International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume 6 Issue 23 (December 2024) PP. 687-707
DOI: 10.35631/IJMOE.623047

INTERNATIONAL JOURNAL OF MODERN EDUCATION (IJMOE)
www.ijmoe.com

GLOBAL ACADEMIC EXCELLENCE

BRIDGING DIGITAL TOOLS AND SCIENTIFIC LITERACY: A SYSTEMATIC REVIEW ON INQUIRY-BASED LEARNING APPROACHES

Azneezal Ar-Rashid Mohd Ramli[1*], Mohamad Termizi Borhan[2]

[1] Universiti Pendidikan Sultan Idris, 45900 Tanjong Malim, Perak, Malaysia
Email: azneezalarrashid@gmail.com
[2] Universiti Pendidikan Sultan Idris, 45900 Tanjong Malim, Perak, Malaysia
Email: termizi@fsmt.upsi.edu.my
[*] Corresponding Author

Article Info:

Article history:
Received date: 27.10.2024
Revised date: 11.11.2024
Accepted date: 15.12.2024
Published date: 24.12.2024

To cite this document:

Ramli, A. A. M., & Borhan, M. T. (2024). Bridging Digital Tools And Scientific Literacy: A Systematic Review On Inquiry-Based Learning Approaches. *International Journal of Modern Education, 6* (23), 687-707.

DOI: 10.35631/IJMOE.623047

This work is licensed under CC BY 4.0

Abstract:

This systematic review meticulously explores the incorporation of digital tools within inquiry-based learning (IBL) frameworks to enhance scientific literacy, addressing pivotal questions concerning effective, digitally enabled educational strategies. Specifically, the study investigates (1) how digital tools support the effectiveness of IBL across diverse educational contexts, (2) the ways in which IBL enhances scientific literacy at various educational levels, and (3) the impact of innovative and hybrid IBL approaches on student engagement and understanding in scientific subjects. Adhering to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure methodological rigor and transparency, this review synthesizes empirical research published between 2020 and 2024, initially identifying 389 articles from Scopus and Web of Science databases, with 35 meeting stringent inclusion criteria. The analysis reveals that the incorporation of digital tools, for example, simulation software, collaborative platforms, and gamified learning environments—within IBL significantly transforms scientific literacy by fostering critical thinking, student engagement, as well as collaborative skills. Furthermore, the adaptability of IBL across diverse educational settings, complemented by gamification and culturally relevant methodologies, facilitates greater accessibility and inclusivity in science education, thereby preparing students for academic success and informed participation in a scientifically literate society. Despite the evident transformative potential of digital tools in advancing scientific literacy, the review underscores the necessity for further research to optimize their implementation, particularly within underrepresented and varied educational contexts. This comprehensive synthesis contributes to the discourse on educational technology by providing critical insights and delineating future

International Journal of Modern Education IJMOE
EISSN: 2637-0905
Volume 6 Issue 23 (December 2024) PP. 687-707
DOI: 10.35631/IJMOE.623047
research directions aimed at cultivating a scientifically literate generation through digitally empowered IBL.

Keywords:

Digital, Inquiry-Based Learning, Scientific Literacy

Introduction

In today's rapidly evolving world, scientific literacy has emerged as a cornerstone of effective citizenship and informed decision-making. As educational paradigms shift to accommodate the complexities of the 21st century, the ability to understand, interpret, and apply scientific concepts is paramount. Scientific literacy not only encompasses the comprehension of scientific knowledge but also includes problem-solving, critical thinking, as well as the capacity to engage with scientific issues contextually (Baltikian, Kärkkäinen, & Kukkonen, 2024; Essalih, Ourahay, & Khzami, 2024). The Program for International Student Assessment (PISA) 2015 highlighted significant disparities in scientific literacy across nations, with countries like Lebanon ranking notably low. Such findings underscore the urgent need to enhance scientific literacy levels globally, particularly with secondary school students who are at a pivotal stage in their educational journey. Furthermore, gender-based disparities in scientific literacy, as explored by Baltikian et al. (2024), reveal the necessity for inclusive educational strategies that address diverse learner needs, ensuring equitable scientific understanding across all student demographics.

The integration of digital tools into educational frameworks has revolutionized the landscape of science education, offering unprecedented opportunities to improve scientific literacy via innovative teaching approaches. Digital technologies, ranging from augmented reality (Mufit & Dhanil, 2024) to intelligent personal assistants (Nasri, Nasri, Nasri, & Abd Talib, 2023), provide dynamic platforms for interactive and personalized learning experiences. These tools facilitate the visualization of complex scientific phenomena, support inquiry-based learning (IBL), and promote higher-order thinking skills essential for scientific literacy (Eymur & Çetin, 2024; Kousloglou, Petridou, Molohidis, & Hatzikraniotis, 2023). The advent of mobile technology-supported IBL (mIBL) and sensor-based learning platforms exemplifies how digital advancements can foster collaboration, communication, and critical thinking among students (Chang, Lyu, Wu, & Min, 2024; Kousloglou et al., 2023). However, the successful integration of these technologies requires careful consideration of pedagogical practices, teacher preparedness, and the alignment of digital tools with curriculum objectives to ensure they effectively bridge the gap between technological innovation and scientific literacy (Litina & Rubene, 2024; Van Hoe, Wiebe, Rotsaert, & Schellens, 2024).

IBL approaches, which emphasize student-centered exploration and the active construction of knowledge, play a crucial role in developing scientific literacy. By engaging students in authentic scientific inquiries, these approaches foster a deeper grasp of scientific concepts as well as the essence of scientific inquiry itself (Cirkony, 2023; Koswojo & Pratidhina, 2023). Studies have demonstrated that inquiry-based methods, whether through traditional laboratory settings or enhanced by digital tools, significantly improve the ability of students to solve problems, think critically, as well as articulate scientific arguments (Lestari, Paidi, & Suwarjo, 2024; Yaman & Hand, 2024). Additionally, the collaborative aspects of IBL, such as peer assessment and group projects, enhance students' interpersonal skills and their ability to engage in evidence-based reasoning (Bossér, 2024; Van Hoe et al., 2024). Despite the proven benefits, challenges such as limited teacher training, inadequate digital infrastructure, and resistance to pedagogical change persist, hindering the full potential of digital tools in fostering scientific literacy (Chang et al., 2024; Rusdiyana, Indriyanti, Hartono, & Isnaeni, 2024). This systematic review seeks to synthesize current studies on the intersection of digital tools, and IBL approaches, identifying effective strategies and highlighting areas for further investigation to fill the gap between technological advancements as well as the cultivation of scientific literacy in educational settings.

Literature Review

Innovative and hybrid inquiry-based learning (IBL) methodologies have emerged as critical tools in advancing students' inquiry skills, scientific literacy, motivation, and overall engagement across diverse educational settings. The integration of digital tools, culturally contextualized project-based learning, and sophisticated pedagogical strategies fosters highly effective environments for scientific inquiry. Numerous studies highlight that these approaches not only enhance learning outcomes but also respond effectively to the varied needs of contemporary learners by making science more accessible and engaging. Researchers such as Zheng, Bai, Yang and Xu (2024), Blackmore and Rønningsbakk (2023) and Tavares, Marques Vieira and Pedro (2021) have demonstrated that digital tools like mobile applications, virtual learning environments, and interactive platforms significantly impact students' understanding of scientific concepts, enhance self-regulation, and improve knowledge integration. These findings underscore the value of structured, guided learning methodologies that incorporate digital and collaborative tools to enhance IBL.

A synthesis of findings by Ješková et al. (2022), Liang, Li, Tian and Li (2023) and Bónus, Antal and Korom (2024) demonstrates the efficacy of technology-infused approaches in fostering students' inquiry skills and promoting scientific literacy. Ješková et al. (2022) illustrate how digital resources, coupled with formative assessment tools, enhance inquiry-based science education (IBSE) by enabling precise skill development in areas such as data interpretation. Their study highlights statistically significant gains in inquiry competencies when digital resources are integrated with structured inquiry tasks. Liang et al. (2023) present an innovative curriculum reform within elective chemistry courses, incorporating intangible cultural heritage as a contextual framework for improving chemical science literacy. This project-based approach, combining experimental and reflective elements, notably enhanced student engagement, self-efficacy, and performance. Bónus et al. (2024) further underscore the potential of digital inquiry games like BioScientist, demonstrating moderate improvements in students' inquiry skills while maintaining curricular alignment. Though the program did not significantly enhance biology motivation, its success illustrates the potential of digital games to seamlessly integrate into traditional science curricula.

Research on the role of play and gamification further supports the value of inquiry-based methodologies, as seen in the studies by Vartiainen and Kumpulainen (2020), Cheng, Su and Kinshuk (2021), and Liang et al. (2023). Vartiainen and Kumpulainen (2020) analyze the role of imaginative play in enhancing inquiry among preschool children, identifying it as a catalyst for cognitive engagement and inquiry skill development. They outline four key components of scientific play: imaginative contextualization, creative reinterpretation, problem-solving through imaginary frameworks, and immersive science communication. Cheng et al. (2021) explored gamified learning through smartphone-controlled paper airplanes, effectively

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume 6 Issue 23 (December 2024) PP. 687-707
DOI: 10.35631/IJMOE.623047

engaging junior high students in scientific inquiry. Bónus et al. (2024) incorporated game mechanics into BioScientist, illustrating that gamification can sustain interest and reinforce inquiry skills, particularly in biology. These findings underscore that play and gamification, when integrated into inquiry-based frameworks, not only sustain interest but also deepen learning outcomes, especially among younger learners who thrive in interactive and experiential environments.

The scalability and adaptability of IBL approaches are also emphasized in the research by Liang et al. (2023), Sotiriou, Lazoudis and Bogner (2020) and Shea, Richardson and Swan (2022). Sotiriou et al. (2020) examined a Europe-wide initiative that leveraged e-learning tools, including virtual laboratories and augmented reality, to support inquiry learning across schools. Their findings showed a marked increase in high-achieving students, suggesting that technology-supported inquiry models can effectively extend the reach and impact of IBSE. Liang et al. (2023) also highlighted the effectiveness of situational teaching and reflective methodologies, linking academic content with culturally relevant contexts. Shea et al. (2022) addressed challenges throughout the COVID-19 pandemic, advocating for an enhanced Community of Inquiry (CoI) model that incorporates 'Learning Presence' to support collaborative learning in online environments. Collectively, these studies affirm that IBL, supported by comprehensive digital frameworks, can scale effectively across educational systems, even during significant disruptions such as remote education.

Collaborative and interdisciplinary learning environments enhance the effectiveness of IBL approaches in promoting scientific literacy. Van Hoe et al. (2024) investigated the implementation of peer assessment within computer-supported collaborative inquiry learning (CSCiL) in secondary STEM education. Their findings indicated that peer assessment efficiently scaffolded inquiry outputs as well as fostered a collaborative learning culture. Similarly, Karamustafaoğlu and Pektaş (2023) explored the impact of inquiry-based STEM activities in out-of-school environments, finding significant improvements in students' problem-solving skills and STEM awareness. Rissanen, Hoang and Spila (2023) evaluated an interdisciplinary science experience program, enhancing students' sense of belonging and scientific literacy skills through project-based learning and collaborative challenges. El Bedewy, Lavicza, Sabitzer, Houghton and Nurhasanah (2024) proposed transdisciplinary STEAM practices that integrate architectural modeling with cultural and historical contexts, fostering students' computational thinking and mathematical knowledge. Cirkony (2023) emphasized the significance of genuine science inquiry tasks that foster flexibility, creativity, and collaboration, further supporting scientific literacy development. Additionally, Essalih et al. (2024) and Kirchhoff, Randler and Großmann (2023) compared outreach science labs with traditional school labs, finding that outreach labs significantly enhance students' intrinsic motivation and perceived competence.

Effective implementation of IBL and digital tools requires robust teacher practices and professional development. Essalih et al. (2024) examined Moroccan primary school teachers' perceptions of inquiry-based methods, revealing a gap in teachers' understanding and skills. This highlights the importance of focused professional development programs to equip educators with the skills needed to foster scientific literacy. Bossér (2024) explored how transforming school science practices could foster practical scientific literacy, emphasizing the importance of teacher reflection and the integration of socioscientific issues into teaching. Teachers actively engaged in professional development were better equipped to create

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume 6 Issue 23 (December 2024) PP. 687-707
DOI: 10.35631/IJMOE.623047

inclusive learning environments. Similarly, Lestari et al. (2024) validated an inquiry-based instructional model aimed at improving scientific argumentation in Indonesian lower secondary schools, showcasing the importance of instructional design in supporting teachers' efforts to improve scientific skills.

Understanding the historical and policy contexts of science education provides valuable insights into scientific literacy initiatives. (Suliyanah, Amiruddin, & Prahani, 2024) conducted a bibliometric analysis of emerging technologies in physics education, revealing a growing emphasis on technological integration in science education. Chang et al. (2024) discussed Taiwan's science curriculum reform, aligning with global trends that emphasize scientific literacy as a transferable educational outcome. Their work illustrates how policy-driven curriculum changes can create structured frameworks for improving scientific literacy. Additionally, Litina and Rubene (2024) explored how digital school culture impacts science education, finding that strategic digital integration significantly improves scientific literacy by fostering a culture that values technological responsiveness. These studies collectively highlight the influence of historical developments and policy initiatives in shaping effective science education practices.

Research Question

Research questions (RQs) are essential in a systematic literature review (SLR) as they establish the foundational framework and guide the entire process. They define the review’s scope and focus, directing the criteria for selecting studies to exclude or include, which helps keep the review specific and relevant. A well-crafted RQ facilitates an exhaustive and systematic search, minimizing bias and promoting a thorough synthesis of the available evidence. RQs assist in categorizing and organizing data from studies, providing a structured framework for analysis, and ensuring findings are actionable. They enhance clarity, eliminate ambiguity, and maintain focus, making the findings pertinent. Additionally, well-formulated RQs contribute to the transparency and reproducibility of the review, enabling replication, verification, or extension of the review in related areas. Ultimately, they align the review with the study's objectives, whether to identify gaps, evaluate intervention effectiveness, or examine trends. In essence, RQs serve as the backbone of a rigorous and meaningful SLR.

Formulating RQs is the most crucial task in the planning phase and remains a core element of any SLR, as it guides the entire review process (Keele, 2007). In this study, the objective is to determine as well as assess the state-of-the-art in [specific field]. To guide the formulation of RQs, the PICo framework—a mnemonic used in qualitative research as proposed by Lockwood, Munn and Porritt (2015)—was employed. PICo stands for Population (P), Interest (I), and Context (Co): 1) Population (P) refers to the group or participants of interest, such as a specific demographic, patient group, or community; 2) Interest (I) represents the main focus or phenomenon of interest, such as an experience, behavior, or intervention; 3) Context (Co) defines the setting or environment in which the population and interest are situated, such as geographical or social settings. Using the PICo framework ensures a clear and systematic structure of RQs, simplifying the literature search and study design. This study developed two RQs, as delineated below:

1. How do digital tools support the effectiveness of inquiry-based learning for students in various educational contexts?

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume 6 Issue 23 (December 2024) PP. 687-707
DOI: 10.35631/IJMOE.623047

2. In what ways does inquiry-based learning improve scientific literacy among students across different educational levels?
3. How do innovative and hybrid inquiry-based learning approaches impact students' engagement and understanding in scientific subjects?

Material and Methods

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, as described by Page et al. (2021), is widely considered the standard for SLRs, supporting transparency, comprehensiveness, as well as consistency. By following PRISMA guidelines, researchers enhance the accuracy and rigor of their analyses, with structured guidance on identifying, screening, and including relevant studies. This method underscores the importance of randomized studies, which reduce bias and provide strong evidence. Scopus and Web of Science were chosen for their extensive coverage and robustness. PRISMA consists of four stages: identification, screening, eligibility, as well as data abstraction. In the identification phase, databases are searched to capture relevant studies. During screening, studies are evaluated against predefined criteria to exclude irrelevant research. In the eligibility phase, studies are assessed to confirm inclusion standards. Lastly, data abstraction involves extracting and synthesizing data from selected studies to produce meaningful, reliable conclusions, ensuring rigorous and trustworthy insights.

Identification

In this research, key steps of the systematic review process were employed to compile a significant collection of pertinent literature. The process started by selecting keywords and identifying related terms with the help of encyclopedias, thesauri, dictionaries, as well as past studies. All relevant terms were gathered, leading to the formulation of search strings for the Scopus as well as WoS databases (refer to Table 1). This initial review phase yielded 389 publications related to the study topic across the two databases.

Table 1: The Search String

Scopus	ALL (digital AND "inquiry based learning" OR "inquiry-based learning" AND "scientific literacy") **Date of Access: October 2024**
WoS	digital AND "inquiry based learning" OR "inquiry-based learning" AND "scientific literacy" (All Fields) **Date of Access: October 2024**

Screening

During the screening phase, potentially relevant research items are assessed to confirm their alignment with the developed RQs. This stage often involves choosing topics related to digital IBL and scientific literacy, while also removing duplicate documents. After initially discarding 204 publications, 184 papers remained for deeper analysis, relying on particular exclusion as well as inclusion criteria (refer to Table 2). Here, the literature was prioritized as it acts as the major source of valuable insights, encompassing book chapters, conference papers, reviews, conference reviews as well as chapters excluded from the latest research. The review considered only publications in English from 2020 to 2024, following strict criteria that

Volume 6 Issue 23 (December 2024) PP. 687-707
DOI: 10.35631/IJMOE.623047

excluded non-English publications, those published prior to 2020, conference papers, book reviews, and in-press items.

Table 2: The Selection Criterion is Searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2020 – 2024	< 2020
Literature type	Journal (Article)	Conference Paper, Book Chapter, Conference Review, Review, Book
Publication Stage	Final	In Press

Eligibility

In the third step, known as the eligibility phase, 184 articles were selected for review. At this stage, the titles and key content of each article were thoroughly examined to confirm that they satisfy the inclusion criteria as well as aligned with the current research objectives. Consequently, 149 articles were excluded for reasons such as being outside the relevant field, having insignificant titles, presenting abstracts that did not relate to the objectives of the study or inadequate full-text access to empirical evidence. Consequently, 35 articles remained for the subsequent review.

Data Abstraction and Analysis

An integrative analysis was employed as one of the assessment methods in this study to examine and combine various research designs (quantitative approaches). The purpose of the study was to identify key topics and subtopics. Data collection marked the initial phase in developing the themes. As illustrated in Figure 2, the authors carefully reviewed a collection of 35 publications for statements or content relevant to the study's topics. They then assessed the significant studies related to digital IBL as well as scientific literacy. The methodology and findings of all the studies are currently under review. Subsequently, the author worked with co-authors to identify themes based on the evidence within the study's context. A log was maintained during the data analysis to document any analyses, insights, questions, or other relevant thoughts regarding data interpretation. In the final step, the authors compared their results to check for inconsistencies in the theme development. It is important to note that any disagreements about the concepts are discussed among the authors.

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume 6 Issue 23 (December 2024) PP. 687-707
DOI: 10.35631/IJMOE.623047

Table 3: Number and Details of Primary Studies Database

No	Authors	Title	Journal	Scopus	WoS
1	(Chen, Gijlers, Sui, & Chang, 2023)	Asian Students' Cultural Orientation and Computer Self-Efficacy Significantly Related to Online Inquiry-Based Learning Outcomes on the Go-Lab Platform	Journal of Science Education and Technology	/	
2	(Junanto, Budiyono, Akhyar, & Suryani, 2024)	Listen-search-read-discuss: an innovative lesson design to improve students' scientific literacy in higher education	International Journal of Evaluation and Research in Education	/	
3	(Ješková et al., 2022)	Active Learning in STEM Education with Regard to the Development of Inquiry Skills	Education Sciences	/	
4	(Šmida, Čipková, & Fuchs, 2024)	Developing the test of inquiry skills: measuring the level of inquiry skills among pupils in Slovakia	International Journal of Science Education	/	
5	(Chua et al., 2024)	Striving for Authentic and Sustained Technology Use in the Classroom: Lessons Learned from a Longitudinal Evaluation of a Sensor-Based Science Education Platform	International Journal of Human-Computer Interaction	/	
6	(Blackmore & Rønningsbakk, 2023)	Let us explain everything: pupils' perspectives of the affordances of mobile technology during primary science inquiry	Frontiers in Education	/	
7	(Cirkony, 2023)	Flexible, creative, constructive, and collaborative: the makings of an authentic science inquiry task	International Journal of Science Education	/	
8	(Heliawati, Lidiawati, Adriansyah, & Herlina, 2022)	Ethnochemistry-based adobe flash learning media using indigenous knowledge to improve students' scientific literacy	Jurnal Pendidikan IPA Indonesia	/	
9	(Liang et al., 2023)	Study Reporting an Elective Chemistry Course Titled "The Mysteries of Chemistry in Intangible Cultural Heritage" to Fulfill the Vision of Science Literacy	Journal of Chemical Education	/	
10	(Van Hoe et al., 2024)	The implementation of peer assessment as a scaffold during computer-supported collaborative inquiry learning in secondary STEM education	International Journal of STEM Education	/	

11	(Zheng et al., 2024)	Exploring the Effects and Inquiry Process Behaviors of Fifth-Grade Students Using Predict-Observe-Explain Strategy in Virtual Inquiry Learning	Journal of Science Education and Technology	/
12	(Lin, Yang, & Lin, 2024)	Fostering ecosystem understanding: The synergistic impact of inquiry-based instruction and information literacy	Computers and Education	/
13	(Hendratmoko, Madlazım, Wıdodo, & Sanjaya, 2023)	The impact of inquiry-based online learning with virtual laboratories on students' scientific argumentation skills	Turkish Online Journal of Distance Education	/
14	(Kousloglou et al., 2023)	Assessing Students' Awareness of 4Cs Skills after Mobile-Technology-Supported Inquiry-Based Learning	Sustainability (Switzerland)	/
15	(Bónus et al., 2024)	Digital Game-Based Inquiry Learning to Improve Eighth Graders' Inquiry Skills in Biology	Journal of Science Education and Technology	/
16	(Badaruddin, Budi, & Sumantri, 2024)	The effectiveness of science encyclopedia-assisted project-based learning integrated with the STEM approach in enhancing pre-service elementary teachers' scientific literacy	Journal of Education and e-Learning Research	/
17	(Guo, Qiao, & Ibrahim, 2022)	The Mechanism of Influence Between ICT and Students' Science Literacy: a Hierarchical and Structural Equation Modelling Study	Journal of Science Education and Technology	/
18	(Ding, 2022)	Examining the context of better science literacy outcomes among U.S. schools using visual analytics: A machine learning approach	International Journal of Educational Research Open	/
19	(Cheng et al., 2021)	Integrating Smartphone-Controlled Paper Airplane Into Gamified Science Inquiry for Junior High School Students	Journal of Educational Computing Research	/
20	(Valle et al., 2021)	Community Science, Storytelling, or Inquiry-Based Learning? Evaluating Three Technology-Enhanced Pedagogical Approaches in an Online Botany Course	American Biology Teacher	/
21	(Ahied, Muharrami, Fikriyah, & Rosidi, 2020)	Improving students' scientific literacy through distance learning with augmented reality-based multimedia amid the covid-19 pandemic	Jurnal Pendidikan IPA Indonesia	/
22	(Vartiainen & Kumpulainen, 2020)	Playing with science: manifestation of scientific play in early science inquiry	European Early Childhood Education Research Journal	/

International Journal of Modern Education IJMOE
EISSN: 2637-0905
Volume 6 Issue 23 (December 2024) PP. 687-707
DOI: 10.35631/IJMOE.623047

23	(Grabau, Lavonen, & Juuti, 2021)	Finland, a package deal: Disciplinary climate in science classes, science dispositions and science literacy	Sustainability (Switzerland)	/	
24	(Chou, Liang, Huang, & She, 2022)	The Impacts of Online Skeuomorphic Physics Inquiry–Based Learning With and Without Simulation on 8th Graders' Scientific Inquiry Performance	Journal of Science Education and Technology	/	
25	(Wang, Chen, & Yen, 2021)	Effects of metacognitive scaffolding on students' performance and confidence judgments in simulation-based inquiry	Physical Review Physics Education Research	/	
26	(Tavares et al., 2021)	Mobile app for science education: Designing the learning approach	Education Sciences	/	
27	(Sotiriou et al., 2020)	Inquiry-based learning and E-learning: how to serve high and low achievers	Smart Learning Environments	/	
28	(Novitra, 2021)	Development of Online-based Inquiry Learning Model to Improve 21st-Century Skills of Physics Students in Senior High School	Eurasia Journal of Mathematics, Science and Technology Education	/	
29	(Natale, Mello, Trivelato, Marzin-Janvier, & Manzoni-de-Almeida, 2021)	Evidence of scientific literacy through hybrid and online biology inquiry-based learning activities	Higher Learning Research Communications	/	
30	(Li, Hong, Chai, Tsai, & Lin, 2020)	Fostering Students' Scientific Inquiry through Computer-Supported Collaborative Knowledge Building	Research in Science Education	/	
31	(Mamun, 2022)	Fostering self-regulation and engaged exploration during the learner-content interaction process: the role of scaffolding in the online inquiry-based learning environment	INTERACTIVE TECHNOLOGY AND SMART EDUCATION	/	
32	(Sui, Chen, Cheng, & Chang, 2023)	The Go-Lab Platform, an Inquiry-learning Space: Investigation into Students' Technology Acceptance, Knowledge Integration, and Learning Outcomes	JOURNAL OF SCIENCE EDUCATION AND TECHNOLOGY		/
33	(Shea et al., 2022)	Building bridges to advance the community of inquiry framework for online learning	EDUCATIONAL PSYCHOLOGIST		/
34	(Virtič, 2022)	Teaching science & technology: components of scientific literacy and insight into the steps of research	INTERNATIONAL JOURNAL OF SCIENCE EDUCATION		/

Volume 6 Issue 23 (December 2024) PP. 687-707
DOI: 10.35631/IJMOE.623047

35	(Chou et al., 2022)	The Impacts of Online Skeuomorphic Physics Inquiry-Based Learning With and Without Simulation on 8th Graders' Scientific Inquiry Performance	JOURNAL OF SCIENCE EDUCATION AND TECHNOLOGY	/

International Journal of Modern Education
EISSN: 2637-0905
IJMOE
Volume 6 Issue 23 (December 2024) PP. 687-707
DOI: 10.35631/IJMOE.623047

Quality of Appraisal

Following the guidelines proposed by Keele (2007), we identified the primary studies—original research articles, papers, or documents included in the systematic review post-selection process—as the primary evidence to discuss the RQs. We then assessed the quality of the research presented and conducted a quantitative comparison using the quality assessment (QA) approach of Abouzahra, Sabraoui and Afdel (2020), which includes six QA criteria for our SLR. Each criterion was rated using a scoring system with three possible results: Assign a score of 1 for "Yes" (Y) if fully met, 0.5 for "Partly" (P) if partially met, and 0 for "No" (N) if not met. The six QA criteria are as follows: QA1. Is the purpose of the study clearly stated? QA2. Is the interest and the usefulness of the work clearly presented? QA3. Is the study methodology clearly established? QA4. Are the concepts of the approach clearly defined? QA5. Is the work compared and measured with other similar work? and QA6. Are the limitations of the work clearly mentioned? This structured assessment ensures a comprehensive evaluation of each study's quality and relevance to the research objectives, thereby maintaining the integrity and rigor of the SLR process.

The table outlines a quality assessment (QA) procedure used to evaluate a study based on specific criteria. Three experts review the study, rating each criterion as "Yes" (Y), "Partly" (P), or "No" (N). The criteria include: 1) Is the purpose of the study clearly stated? This criterion assesses if the study's objectives are well-defined and clearly expressed, which helps establish the direction and scope of the research. 2) Is the interest and usefulness of the work clearly presented? This criterion examines if the study's importance and potential contributions are effectively communicated, assessing its relevance and impact. 3) Is the study's methodology clearly outlined? This examines whether the research design is thoroughly described and suitable for achieving the study's aims. A well-defined methodology is essential for the study's validity and reproducibility. 4) Are the concepts within the approach clearly defined? This criterion looks at whether the theoretical framework and main concepts are clearly explained. Clear definitions are crucial for understanding the study's approach. 5) Is the work compared with similar studies? This assesses whether the study has been measured against existing research, which helps situate it within the broader academic field and emphasizes its contributions. 6) Are the study's limitations clearly stated? Each expert independently evaluates the study based on these criteria, and their scores are then combined to produce an overall mark. For a study to advance to the next stage, the total score obtained by adding the scores from all three experts must be greater than 3.0. This benchmark ensures that only studies meeting a specific quality standard move forward.

International Journal of Modern Education
EISSN: 2637-0905
Volume 6 Issue 23 (December 2024) PP. 687-707
DOI: 10.35631/IJMOE.623047

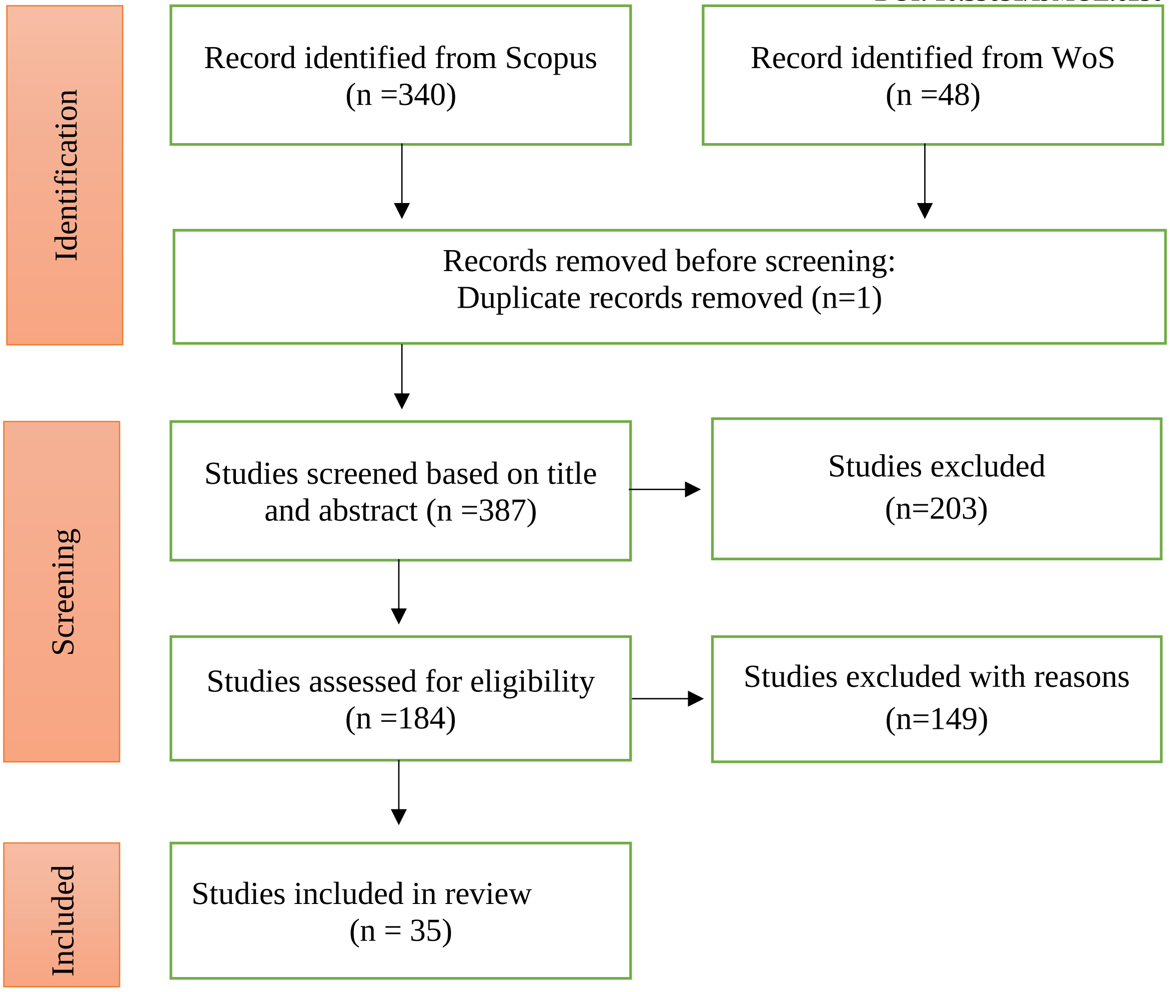

Figure 1: Selecting Articles to be Reviewed Following PRISMA (Page et al., 2021)

Result and Finding

The quality assessment results of the selected major research studies provide significant insights into their overall performance across six key criteria (QA1 to QA6). Scores ranged from 4.5 to 6, corresponding to percentages between 75% and 100%. A distinguished group of studies, including PS7, PS9, PS15, PS29, PS31, and PS35, achieved perfect scores of 100%. These studies demonstrated exemplary research practices, characterized by comprehensive designs, clear articulation of objectives, methodological rigor, well-defined concepts, effective integration with existing literature, and explicit acknowledgment of limitations, positioning them as ideal references for future scholarly work. Fifteen studies—PS1, PS6, PS11, PS12, PS18, PS19, PS22, PS23, PS24, PS25, PS27, PS30, PS32, PS33, and PS34—scored 91.67%, reflecting solid quality across most criteria, though minor weaknesses were observed, particularly in methodological detail or the discussion of limitations. Eleven additional studies—PS2, PS3, PS4, PS8, PS10, PS13, PS16, PS20, PS21, PS26, and PS28—scored 83.33%, exhibiting generally robust quality but requiring refinement in areas such as methodological transparency and contextualization of findings. At the lower end, three studies—PS5, PS14, and PS17—received the lowest score of 75%. These studies demonstrated notable deficiencies, particularly in methodological clarity and comparative analysis with existing literature, necessitating substantial revisions to enhance their academic rigor and

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume 6 Issue 23 (December 2024) PP. 687-707
DOI: 10.35631/IJMOE.623047
contribution to the field. In sum, this assessment identifies both exemplary research and areas for improvement, serving as a valuable guide for future scholars seeking to elevate the quality and impact of their work.

Data	QA1	QA2	QA3	QA4	QA5	QA6	Total Mark	Percent age (%)
PS1	1	1	1	1	0.5	1	5.5	91.67
PS2	1	1	0.5	1	1	0.5	5	83.33
PS3	1	0.5	1	0.5	1	1	5	83.33
PS4	0.5	1	1	1	0.5	1	5	83.33
PS5	1	0.5	0.5	1	1	0.5	4.5	75
PS6	1	1	1	0.5	1	1	5.5	91.67
PS7	1	1	1	1	1	1	6	100
PS8	0.5	1	1	1	0.5	1	5	83.33
PS9	1	1	1	1	1	1	6	100
PS10	1	1	0.5	1	1	0.5	5	83.33
PS11	1	1	1	0.5	1	1	5.5	91.67
PS12	0.5	1	1	1	1	1	5.5	91.67
PS13	1	0.5	1	1	1	0.5	5	83.33
PS14	0.5	1	0.5	1	0.5	1	4.5	75
PS15	1	1	1	1	1	1	6	100
PS16	1	0.5	1	0.5	1	1	5	83.33
PS17	0.5	1	0.5	1	1	0.5	4.5	75
PS18	1	1	1	1	0.5	1	5.5	91.67
PS19	1	0.5	1	1	1	1	5.5	91.67
PS20	0.5	1	1	1	1	0.5	5	83.33
PS21	1	0.5	0.5	1	1	1	5	83.33
PS22	1	1	1	1	0.5	1	5.5	91.67
PS23	1	1	1	0.5	1	1	5.5	91.67
PS24	1	1	1	1	1	0.5	5.5	91.67
PS25	1	1	0.5	1	1	1	5.5	91.67
PS26	0.5	1	1	1	0.5	1	5	83.33
PS27	1	0.5	1	1	1	1	5.5	91.67
PS28	1	1	1	0.5	1	0.5	5	83.33
PS29	1	1	1	1	1	1	6	100
PS30	1	1	1	1	0.5	1	5.5	91.67
PS31	1	1	1	1	1	1	6	100
PS32	1	1	0.5	1	1	1	5.5	91.67
PS33	1	1	1	1	1	0.5	5.5	91.67
PS34	0.5	1	1	1	1	1	5.5	91.67
PS35	1	1	1	1	1	1	6	100

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume 6 Issue 23 (December 2024) PP. 687-707
DOI: 10.35631/IJMOE.623047

Summary:

Highest Score: Studies PS7, PS9, PS15, PS29, PS31, and PS35 achieved a perfect 100%, demonstrating excellence in research design, clarity of purpose, methodological rigor, concept definition, literature comparison, and limitation acknowledgment.

Lowest Score: Studies PS5, PS14, and PS17 scored 75%, meeting only some criteria, with notable gaps in methodology and limitation discussions, necessitating improvement for greater scholarly contribution.

The Role of Digital Tools in Supporting Inquiry-Based Learning

Digital tools play a crucial role in supporting inquiry-based learning (IBL), particularly in enhancing scientific literacy and promoting student engagement. Research by Tavares et al. (2021) and other (Blackmore & Rønningsbakk, 2023; Tavares et al., 2021; Zheng et al., 2024) demonstrates that tools such as mobile applications, virtual environments, and interactive platforms significantly impact students' comprehension of scientific concepts, self-regulation, and knowledge integration. These studies highlight the integration of technology into IBL, emphasizing interactive, student-centered approaches. A consistent finding is the positive influence of digital tools on scientific literacy and students' ability to engage in scientific argumentation. Studies Hendratmoko et al. (2023), Heliawati et al. (2022) and Ahied et al. (2020) identify augmented reality, ethnochemistry media, and virtual laboratories as tools that support scientific competency development. Cultural factors also significantly affect IBL outcomes. Research Chen et al. (2023), Chua et al. (2024), and Sui et al. (2023) underscores that cultural orientation and computer self-efficacy influence success in inquiry-based tasks, with culturally responsive learning environments enhancing engagement and efficacy. The impact of storytelling and collaborative frameworks in digital IBL has also been significant. Valle et al. (2021) and Li et al. (2020) found that approaches incorporating storytelling and computer-supported collaborative knowledge building were particularly effective in fostering positive attitudes toward science, especially among female learners. Storytelling was particularly effective in enhancing engagement and appreciation for science topics, demonstrating the value of contextual and narrative-driven learning experiences in digital environments. Additionally, Chou et al. (2022) and Ding (2022) highlighted that the use of visual analytics and online simulations positively influenced students' performance, particularly among lower achievers. Simulations accelerated students' development of scientific inquiry skills and bridged achievement gaps, especially in challenging subjects like physics, underlining the potential of simulations to equalize opportunities for learning.

Inquiry-Based Learning for Enhancing Scientific Literacy

The role of IBL in enhancing scientific literacy has been widely substantiated through numerous studies that investigate various aspects of educational development. Many researchers emphasize the importance of collaborative and scaffolded learning environments in strengthening scientific literacy among students. For example, Van Hoe et al. (2024) incorporated peer assessment into computer-supported collaborative inquiry learning (CSCiL) environments, which improved students' skills in forming RQs, handling data, and refining conclusions. Similarly, Badaruddin et al. (2024) reported positive outcomes from integrating a science encyclopedia-assisted project-based learning approach with STEM elements, significantly improving pre-service elementary teachers' scientific literacy. These studies highlight the effectiveness of structured learning methodologies and the incorporation of collaborative tools to improve inquiry-based education. Modern tools and methodologies play a crucial role in enriching IBL. Kousloglou et al. (2023) assessed the influence of mobile-

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume 6 Issue 23 (December 2024) PP. 687-707
DOI: 10.35631/IJMOE.623047
technology-supported IBL on the awareness of the students with regards to the 4Cs (Collaboration, Communication, Critical Thinking, as well as Creativity), finding substantial impacts on collaboration and communication skills. This suggests that mobile technology not only enhances access to learning materials but also facilitates active learning through timely feedback. Similarly, Chou et al. (2022) explored the effects of online skeuomorphic physics IBL with and without simulations, concluding that simulations significantly accelerated the establishment of scientific inquiry skills as well as helped bridge the achievement gap. These outcomes demonstrate the potential of digital tools to create more equitable learning environments by supporting students who may struggle with traditional instruction. Scaffolded inquiry is essential for developing higher-order thinking skills and fostering active learning. Li et al. (2020) examined the effects of combining inquiry-based instruction with information literacy in environmental education, showing significant improvements in students' understanding of complex ecosystem concepts. Similarly, Wang et al. (2021) observed that metacognitive scaffolding in simulation-based inquiry tasks improved students' confidence in handling variables, interpreting data, and understanding graphs. Authentic inquiry experiences and supportive learning environments are fundamental in enhancing scientific literacy. Cirkony (2023) analyzed a guided-inquiry multimodal approach in teaching sustainable design, highlighting how flexibility, creativity, and collaboration in inquiry tasks encouraged active student engagement in scientific practices. Natale et al. (2021) provided similar insights with their study of hybrid as well as online biology inquiry activities that fostered scientific literacy via epistemic practices. Supportive environments, such as those examined by Grabau et al. (2021), show that a positive disciplinary climate and teaching support are predictive of higher science literacy. Additionally, Junanto et al. (2024) introduced the LISERED model to improve scientific literacy through an interactive, engaging learning environment, while Šmida et al. (2024) stressed the importance of systematic assessment tools for addressing skill gaps. These studies emphasize that inquiry-based strategies, when combined with supportive environments, are key to fostering scientific literacy and preparing students for active participation in a knowledge-driven society.

Innovative and Hybrid Inquiry-Based Learning Approaches

Innovative and hybrid IBL methodologies have emerged as essential in advancing students' inquiry skills, scientific literacy, and motivation across diverse educational settings. The integration of digital tools, culturally contextualized project-based learning, and sophisticated pedagogical strategies fosters highly effective environments for scientific inquiry. Studies by Ješková et al. (2022), Liang et al. (2023), and Bónus et al. (2024) demonstrate the efficacy of technology-infused approaches in fostering inquiry skills and promoting scientific literacy. Ješková et al. (2022) illustrate how digital resources, paired with formative assessment tools, enhance inquiry-based science education (IBSE) by developing skills such as data interpretation and accuracy. Liang et al. (2023) employed a project-based, culturally contextualized approach in chemistry courses, combining experimental and reflective elements to significantly improve student engagement, self-efficacy, and chemistry performance. Bónus et al. (2024) explored the BioScientist digital game-based inquiry program, finding moderate improvements in inquiry skills, demonstrating the potential of digital games to integrate effectively into traditional science curricula. Collectively, these studies underscore the substantial impact of digital and inquiry-based methodologies on science education outcomes. Research on the role of play and gamification further supports the value of inquiry-based methodologies, with studies by Vartiainen and Kumpulainen (2020), Cheng et al. (2021), and Bónus et al. (2024). Vartiainen and Kumpulainen (2020) analyzed the interplay between

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume 6 Issue 23 (December 2024) PP. 687-707
DOI: 10.35631/IJMOE.623047
scientific play and inquiry in preschool children, identifying imaginative play as a catalyst for cognitive engagement and inquiry skill development. They identified four key components of scientific play that support inquiry learning: imaginative contextualization, creative reinterpretation, problem-solving through imaginary frameworks, and immersive science communication. Cheng et al. (2021) explored the effectiveness of smartphone-controlled paper airplanes in a gamified learning structure, engaging junior high students in scientific inquiry. Bónus et al. (2024) integrated game mechanics into the BioScientist digital game, demonstrating that gamification can sustain interest and reinforce inquiry skills, particularly in biology. These findings highlight that play and gamification, when strategically integrated into inquiry-based frameworks, not only sustain student interest but also deepen learning outcomes, particularly among younger learners. The scalability and adaptability of IBL approaches are key themes in the research, as noted by Sotiriou et al. (2020), Liang et al. (2023), and Shea et al. (2022). Sotiriou et al. (2020) examined a Europe-wide initiative that leveraged e-learning tools, including virtual laboratories and augmented reality, to support inquiry learning across a large sample of schools. Their findings showed a marked increase in high-achieving students, suggesting that technology-supported inquiry models can effectively extend the reach and impact of IBSE. Liang et al. (2023) emphasize the importance of situational teaching and reflective methodologies in fostering a nuanced understanding of scientific concepts, linking academic content with culturally meaningful contexts. Shea et al. (2022) analyzed challenges during the COVID-19 pandemic and advocated for an enhanced Community of Inquiry (CoI) model that incorporates ‘Learning Presence’ to better support collaborative learning in online environments. These studies affirm that IBL, supported by comprehensive digital and pedagogical frameworks, can be scaled across educational systems, even during significant disruptions like the global shift to remote education.

Discussion and Conclusion

The integration of digital tools with inquiry-based learning (IBL) methodologies has significantly advanced scientific literacy and student engagement. Digital tools, including mobile applications, virtual platforms, and simulations, facilitate the comprehension of scientific concepts by supporting self-regulation and knowledge integration. These tools promote scientific argumentation and enable students to apply theoretical insights in real-world contexts. Cultural responsiveness further enhances their effectiveness, as tools aligned with students' cultural values foster greater engagement and improved learning outcomes. Storytelling and collaborative frameworks within digital platforms, especially for female students, have been particularly effective in cultivating positive science attitudes through relevant, narrative-driven experiences. The implementation of visual analytics and simulations optimizes learning by enhancing comprehension and supporting lower-achieving students, contributing to a more inclusive educational environment. IBL is most effective in scaffolded, collaborative settings, where it fosters cognitive engagement and scientific reasoning. Project-based, STEM-integrated methods and peer assessment within CSCiL environments positively impact research formulation, data management, and scientific reasoning skills. Research demonstrates IBL’s adaptability and scalability, particularly during large-scale disruptions like the COVID-19 pandemic, where online-enhanced IBL approaches maintained student engagement and academic progression. Innovative instructional models such as Listen-Search-Read-Discuss further emphasize supportive, inquiry-based climates that foster a deeper understanding of scientific processes. The inclusion of gamification, particularly for younger learners, enhances cognitive engagement and inquiry skills through interactive, experiential

Volume 6 Issue 23 (December 2024) PP. 687-707
DOI: 10.35631/IJMOE.623047

learning. IBL, when supported by digital tools, culturally contextualized content, and dynamic instructional strategies, transforms scientific literacy and engagement. Technology integration within IBL frameworks not only improves content acquisition but also encourages active participation, critical thinking, and higher-order cognitive skills. In sum, the synergy of digital tools and structured IBL approaches contributes to educational inclusivity, equipping students for academic success and informed participation in a scientifically literate global society.

Funding Statement
This work was supported by Hadiah Latihan Persekutuan Separuh Masa (HLPS) (literally translated as 'Part-Time Federal Training Prizes') from the Ministry of Education, Malaysia.

Conflicts of Interest
The author(s) reported no conflicts of interest.

Acknowledgment
The authors would like to acknowledge Ministry of Education, Malaysia for this project.

References
Abouzahra, A., Sabraoui, A., & Afdel, K. (2020). Model composition in Model Driven Engineering: A systematic literature review. Information and Software Technology, 125, 1–18. https://doi.org/10.1016/j.infsof.2020.106316

Ahied, M., Muharrami, L. K., Fikriyah, A., & Rosidi, I. (2020). Improving studentsâ€TM scientific literacy through distance learning with augmented reality-based multimedia amid the covid-19 pandemic. Jurnal Pendidikan IPA Indonesia, 9(4), 499–511.

Badaruddin, A., Budi, A. S., & Sumantri, M. S. (2024). The Effectiveness of Science Encyclopedia-Assisted Project-Based Learning Integrated with the STEM Approach in Enhancing Pre-Service Elementary Teachers' Scientific Literacy. Journal of Education and E-Learning Research, 11(3), 597–605.

Baltikian, M., Kärkkäinen, S., & Kukkonen, J. (2024). Assessment of scientific literacy levels among secondary school students in Lebanon: Exploring gender-based differences. Eurasia Journal of Mathematics, Science and Technology Education, 20(3), 1–18.

Blackmore, K., & Rønningsbakk, L. (2023). Let us explain everything: pupils' perspectives of the affordances of mobile technology during primary science inquiry. Frontiers in Education, 8, 1–14.

Bónus, L., Antal, E., & Korom, E. (2024). Digital Game-Based Inquiry Learning to Improve Eighth Graders' Inquiry Skills in Biology. Journal of Science Education and Technology, 33(4), 1–17.

Bossér, U. (2024). Transformation of School Science Practices to Promote Functional Scientific Literacy. Research in Science Education, 54(2), 265–281.

Chang, T.-C., Lyu, Y.-M., Wu, H.-C., & Min, K.-W. (2024). Introduction of Taiwanese literacy-oriented science curriculum and development of an aligned scientific literacy assessment. Eurasia Journal of Mathematics, Science and Technology Education, 20(1), 1–11.

Chen, H.-C., Gijlers, H., Sui, C.-J., & Chang, C.-Y. (2023). Asian Students' Cultural Orientation and Computer Self-Efficacy Significantly Related to Online Inquiry-Based Learning Outcomes on the Go-Lab Platform. Journal of Science Education and Technology, 32(5), 743–758.

Volume 6 Issue 23 (December 2024) PP. 687-707
DOI: 10.35631/IJMOE.623047
Cheng, M., Su, C.-Y., & Kinshuk. (2021). Integrating smartphone-controlled paper airplane into gamified science inquiry for junior high school students. Journal of Educational Computing Research, 59(1), 71–94.

Chou, R.-J., Liang, C.-P., Huang, L., & She, H.-C. (2022). The impacts of online skeuomorphic physics inquiry–based learning with and without simulation on 8th graders' scientific inquiry performance. Journal of Science Education and Technology, 31(3), 357–371.

Chua, Y., Cooray, S., Cortes, J. P. F., Denny, P., Dupuch, S., Garbett, D. L., … Reis, A. (2024). Striving for Authentic and Sustained Technology Use in the Classroom: Lessons Learned from a Longitudinal Evaluation of a Sensor-Based Science Education Platform. International Journal of Human–Computer Interaction, 40(18), 5073–5086.

Cirkony, C. (2023). Flexible, creative, constructive, and collaborative: the makings of an authentic science inquiry task. International Journal of Science Education, 45(17), 1440–1462.

Ding, C. (2022). Examining the context of better science literacy outcomes among US schools using visual analytics: A machine learning approach. International Journal of Educational Research Open, 3, 1–11.

El Bedewy, S., Lavicza, Z., Sabitzer, B., Houghton, T., & Nurhasanah, F. (2024). Exploring Transdisciplinary, Technology-Assisted, and Architectural Modelling STEAM Practices through a Cultural Lens. European Journal of Science and Mathematics Education, 12(2), 211–235.

Essalih, S., Ourahay, M., & Khzami, S. (2024). Perceptions and practices of science teachers for the development of critical thinking through inquiry: a qualitative study of Moroccan primary schools. Education 3-13, 52(5), 662–677.

Eymur, G., & Çetin, P. S. (2024). Investigating the role of an inquiry-based science lab on students' scientific literacy. Instructional Science, 52(5), 743–760.

Grabau, L. J., Lavonen, J., & Juuti, K. (2021). Finland, a package deal: Disciplinary climate in science classes, science dispositions and science literacy. Sustainability, 13(24), 1–16.

Guo, Q., Qiao, C., & Ibrahim, B. (2022). The mechanism of influence between ICT and students' science literacy: a hierarchical and structural equation modelling study. Journal of Science Education and Technology, 31(2), 272–288.

Heliawati, L., Lidiawati, L., Adriansyah, P. N. A., & Herlina, E. (2022). Ethnochemistry-based adobe flash learning media using indigenous knowledge to improve students' scientific literacy. Jurnal Pendidikan IPA Indonesia, 11(2), 271–281.

Hendratmoko, A. F., Madlazım, M., Wıdodo, W., & Sanjaya, I. G. M. (2023). The impact of inquiry-based online learning with virtual laboratories on students' scientific argumentation skills. Turkish Online Journal of Distance Education, 24(4), 1–20.

Ješková, Z., Lukáč, S., Šnajder, Ľ., Guniš, J., Klein, D., & Kireš, M. (2022). Active learning in STEM education with regard to the development of inquiry skills. Education Sciences, 12(10), 1–21.

Junanto, T., Budiyono, B., Akhyar, M., & Suryani, N. (2024). Listen-search-read-discuss: an innovative lesson design to improve students' scientific literacy in higher education. International Journal of Evaluation and Research in Education (IJERE), 13(6), 4073–4081.

Karamustafaoğlu, O., & Pektaş, H. M. (2023). Developing students' creative problem solving skills with inquiry-based STEM activity in an out-of-school learning environment. Education and Information Technologies, 28(6), 7651–7669.

Keele, S. (2007). Guidelines for performing systematic literature reviews in software engineering. Kitchenham.

International Journal of Modern Education
IJMOE
EISSN: 2637-0905
Volume 6 Issue 23 (December 2024) PP. 687-707
DOI: 10.35631/IJMOE.623047
Kirchhoff, T., Randler, C., & Großmann, N. (2023). Experimenting at an outreach science lab versus at school—Differences in students' basic need satisfaction, intrinsic motivation, and flow experience. Journal of Research in Science Teaching, 60(10), 2255–2293.

Koswojo, J., & Pratidhina, E. (2023). Development of an Inquiry-Based Module with Scientific Equipment to Facilitate Primary School Students Learning the Force Concept. Journal of Education and E-Learning Research, 10(2), 314–322.

Kousloglou, M., Petridou, E., Molohidis, A., & Hatzikraniotis, E. (2023). Assessing students' awareness of 4cs skills after mobile-technology-supported inquiry-based learning. Sustainability, 15(8), 1–21.

Lestari, D. P., Paidi, P., & Suwarjo, S. (2024). Effect of the inquiry-based nature of science argumentation instructional model in scientific literacy skills. Journal of Education and Learning, 18(3), 734–744.

Li, P.-J., Hong, H.-Y., Chai, C. S., Tsai, C.-C., & Lin, P.-Y. (2020). Fostering students' scientific inquiry through computer-supported collaborative knowledge building. Research in Science Education, 50, 2035–2053.

Liang, Y., Li, M., Tian, C., & Li, H. (2023). Study reporting an elective chemistry course titled "the mysteries of chemistry in intangible cultural heritage" to fulfill the vision of science literacy. Journal of Chemical Education, 100(7), 2654–2663.

Lin, J.-H., Yang, S. C., & Lin, J.-Y. (2024). Fostering ecosystem understanding: The synergistic impact of inquiry-based instruction and information literacy. Computers and Education, 220, 1–29.

Litina, S., & Rubene, Z. (2024). The Effect of Digital School Culture on Science Education and Scientific Literacy: A Scoping Review. Journal of Education Culture and Society, 15(1), 41–55.

Lockwood, C., Munn, Z., & Porritt, K. (2015). Qualitative research synthesis: Methodological guidance for systematic reviewers utilizing meta-aggregation. International Journal of Evidence-Based Healthcare, 13(3), 179–187.

Mamun, M. A. Al. (2022). Fostering self-regulation and engaged exploration during the learner-content interaction process: the role of scaffolding in the online inquiry-based learning environment. Interactive Technology and Smart Education, 19(4), 482–509.

Mufit, F., & Dhanil, M. (2024). Effectiveness of augmented reality with cognitive conflict model to improve scientific literacy of static fluid material. International Journal of Information and Education Technology, 14(9), 1199–1207.

Nasri, N. M., Nasri, N., Nasri, N. F., & Abd Talib, M. A. (2023). The Impact of integrating an intelligent personal assistant (IPA) on secondary school physics students' scientific inquiry skills. IEEE Transactions on Learning Technologies, 16(2), 232–242.

Natale, C. C., Mello, P. S., Trivelato, S. L. F., Marzin-Janvier, P., & Manzoni-de-Almeida, D. (2021). Evidence of Scientific Literacy through Hybrid and Online Biology Inquiry-Based Learning Activities. Higher Learning Research Communications, 11, 33–49.

Novitra, F. (2021). Development of Online-Based Inquiry Learning Model to Improve 21st-Century Skills of Physics Students in Senior High School. Eurasia Journal of Mathematics, Science and Technology Education, 17(9), 1–20.

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. The BMJ, 372, 1–9.

Rissanen, A., Hoang, J. G., & Spila, M. (2023). First-year interdisciplinary science experience enhances science belongingness and scientific literacy skills. Journal of Applied Research in Higher Education, 15(5), 1561–1586.

Volume 6 Issue 23 (December 2024) PP. 687-707
DOI: 10.35631/IJMOE.623047
Rusdiyana, R., Indriyanti, D. R., Hartono, H., & Isnaeni, W. (2024). The Application of On-Line Science-Based Inquiry Learning in Primary Schools. Journal of Turkish Science Education, 21(2), 293–303.

Shea, P., Richardson, J., & Swan, K. (2022). Building bridges to advance the community of inquiry framework for online learning. Educational Psychologist, 57(3), 148–161.

Šmida, D., Čipková, E., & Fuchs, M. (2024). Developing the test of inquiry skills: measuring the level of inquiry skills among pupils in Slovakia. International Journal of Science Education, 46(1), 73–108.

Sotiriou, S. A., Lazoudis, A., & Bogner, F. X. (2020). Inquiry-based learning and E-learning: how to serve high and low achievers. Smart Learning Environments, 7(1), 1–15.

Sui, C.-J., Chen, H.-C., Cheng, P.-H., & Chang, C.-Y. (2023). The Go-Lab platform, an inquiry-learning space: Investigation into students' technology acceptance, knowledge integration, and learning outcomes. Journal of Science Education and Technology, 32(1), 61–77.

Suliyanah, Amiruddin, M. Z., & Prahani, B. K. (2024). Scientific argumentations research for last 10 years: analysis bibliometric. International Journal of Evaluation and Research in Education, 13(4), 2126–2138.

Tavares, R., Marques Vieira, R., & Pedro, L. (2021). Mobile app for science education: Designing the learning approach. Education Sciences, 11(2), 1–23.

Valle, N., Antonenko, P., Endara, L., Davis, E. C., Somarriba, G., Sessa, E., … Burleigh, J. G. (2021). Community science, storytelling, or inquiry-based learning? evaluating three technology-enhanced pedagogical approaches in an online botany course. The American Biology Teacher, 83(8), 513–520.

Van Hoe, A., Wiebe, J., Rotsaert, T., & Schellens, T. (2024). The implementation of peer assessment as a scaffold during computer-supported collaborative inquiry learning in secondary STEM education. International Journal of STEM Education, 11(1), 1–21.

Vartiainen, J., & Kumpulainen, K. (2020). Playing with science: manifestation of scientific play in early science inquiry. European Early Childhood Education Research Journal, 28(4), 490–503.

Virtič, M. P. (2022). Teaching science and technology: components of scientific literacy and insight into the steps of research. International Journal of Science Education, 44(12), 1916–1931.

Wang, H.-S., Chen, S., & Yen, M.-H. (2021). Effects of metacognitive scaffolding on students' performance and confidence judgments in simulation-based inquiry. Physical Review Physics Education Research, 17(2), 1–13.

Yaman, F., & Hand, B. (2024). Exploring Conditions for Utilizing Representations in Chemistry in an Argument-Based Inquiry Environment: Laboratory Only, Technology Only, or a Combination of Laboratory and Technology. Journal of Chemical Education, 101(6), 2231–2243.

Zheng, Y., Bai, X., Yang, Y., & Xu, C. (2024). Exploring the Effects and Inquiry Process Behaviors of Fifth-Grade Students Using Predict-Observe-Explain Strategy in Virtual Inquiry Learning. Journal of Science Education and Technology, 33(4), 590–606.