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The Role of Learning Models in Enhancing Scientific Literacy: A Critical Review Evaluation

*** Winata Tegar Saputra, Diana Rochintaniawati, Rika Rafikah Agustin**
Department of Science Education, Faculty of Mathematics and Science Education, Universitas Pendidikan Indonesia, Bandung Indonesia

*Corresponding Author e-mail: winatategar08@upi.edu

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Abstract

This literature review examines the impact of learning models on students' scientific literacy and provides critiques of the strengths and weaknesses of the literature. These critiques offer recommendations for future research. Additionally, this review analyzes the role of socio-scientific issues in the context of scientific literacy. To conduct this review, 27 articles from Scopus-indexed journals were critically analyzed using the keywords: (1) Socio-scientific issues in science literacy, (2) model-based learning in scientific literacy, (3) inquiry-based learning in scientific literacy, and (4) socio-scientific issues using model-based learning in science literacy. The analysis was facilitated by the Publish or Perish software. The findings of this review suggest that various inquiry learning models have a positive impact on scientific literacy across different topics and support students' learning achievement. However, it was observed that two specific types of inquiry-based learning models, namely open inquiry-based learning and independent inquiry-based learning, were not effective in improving scientific literacy. Therefore, future research should focus on alternative inquiry-based learning models that have shown promising results in improving scientific literacy. Furthermore, this review highlights that the existing literature predominantly discusses socioscientific issues within the framework of curriculum settings and does not adequately address real-life problems associated with these issues.

Keywords: Scientific literacy; Socio-scientific issues; Model learning; Critical review; Science Education

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INTRODUCTION

Scientific literacy is a fundamental aspect of everyday life (Jufrida et al., 2019). It encompasses practical understanding of scientific components, including: (1) knowledge that aligns with the scientific community, (2) comprehension of scientific processes, (3) awareness of evidence and its utilization for understanding, and (4) understanding the interplay between science and societal aspects. Acquiring scientific literacy is particularly crucial for students (Ke et al., 2021), as it enables them to utilize scientific knowledge in addressing complex issues related to environmental changes in the real world (Rahayu et al., 2022).

It is widely recognized that appropriate learning models can enhance students' scientific literacy. The PISA 2025 framework mandates three competencies for scientific literacy: explaining scientific phenomena within scientific inquiry, constructing and evaluating designs for scientific inquiry, and interpreting data and evidence (OECD, 2023). Effective learning models allow students to approach scientific phenomena from multiple perspectives, similar to scientists (Passmore et al., 2014). The utility of model-based learning extends to various domains, such as cognitive, metacognitive, social, material, and epistemological aspects (Louca & Zacharia, 2012). According to Widodo (2021), the name and specific stages of learning models are not as important as the order in which students engage with them. Learning models must be designed to achieve desired learning outcomes and competencies (Magdalena et al., 2024). It is crucial that learning models designed to enhance scientific literacy support students' cognitive processes.Other than model-based learning, students require contextualization to enhance their scientific literacy (OECD, 2023). PISA 2025 introduces additional competencies, which encompass the skills of researching, evaluating, and utilizing scientific information for decision-making, action, and understanding societal implications. This highlights the significant role of social context in scientific literacy. Socio-Scientific Issues (SSI), in particular, provide the necessary social context, inquiry techniques, and reasoning abilities for students to comprehend scientific concepts (Zeidler & Nichols, 2009).

The primary objective of SSI education is to foster "functional scientific literacy" in students. This entails equipping them with strategies to make informed decisions, analyze, synthesize, and evaluate information from diverse sources, apply moral reasoning to address ethical concerns, and recognize the intricate interconnectedness inherent in contextualized science learning (Zeidler et al., 2019). The use of socioscientific models allows students to connect scientific information with broader social settings, empowering them to make well-informed decisions regarding the SSI they encounter in their daily lives (Ke et al., 2021).

Presley et al. (2013) outline the three main components of the framework for SSI-based instruction:

1. Design Elements: These elements consist of four sub-components, including (a) centering education around a compelling problem, (b) introducing the problem initially, (c) providing support for more complex activities such as reasoning, decision-making, and argumentation, and (d) concluding the encounter.
2. Learner Experiences: This fundamental element of the SSI framework defines essential learning experiences and opportunities, including (a) employing higher-order thinking skills such as argumentation, reasoning, decision-making, and position-taking, (b) critically examining theories and concepts from relevant scientific domains, (c) gathering and analyzing scientific evidence related to the problem, and (d) engaging in discussions about the societal aspects (e.g., political and economic factors) of the topic under consideration.
3. Teacher Attributes: The third core component of the SSI framework encompasses (a) possessing knowledge of the topic, including familiarity with relevant scientific content and awareness of societal factors surrounding the problem, (b) adopting a learner-centered approach, being open and transparent about one's knowledge gaps, and presenting oneself as a contributor to knowledge rather than the sole authority, and (c) effectively managing ambiguity within the classroom.Previous research discussed in the literature review conducted by Aristeidou & Herodotou (2020) revealed three main issues: 1) the identification and critical analysis of the learning impact of citizens' engagement in online citizen science projects, 2) the examination of how this has been studied in recent literature, and 3) the systematic assessment of resources in databases linked to citizen science, technology, and education.

Hudha et al. (2023) presented the results of a systematic literature study conducted to examine the impact of project-based learning on scientific literacy. The data for this study was gathered between 2012 and 2022. In order to address the research topics, Kumar et al. (2024) utilized a qualitative study that employed the systematic literature review (SLR) technique. This study also explored issues related to environmental literacy and employed environmental SSI as a context. Cavagnetto (2010) investigated how argument is used to promote scientific literacy by examining the traits of argument-based interventions in the research literature.

To comprehensively assess and synthesize the body of literature on "scientific literacy," "Bildung-oriented science education," and "science education frameworks," the article by Kilag et al. (2023) employed a critical review and meta-analysis technique.

Istyadji and Sauqina (2023) conducted a thorough examination of the literature regarding the frameworks used globally to develop scientific literacy tools and provided an overview of such frameworks to determine the authorities in scientific literacy that are considered reputable.The critical review conducted by Sadler (2004) examined socio-scientific issues and covered several important aspects: (a) Socioscientific argumentation; (b) The relationship between conceptualizations of the nature of science and decision-making regarding socio-scientific issues; (c) The assessment of data related to socio-scientific issues, including students' views on what constitutes evidence; and (d) The impact of individuals' conceptualizations on their informal logic. It is worth noting that while socio-scientific issues are not the only means of fostering scientific literacy, they can be an effective option for supporting students' intellectual and social development.

In a review by Yun et al. (2022), socio-scientific issues were examined through the lens of exhibitions. The authors focused on theoretical discussions surrounding exhibitions, namely critical reflection, contextualized information, and opinion sharing. These discussions centered on socioscientific themes and aimed to provide a comprehensive understanding of the exhibitions by precisely outlining their features and scope. Additionally, exhibitions based on socio-scientific issues require that the topics be presented as dynamic processes, rather than static products. The objective is to enhance public participation and the social relevance of science centers, with the aim of improving individuals' perspectives on the limits of science and technology within a social context.

Li and Guo (2021) conducted a bibliometric analysis on scientific literacy, exploring its relationship with informal reasoning, cognitive abilities, social knowledge, argumentation, instruments, learning styles, and inquiry-based learning. This analysis revealed a lack of strategic utilization of scientific literacy in the context of suggested socio-scientific issue mitigation or coping techniques. Notably, no critical review has been conducted examining the role of learning models and socio-scientific contexts in enhancing scientific literacy. This study aims to address this literature gap by providing the first critical review of learning models specifically in the context of socio-scientific issues and their impact on scientific literacy.

The problem statement of this study is to critically review and evaluate empirical studies on the influence of learning models on scientific literacy, as well as to identify the strengths and weaknesses of these models. Accordingly, the research questions are as follows: (1) How do various learning models impact scientific literacy? (2) What are the strengths and weaknesses of these models in influencing scientific literacy? (3) What recommendations can be made for future research to enhance scientific literacy through learning models?

METHOD

This review critically examines various empirical studies to determine the most effective learning models for enhancing scientific literacy. It explores the strengths and weaknesses of the research, as well as proposes suggestions for future studies. The review utilized Publish or Perish 8 and Google Scholar to locate relevant papers. Through Scopus, we identified 200 papers published between 2014 and 2024. However, only 27 papers were retained after excluding those that did not specifically discuss learning models for improving scientific literacy.

Table 1. The number of the article

No	Quartil	Number of articles
1	Quartil 1	18
2	Quartil 2	4
3	Quartil 3	3
4	Quartil 4	1
5	Unknown	1
	Sum	27

The search was conducted using keywords related to socio-scientific issues in science literacy, model-based learning in scientific literacy, inquiry-based learning in scientific literacy, and socio-scientific issues using model-based learning in science literacy. The outline of this article was derived from the analysis of the selected papers. Table 1 presents an index of the articles and their corresponding numbers.

Table 2. The list of the articles with the journal published and the index

No	Article	Journal	Year
1	An international collaborative investigation of beginning seventh-grade students' understandings of scientific inquiry: Establishing a baseline	Journal of Research in Science Teaching (Q1)	2019
2	Assessing students' understanding of models of biological processes: a revised framework	International Journal of Science Education (Q1)	2019
3	Developing and Using Multiple Models to Promote Scientific Literacy in the Context of Socio-Scientific Issues	Science & Education (Q1)	2021
4	Discrimination of the Contextual Features of Top Performers in Scientific Literacy Using a Machine Learning Approach	Research in Science Education (Q1)	2021
5	Students guided inquiry with simulation and its relation to school science achievement and scientific literacy	Computers and Education (Q1)	2020
6	An assessment of how scientific literacy-related aims are actualized in the National Primary Science curricula in China and Finland	International Journal of Science Education (Q1)	2019
7	Assessing Secondary Students' Scientific Literacy: A Comparative Study of Suburban Schools in England and Malaysia	Science Education Internasional (unknown)	2021
8	Scientific literacies for change making: Equipping the young to tackle current societal challenges	Frontiers in Education (Q1)	2022
9	Climate change education in the humanities classroom: a case study of the Lowell school curriculum pilot	Environmental Education Research (Q1)	2020
10	Investigating the development of secondary students' views about scientific inquiry	International Journal of Science Education (Q1)	2020
11	The Influence of Web-Based Learning and Learning Independence Toward Student's Scientific Literacy in Chemistry Course	International Journal of Instruction (Q2)	2019
12	Citizen Science for Scientific Literacy and the Attainment of Sustainable Development Goals in Formal Education	Sustainability (Q2)	2020
13	Scientific literacy and science learning achievement at junior high school	International Journal of Evaluation and Research in Education (Q3)	2019
14	The Effectiveness of Mobile Augmented Reality-Assisted STEM-Based Learning on Scientific Literacy and Students' Achievement	International Journal of Instruction (Q2)	2020
15	Socio-scientific reasoning and environmental	Environmental	2019

No	Article	Journal	Year
	literacy in a field-based ecology class	Education Research (Q1)	
16	Forms of inquiry-based science instruction and their relations with learning outcomes: evidence from high and low performing education systems	International Journal of Science Education (Q1)	2020
17	Interrelationship Between Inquiry-Based Learning and Instructional Quality in Predicting Science Literacy	Research in Science Education (Q1)	2022
18	Impact of model-based science curriculum and instruction on elementary students' explanations for the hydrosphere	Journal of Research in Science Teaching (Q1)	2019
19	Patterns of inquiry-based science instruction and student science achievement in PISA 2015	International Journal of Science Education (Q1)	2020
20	The Influence of Process Oriented Guided Inquiry Learning (POGIL) Model Assisted by Realia Media to Improve Scientific Literacy and Critical Thinking Skills of Primary School Students	European Journal of Educational Research (Q3)	2020
21	Fostering Chemistry Students’ Scientific Literacy for Responsible Citizenship through Socio-Scientific Inquiry-Based Learning (SSIBL)	Sustainability (Q2)	2023
22	Validity of BRADeR Learning Model Development: An Innovative Learning Model to Improve Science Literacy Skills for Junior High School Students	Journal of Curriculum and Teaching (Q4)	2022
23	Integrating scientific literacy skills into a biochemistry course for science majors	Biochemistry and Molecular Biology Education (Q3)	2020
24	Student Development of Model-Based Reasoning About Carbon Cycling and Climate Change in a Socio-Scientific Issues Unit	Journal of Research in Science Teaching (Q1)	2017
25	Measurement of socio-scientific reasoning (SSR) and exploration of SSR as a progression of competencies	International Journal of Science Education (Q1)	2020
26	Assessment of Scientific Literacy: Development and Validation of the Quantitative Assessment of Socio-Scientific Reasoning (QuASSR)	Journal of Research in Science Teaching (Q1)	2017
27	Students’ perceptions of socio-scientific issue-based learning and their appropriation of epistemic tools for systems thinking	International Journal of Science Education (Q1)	2020

Table 2 reveals that the 27 articles are indexed in Scopus. Most of these articles are published in quartile 1 journals and focus on enhancing scientific literacy through various learning models. As Scopus articles undergo rigorous review and are known for their high quality and reliability, they serve as reputable sources. However, all of the articles have certain limitations in terms of their objectives and results. Therefore, this critical review aims to identify gaps and errors in each article in order to highlight areas that require further investigation or future research. The articles were selected based on specific keywords related to socio-scientific issues and scientific literacy in learning models. Table 2 presents the titles of the articles included in this study.

Following the collection of articles, this critical review categorizes the research ideas and explores the connections between them. Through this process, the review has identified gaps in the literature and generated positive outcomes in the field of scientific literacy using different methods. The findings of this research indicate that the learning models examined do not significantly improve scientific literacy. Moreover, the critical review of the 27 analyzed articles has identified areas that require further research in order to advance scientific literacy. The review criteria were thematically analyzed to identify common patterns and discrepancies in the findings related to scientific literacy. Assessment was based on methodological quality, relevance to the research questions, and contribution to the understanding of scientific literacy. Figure 1 illustrates the stages of the critical review process.

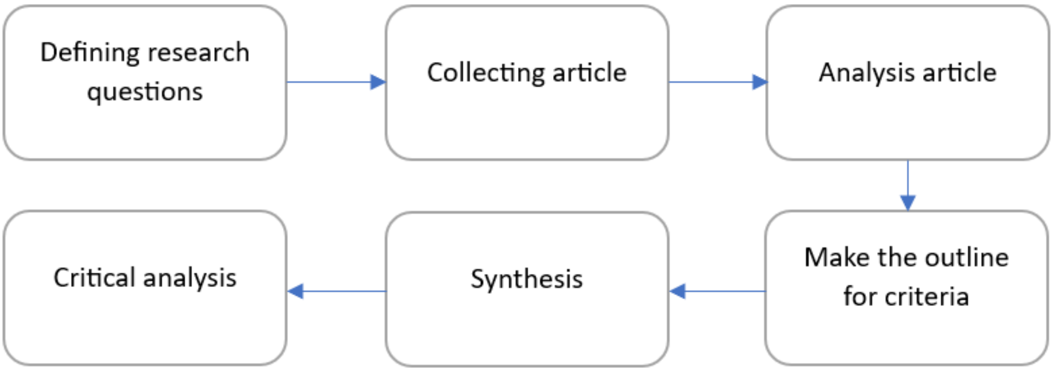

Figure 1. Stage of critical review

Figure 1 showcases the stages involved in this study. The first stage, "Defining research questions," involves identifying key themes and gaps in the literature, which then inform the subsequent stages of article collection and analysis. The stage of "collecting articles" employed the Publish or Perish software and encompassed papers published between 2015 and 2024. The next stage, "Analysis article," involved investigating the articles, including the learning model strategies employed to enhance scientific literacy, as well as examining the results and content of scientific literacy. In the stage of "outline criteria," articles were categorized based on similarities in content or learning models, which were then synthesized. Finally, the last stage, "critical analysis," aimed to identify the strengths and weaknesses of each article as the final outcome.

When describing the strengths and weaknesses of each article, we evaluated them based on methodological rigor. Ultimately, the critical analysis revealed gaps, limitations, and other weaknesses that future researchers in the field of scientific literacy should take into consideration.

RESULTS AND DISCUSSION

The critical review provided in this paper is structured into six sections, corresponding to the numbered articles listed in the outline. The evaluation of the articles is based on three criteria: methodological rigor, relevance to scientific literacy, and clarity of findings. The outline of the analysis can be found in Table 3. There are various models for learning scientific literacy, with one such model being inquiry-based learning. The assessment methodologies employed in studying scientific inquiry include quasi-experimental, comparative, and mixed methods utilizing a model-based science curriculum (Baumfalk et al., 2019). In one of the articles reviewed, the student's ability to model the hydrosphere and demonstrate water movement was investigated. The quantitative analysis focused solely on the student's work. Understanding scientific inquiry is an integral and crucial component of attaining scientific literacy (J. Lederman et al., 2019). While this article sampled students from different countries using the VASI questionnaire, the article did not provide information on how the questionnaire was analyzed.

Table 3. The outline of the review

No	Discussion
1	**Student science achievement related to scientific literacy** (4, 5, 13, 14) • Differentiate the top performers from non-top performers using support vector machine recursive feature elimination (SVM-RFE) simultaneously in the hands-on activity, application of science into daily life, and design the investigation (Chen et al., 2021). The improvement of pre-and post-test scores of scientific literacy correlates with the inquiry process in all of the aspects or phases (Wen et al., 2020) • The correlation test shows that there is a significant link between scientific literacy and science achievement (5, 13). The result shows the correlation between scientific literacy and school science achievement is high or moderate analyzed by Pearson correlation coefficients in conducting the simulation about the phenomenon of buoyancy concept from design experiment, conduct trial, analysis data, and give the conclusion (Wen et al., 2020). Another result shows that low scientific literacy coming from the low category in science study scores fosters a scientific attitude, scientific abilities, reasoning capacity, students capacity to carry out scientific research, science process skills, and confidence (Jufrida et al., 2019) • Students' achievement and scientific literacy improved by the application of STEM-based learning compared to conventional learning in the dimension of scientific contexts (14). The effect size test of STEM-based learning on science literacy is 0.5 which is categorized as sufficient. This value of effect size is influenced by three dimensions of scientific literacy, scientific contexts, scientific knowledge, and scientific competencies. It implies that STEM-based learning has the potential to improve students' scientific literacy. Also, students can conduct the problem-solving process, attitude toward science, have an understanding of the concept, argue the scientific evidence, and be able to use the technology (Wahyu et al., 2020). • The performance of students in science is influenced by the standard of teachers' instruction, the number of teachers in the classroom, the parents' educational and professional background, the disciplinary environment, the amount of time and involvement in learning, the facilities and equipment used by schools for mass media, and the self-efficacy of students (Chen et al., 2021)
2	**Students' inquiry process with the simulation supporting scientific literacy (1, 5, 10, 16, 17, 20, 21)** • inquiry shows good gains in scientific literacy after learning and guided inquiry gives a good assist in supporting scientific literacy (5, 20) guided inquiry can In an inquiry-based learning setting, low science achievers may be ordinary inquiry engagers or driven to analyze data. Additionally, after learning, those students who achieved the highest in science at the middle school level showed the most active participation in inquiry and good improvements in scientific literacy. In particular, high achievers were better equipped to do scientific research with an emphasis on creating experiments based on formulating an experiment question, drawing conclusions, and providing support for those findings from the data gathered (Wen et al., 2020). The process of guided inquiry learning assisted by realia media improves critical thinking and scientific literacy. The Process Oriented Guided Inquiry Learning has two main goals: (1) to increase

No	Discussion
	conceptual and subject mastery; and (2) to increase processing abilities like analysis, critical thinking, and problem-solving (Aiman et al., 2020). • In 19 out of the 20 regions in Independent Inquiry there was a negative correlation with learning outcomes. However, in each of the 16 regions where guided inquiry was used, scores on the science achievement test were positively correlated with it (Aditomo & Klieme, 2020) • open inquiry shows a negative correlation between inquiry-based learning and scientific literacy (17). Students who participate in open inquiry may not receive high grades; they may also feel anxious and stressed during the process; ultimately, this may have a detrimental impact on the teacher-student dynamic. While, the guided inquiry shows a positive correlation with classroom management and could improve the students' science literacy effectively (Kang, 2022) • Socio-scientific inquiry-based learning increasing the students' scientific literacy shows the improvement of the scientific literacy on students examined by a Wilcoxon signed-rank test at pre- and post-test (Georgiou & Kyza, 2023) • The use of Views About Scientific Inquiry (VASI) as a critical component of the achievement in scientific literacy (1, 10) Although there have been cases where students in a nation have performed better than "naïve" in a particular area of scientific inquiry, overall, students around the world have an inadequate comprehension of scientific investigation (J. Lederman et al., 2019). A significant proportion of students had simplistic or ambiguous ideas about different approaches, thinking that scientific studies only use one particular method, or thinking that studies cannot be seen in the natural world and always include an experiment (Concannon et al., 2020).
3	**The model of learning helps improve student scientific literacy (2, 3, 5, 11, 14, 15, 18, 21, 23, 24)** • Assessing scientific literacy in science courses related to curriculum or courses in secondary students use the development framework and model (2, 11, 15, 18, 21, 23, 24) The concept-process models used in biology courses, for example, food chain topic in revised framework changing models, multiple models, nature of models, the purpose of models, and testing models (Jansen et al., 2019). The chemistry courses in topic molecular shape materials help students improve their scientific literacy through web-based learning and effective use of high learning independence (Cahyana et al., 2019). Students acquired SSR competencies linked to field-based ecological course experiences focused on a regional socioscientific issue (Kinslow et al., 2019). Explain the hydrologic phenomena topics in the components, sequences, and explanatory process and the possible effects on elementary pupils' science education of a model-centric elementary science curriculum module and related science instruction (Baumfalk et al., 2019). Discussing chemistry relates with the fuel to encourage scientific literacy in their students in preparation for responsible citizenship (Georgiou & Kyza, 2023), conducting the biochemistry course in nonscience major and giving the output as their argumentation skills in presentation (Taylor, 2020). Conduct biology courses and design the curriculum together, giving particular attention to issue selection and application; modeling techniques; and models utilized by scientific communities to comprehend and elucidate carbon cycling, climate change, and ecological concepts (Zangori et al., 2017). • Science model integrating with scientific literacy (2, 4, 5, 11, 14, 18, 21, 22, 24) examine scientific literacy using several learning models such as biological

No	Discussion
	concept-process models (Jansen et al., 2019), guided inquiry (Wen et al., 2020), Web-based learning (Cahyana et al., 2019), STEM-based learning (Wahyu et al., 2020), socio-scientific inquiry-based learning (Georgiou & Kyza, 2023), BRADeR learning model (Simamora et al., 2022), model-based reasoning (Zangori et al., 2017). • Innovative learning model development could increase scientific literacy by developing instruments in PISA 2015 that include three aspects: context, knowledge, and competency (Cahyana et al., 2019) Also, has a connection with (Advance organizers, scaffolding, constructivism, information processing, problem-solving, and complex cognitive processes (Simamora et al., 2022) • Developing several models to improve the scientific literacy of students such as mechanistic models, system models, mathematical/data models, and socio-scientific models as the references to improving scientific literacy (Ke et al., 2021).
4	**Examine Socio-Scientific to measure scientific literacy (3, 8, 15, 21, 24, 25, 26, 27)** • Development of model in socio-scientific issues in scientific literacy (3, 24) see the development of socio-scientific issues model in classroom settings to improve scientific literacy and engage students to understand the science aspect and also the social aspect (Ke et al., 2021). Using the context of the relationship between the climate change caused by carbon cycling toward students' understanding (Zangori et al., 2017). • The socio-scientific issues related to environmental issues (8, 15, 24) used climate change content as the problem and students' perception and awareness about the cause of climate change towards the solutions (Tasquier et al., 2022). The socio-scientific issues teaching improve scientific literacy and also environmental literacy in socio-scientific reasoning competencies such as complexity, perspectives, inquiry, and skepticism (Kinslow et al., 2019) and students' understanding of the influence of the carbon cycling towards climate change as the development of a model-oriented SSI (Zangori et al., 2017) • Socio-scientific issues integrated with the model learning (21, 24, 27) in socio-scientific inquiry-based learning have three pedagogy frames that are asking, finding out, and acting in chemistry classroom settings about biofuel production context and relating with the scientific concept (Georgiou & Kyza, 2023). An SSI unit that incorporates model-based reasoning would help students create and use models to explain the carbon cycle, climate change, and the relationships between these three concepts and demonstrate how students' model-based reasoning improved throughout the unit as seen by the aspects of model-based explanations becoming more sophisticated, such as components, sequences, and explanatory processes (Zangori et al., 2017). SSI-based learning gives students situations that will inspire them to synthesize their thoughts and create original stances or solutions. By doing this, teachers can: 1) encourage students' interest in science, even if they are not particularly interested in it; 2) support students' agency by allowing them to voice their own opinions or suggest solutions that make sense to them; and 3) give students meaningful contexts in which to explore the epistemic components of SSI learning, such as systems thinking (Ke et al., 2020). • Scientific literacy is promoted by the instrument of Quantitative Assessment of SSR (QuASSR) which shows the changes in SSR in SSI-based instruction (25, 26) found a difficulty gradient that went from recognizing complexity to

No	Discussion
	adopting a stance, and finally to the higher-level skills of skepticism and inquiry, To maximize transfer, the course did the following: (1) made connections to students' prior knowledge and lived experiences; (2) made sure that students practiced decision-making and finding and applying information multiple times in various contexts, allowing them to generalize these skills; and (3) spent time engaging in meta-level discussion regarding the role of science and values in SS (Romine et al., 2020). Higher-order cognitive capacities are attempted to be accounted for by the SSR as a construct. Unlike scientific methods (argumentation, modeling, and explanation) and declarative knowledge, SSR is also influenced by the effect brought about by extracurricular social contacts and life experiences (Romine et al., 2017).

In a previous article (J. S. Lederman et al., 2014), the instruments used argued that knowledge of scientific inquiry is a fundamental part of developing scientific literacy. However, this statement contradicts the article under review, as it only assessed students' responses to the Scientific Inquiry questionnaire without considering their overall scientific literacy. It would be advisable for future studies to include a scientific literacy instrument to ensure accurate correlation.In a study conducted by Wen et al. (2020), it was found that guided inquiry, coupled with a simulated learning environment, was more effective in maintaining students' scientific literacy as compared to traditional science instruction. The level of scientific literacy achieved through guided inquiry was directly proportional to students' science achievement, whereas the simulation only contributed to fundamental content understanding. These findings corroborate the research by Kang (2022), which also demonstrated a positive link between guided inquiry and the improvement of scientific literacy. Notably, effective implementation of guided inquiry relies on teachers who possess the ability to efficiently manage and control the learning environment. Conversely, open inquiry was found to have a negative correlation with scientific literacy. Students who frequently engaged in open inquiry reported feelings of exclusion when the teacher favored only a select few proficient in open inquiry. Additionally, students' performance suffered, leading to increased stress and nervousness during the open inquiry process.

Ultimately, the teacher-student relationship became strained as a result of open inquiry practices. However, it is important to note that this article does not provide a comprehensive context of scientific literacy or depict the disparity between guided inquiry and open inquiry. When comparing guided inquiry and open inquiry as separate constructs, it is believed that the impact of open inquiry outweighs that of directed inquiry. Supporting this perspective, Aditomo & Klieme (2020) conducted a comparison of inquiry-based learning in various countries. Their findings revealed that out of 16 countries where guided inquiry was observed, science achievement test scores were positively correlated with guided inquiry. Conversely, in 19 out of 20 countries where open inquiry was observed, learning outcomes were found to be negatively correlated with open inquiry. However, this article does not delve into the specific activities associated with open inquiry and guided inquiry.A scientific literacy-based learning model is considered innovative in improving students' scientific literacy (Simamora et al., 2022). This model should include brainstorming, reading, analyzing, decision making, and reflection. An alternative inquiry-based learning model is Process Oriented Guided Inquiry Learning (POGIL), which has been shown to significantly enhance students' scientific literacy and critical thinking skills compared to expository learning (Aiman et al., 2020). In this article, a quasi-experimental study was conducted to investigate students' scientific literacy and critical thinking abilities in both control and experimental classes.

Scientific inquiry-based learning can also be combined with socio-scientific issues to create socio-scientific inquiry-based learning (SSIBL), which has the potential to foster students' scientific literacy for civic responsibility (Georgiou & Kyza, 2023). This research provides empirical evidence that SSIBL instruction can effectively enhance students' scientific literacy. The study employed a mixed-method research design but lacked qualitative data instruments.

Scientific literacy, which involves engaging with complex social issues related to scientific phenomena, has the potential to engage students in environmental education (Kinslow et al., 2019). Environmental literacy can be considered a subset of environmental education goals. The data suggests that socio-scientific inquiry (SSI) can support environmental literacy competency. Focusing on SSI in a field-based environmental education curriculum can promote the development of socio-scientific reasoning and environmental literacy competencies among high school students.

Other learning models that improve scientific literacy include the concept-process and web-based models. The concept-process model is beneficial for studying scientific methods such as hypothesis testing. However, it is primarily used in biology education for communication or illustration purposes, which often misses the opportunity to introduce students to the scientific method (Jansen et al., 2019). The use of web media has a positive impact on scientific literacy. However, its effectiveness varies among student groups with different levels of learner independence. This model is effective for students with high learning independence but not for those with low learning independence (Cahyana et al., 2019). However, this claim lacks experimental data to support it.The context of socio-scientific issues is commonly recognized as a means of enhancing scientific literacy (Ke et al., 2021). Several models have been proposed to improve scientific literacy in the face of complex issues. This article serves as a valuable resource for future research aiming to apply specific models in order to enhance students' scientific literacy. However, it fails to provide an analysis of student scientific literacy using both qualitative and quantitative methods.

In another article, model-based reasoning in socio-scientific issues related to carbon cycling and climate change is explored (Zangori et al., 2017). The authors employ an explanatory sequential mixed methods approach, first analyzing the quantitative data and then analyzing the qualitative data. The quantitative data in this study is presented in a clear manner, showcasing the students' ability to illustrate carbon cycling and climate change using an assessment rubric. However, these scoring levels do not indicate the specific category (e.g., good, moderate, or low), and the interview process lacks information about the context discussed. Furthermore, the article does not offer any recommendations for future research.

Design-based research projects have also demonstrated their effectiveness in improving scientific literacy (Baumfalk et al., 2019). Student engagement in activities such as developing, implementing, revising, and testing significantly enhances scientific literacy. The Concept Process Model also proves to be supportive in improving students' understanding of concept-process models in biology, leading to higher scientific literacy (Jansen et al., 2019). However, these studies fail to provide specific scores on students' scientific literacy.

Lastly, STEM-based learning has shown to be an effective method for improving scientific literacy (Wahyu et al., 2020). Unfortunately, the authors do not include figures in the article, nor do they provide details about the specific augmented reality used and the STEM fields that are supported by augmented reality.Based on the aforementioned studies on learning models and scientific literacy, it has been suggested that students' level of scientific literacy is influenced by the models employed by their teachers (Chen et al., 2021). Additionally, Chen et al. (2021) identified several other important contributing factors, including the quality of teachers' instructional practices, parents' educational and professional backgrounds, the school's disciplinary environment, the amount of time and effort students invest in learning, the availability of mass media resources at school, the number of teachers, and students' self-efficacy.

Similarly, this research underscores the significance of teachers' practices in enhancing scientific literacy. Therefore, for future research, it is important to explore various learning models that can aid students in improving their scientific literacy. Among the learning models, inquiry-based learning has shown promise in enhancing scientific literacy. However, it should be noted that not all types of inquiry-based learning are effective in this regard. Open inquiry-based learning, for example, may not significantly improve scientific literacy because it lacks guidance and support from the teacher, thereby limiting students' exposure to learning science. Additionally, students may struggle to acquire the necessary knowledge and skills and may not be able to draw meaningful conclusions. Furthermore, this critical review highlights the existence of studies that have examined the context of social science issues that are unrelated to the global goals of the Sustainable Development Goals (SDGs).

CONCLUSION

The findings of this review indicate that the majority of model-based learning approaches have a positive impact on students' scientific literacy, with the exception of open inquiry-based learning. Model-based learning has a significant influence on scientific literacy, particularly among high-achieving students. Furthermore, the inclusion of socio-scientific issues proves to be an effective means of enhancing scientific literacy, as it enables students to apply their scientific understanding to real-world problems. This critical review provides objective insights for future research, emphasizing the importance of conducting comprehensive analyses and using appropriate assessment instruments. However, it should be noted that this research primarily focused on identifying strengths and weaknesses, without delving into the background or objectives of the individual studies. Therefore, future research should aim to systematically examine various learning models and contexts in order to further enhance scientific literacy.

RECOMMENDATION

Future research should focus on the development of systematic or literature reviews on scientific literacy and model-based learning, as there is a scarcity of studies in this area. In order to enhance clarity and flow, researchers should also explore the effectiveness of different learning models, including inquiry-based and web-based learning, in improving scientific literacy. Moreover, the use of socio-scientific issues, such as earthquakes and air pollution, can provide real-world relevance and context to scientific literacy. Analyzing learning models that do not effectively enhance scientific literacy can also offer valuable insights for improving educational strategies.

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