FWU Journal of Social Sciences*, 17(1), 91–109. doi:10.51709/19951272/Spring2023/7
- Nurlaela, E. (2023). Implementation of guided inquiry learning with a scientific approach to improve class VII middle school students' science process skills on density material. *Formosa Journal of Applied Sciences*, 2(10), 2327–2338. doi:10.55927/fjas.v2i10.6335
- Organisation for Economic Co-operation and Development. (2019). *PISA 2018 results (Volume I): What students know and can do*. OECD Publishing. doi:10.1787/5f07c754-en
- Ouzzine, A., Erguig, R., & Boudlal, A. (2022). Discovery-based teaching methodology: A framework for quality teaching and learning. *Journal of Applied Language and Culture Studies*, 5, [page range if available]. Retrieved from <https://revues.imist.ma/index.php?journal=JALCS>
- Owolade, A. O., Oladipupo, P. O., Kareem, A. O., & Salami, M. O. (2022). Effectiveness of guided and open inquiry instructional strategies on science process skills and self-efficacy of biology students in Osun State, Nigeria. *Journal of Spread Corporation*, 11(1), 56–74.
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *PLOS Medicine*, 18(3), e1003583. doi:10.1371/journal.pmed.1003583
- Panjaitan, M. B., & Siagian, A. (2020). The effectiveness of inquiry-based learning model to improve science process skills and scientific creativity of junior high school students. *Journal of Education and E-Learning Research*, 7(4), 380–386. doi:10.20448/journal.509.2020.74.380.386
- Ping, I. L. L., Halim, L., & Osman, K. (2020). Explicit teaching of scientific argumentation as an approach in developing argumentation skills, science process skills and biology understanding. *Journal of Baltic Science Education*, 19(2), 276–288. doi:10.33225/jbse/20.19.276
- Potier, D. N. (2023). The use of guided inquiry to support student progress and engagement in high school chemistry. *Journal of Chemical Education*, 100(2), 1033–1038. doi:10.1021/acs.jchemed.2c00793
- Sachyani, D., Waxman, P. T., Sadeh, I., Herman, S., Levi Ferber, M., Yaacobi, M., ... Zion, M. (2023). Teachers' views of future-oriented pedagogy as part of inquiry-based molecular biology teaching in high school biology laboratories. *Journal of Biological Education*, 00(00), 1–22. doi:10.1080/00219266.2023.2174157
- Sarioğlu, S. (2023). Development of online science process skills test for 8th grade pupils. *Journal of Turkish Science Education*, 20(3), 418–432. doi:10.36681/tused.2023.024
- Senisum, M., Susilo, H., Suwono, H., & Ibrohim. (2022). GIRESiMCo: A learning model to scaffold students' science process skills and biology cognitive learning outcomes. *Education Sciences*, 12(4).doi:10.3390/educsci12040228
- Szalay, L. (2015). Promoting inquiry-based teaching of chemistry. *LUMAT*, 3(3)
- 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. doi:10.32890/mjli2020.17.1.7
- Tornee, N., Bunterm, T., Lee, K., & Muchimapura, S. (2019). Examining the effectiveness of guided inquiry with problem-solving process and cognitive function training in a high

school chemistry course. *Pedagogies*, 14(2), 126–149.
doi:10.1080/1554480X.2019.1597722

Waked, A., Pilotti, M., & Abdelsalam, H. M. (2024). Differences that matter: Inquiry-based learning approach to research writing instruction. *Scientific Reports*, 14(1), 1–9.
doi:10.1038/s41598-024-78962-7

Zainal, S., Che Mohd Yusoff, R., Abas, H., Yaacub, S., & Megat Zainuddin, N. (2021). Review of design thinking approach in learning IoT programming. *International Journal of Advanced Research in Future Ready Learning and Education*, 24.