Toward student's scientific literacy in science learning: a systematic literature review and bibliometric analysis

A. Zaida Ilma[a], and H. Kuswanto[b]

[a]*Doctoral Program of Natural Science Education Department, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta, Jl. Colombo 1 Yogyakarta, Indonesia,*
e-mail: arinazaida.2024@student.uny.ac.id;
https://orcid.org/0000-0002-7577-206X,

[b]*Physics Education Department, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta, Jl. Colombo 1 Yogyakarta, Indonesia,*
e-mail: herukus61@uny.ac.id
https://orcid.org/0000-0002-2693-8078

Received 15 October 2024; accepted 28 November 2024

One of the main goals of science education is to create a young generation who has adequate scientific literacy skills. This study aims to analyze research trends, implications of empirical research, and review and bibliometric analysis of scientific literacy in science education. The research method used is a systematic literature review and bibliometric analysis with Biblioshiny software. Data were obtained from SCOPUS and Web of Science (WoS) from 2014 to August 2024. The data selection process was carried out using PRISMA, with which 140 documents were obtained. The research trend of scientific literacy in science education shows an increase. Empirical research has been carried out by countries such as the United States, the European Union, the United Kingdom, and Indonesia. Article review in science learning towards scientific literacy has been developed using various methods. Bibliometric analysis shows three clusters of co-occurrences including educational literacy, scientific literacy, and human. The visual representation of the scope of scientific literacy can develop along with the development of science content and context in life. Future research can conduct empirical research that focuses on developing learning strategies and assessments as well as conducting critical review research to optimize research on scientific literacy.

Keywords: Assessment; learning strategy; science learning; scientific literacy.

DOI: https://doi.org/10.31349/RevMexFisE.22.020222

1. Introduction

Scientific literacy has received increasing attention after the COVID-19 pandemic. UNESCO (2020) explains nine big ideas for building the foundations of post-pandemic education. One of these ideas explains ensuring scientific literacy in the education curriculum. This is also a momentum to reflect on the curriculum to deal with misinformation through scientific knowledge. Moreover, scientific literacy is not just an academic skill but an important competency that empowers individuals to navigate an increasingly complex world [1]. When individuals face various challenges such as climate change [2], health crises [2], and technological advances [4], the need for scientifically literate individuals becomes increasingly urgent.

One of the main goals of science education is to create a young generation who has adequate scientific literacy skills. Various efforts have been made by academics to promote a culture of literacy, including scientific literacy. The development of scientific literacy has increased over several decades. This is influenced by shifts in educational paradigms, societal needs, and the rapid expansion of scientific knowledge. However, despite progress in the profile of prospective science teachers who are highly motivated in their teaching [5], evidence shows that significant gaps still exist in the level of scientific literacy among various groups at the secondary education level [6] to basic education [7]. The gap in student achievement in science learning may lie in the inequality of standardized testing, limited response modalities, inappropriate language demands, lack of authentic measures, and culturally sensitive administrative conditions [8]. Improving science learning requires flexibility with the strengths of educators and student interests [9]. This shows the urgent need for research and targeted interventions. We believe that scientific literacy develops along with world developments and does not only focus on science in general but is divided into specific parts of science such as biology literacy [10,11], chemistry [12], physics [13], earth and space science [14]. Therefore, scientific literacy is increasingly important in education today to help students face the complex changes in the world that are necessary to achieve it.

Historically, the conceptualization of scientific literacy has undergone considerable transformation. Early definitions primarily emphasized the acquisition of knowledge about scientific facts and principles [9]. However, over time, the understanding of scientific literacy has expanded and includes not only knowledge but also the skills and attitudes needed for critical thinking, problem-solving, and decision-making in scientific contexts [15]. The National Science Education Standards (NSES) in the United States advocate a more holistic approach to scientific literacy, emphasizing the importance of inquiry-based learning, integration of science with other disciplines, and the cultivation of a scientific mindset among students. Despite advances in educational frameworks, several studies [16-18] show that many individuals, including students, demonstrate a lack of proficiency in scientific literacy. Assessments such as the Program for International Student Assessment (PISA) [19] and the National Assessment of Educational Progress (NAEP) [20] consistently reveal that most students do not meet basic levels of scientific literacy. These assessments highlight not only deficiencies in knowledge but also an inability to apply scientific reasoning and address scientific issues critically. The implications of these findings are far-reaching, including suggesting that many individuals may struggle to make informed choices about health, the environment, and technology to the point of weakening society's capacity to address pressing global challenges.

In addition, the need to increase scientific literacy is not only limited to the field of formal education. The rapid spread of information in the digital era has created an environment where misinformation and pseudoscience can easily proliferate. In this context, the ability to critically evaluate scientific claims and distinguish credible sources of information is essential. The COVID-19 pandemic has emphasized the importance of scientific literacy in public discourse, as individuals must navigate the abundance of information regarding health guidelines, vaccinations, and viral transmission [21-23]. The ability to understand and apply scientific knowledge in situations such as these are critical to personal and societal wellbeing.

Given the important role of scientific literacy in cultivating an informed society, research efforts should focus on identifying effective strategies for increasing scientific literacy in diverse populations. This includes reviewing and exploring previous research findings regarding scientific literacy research in science education. This research aims to analyze research trends, implications of empirical research, and article review as well as bibliometric analysis of scientific literacy in science education.

2. Methods

This research uses systematic literature review (SLR) and bibliometric analysis techniques to answer several research questions. SLR can provide inspiration related to theme mapping by looking at the conceptual framework for future research [24]. In addition, it aims to sharpen the information that is to be investigated from a study [25]. Meanwhile, bibliometrics can display the main trends during a certain period in a database such as Scopus or Web of Science (WOS) using software [26,27]. The combination of both can strengthen the findings of the review process carried out [28]. In this study, the SLR and Bibliometrics methods will be combined to answer the research questions.

2.1. Research questions

This research examines the findings of research conducted from 2014 to August 2024 regarding scientific literacy in science education. The research questions (RQ) in this research are as follows:

RQ 1: What are the trends in scientific literacy research in science education from 2014 to 2024 based on research type, number of publications, scope, and level of education?

RQ 2: What are the implications of empirical research in science learning on scientific literacy?

RQ 3: What are the implications of article review in science learning for scientific literacy?

RQ 4: What is the bibliometric analysis of scientific literacy research in science learning?

2.2. Strategies for finding articles

Article reviews were obtained from the SCOPUS and Web of Science (WoS) databases (see Table I). This review uses PRISMA guidelines [29] (see Fig. 1). PRISMA is a framework used to report and synthesize literature reviews through steps 1) identifying research literature from database searches; 2) screening articles using inclusion and exclusion criteria; 3) assessing full-text articles for eligibility; and 4) coding and reporting the final articles included in the review.

TABLE I. Article searching process.

Database	Query or Keyword	Period	Articles (N)
Scopus	TITLE-ABS-KEY (scientific AND literacy) AND PUBYEAR > 2013 AND PUBYEAR < 2025 AND (LIMIT-TO (SUBJAREA, "SOCI")) AND (LIMIT-TO (EXACTKEYWORD, "Scientific Literacy")) AND (LIMIT-TO (OA , "all"))	2014-August 2024	313
WoS	"Scientific Literacy"	2014-August 2024	592

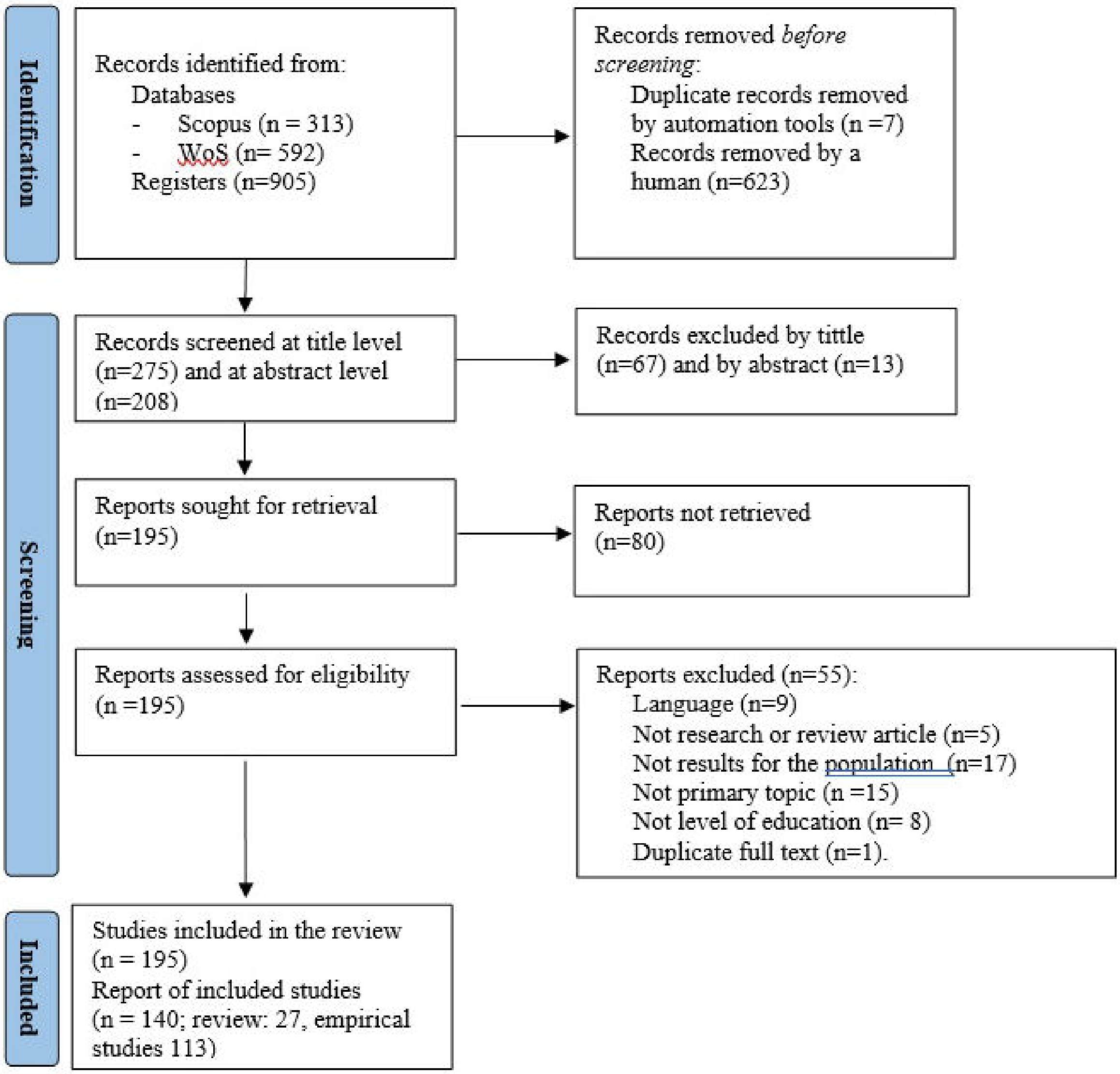

FIGURE 1. PRISMA stages for selecting studies.

TABLE II. Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
Publication year 2014 - August 2024	$<$ 2014 or $>$ August 2024
Using English	Not using English
Type of research article or review	Apart from research articles or reviews (proceedings or chapter books, etc.)
Discusses scientific literacy in science education or anything relevant	Discussing scientific literacy outside the context of science education or is not relevant

2.3. Inclusion and exclusion criteria

In selecting articles, inclusion and exclusion criteria were used. This was done to avoid bias before searching for articles and to increase reliability [30]. Inclusion criteria are criteria that are parameters for selecting articles to be reviewed, while exclusion criteria are criteria that are used to eliminate articles that do not meet the objectives of the review. The inclusion and exclusion criteria applied in this article search can be seen in Table II.

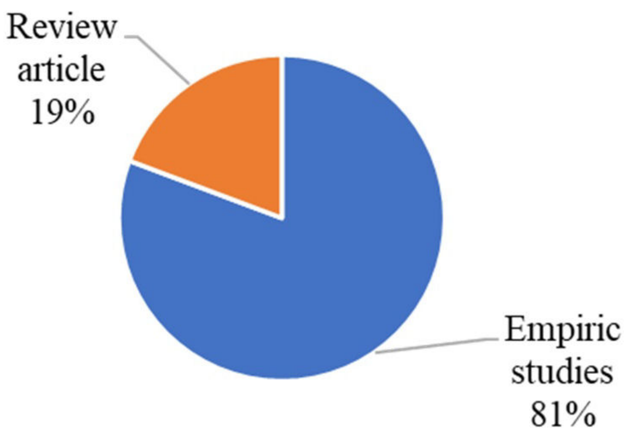

FIGURE 2. Type of document.

2.4. Data analysis

Data analysis was conducted based on research questions. Several tools were used to perform bibliometric analysis with Biblioshiny. The data analyzed using Biblioshiny were data in BibTex format using the R and R Studio programs.

3. Results

3.1. Profile of studies

3.1.1. Type of document

The review was carried out on 140 articles consisting of two types of documents, namely empirical research (81.00%) and article review (19.00%) (see Fig. 2). This shows that scientific literacy research has been widely applied in empirical research. This research investigates the extent to which research on scientific literacy, both in empirical research and article review, has been developed. This step was taken to find gaps in previous research to overcome these gaps.

3.1.2. Publication year

The term scientific literacy was first introduced by Paul deHart Hurd in 1958 [31] and was developed with a holistic assessment of OECD countries from 2000 to 2023, and the PISA 2025 framework began to be designed [19]. Based on the results of the analysis of this article review, the development of scientific literacy research reached its peak in 2023 and is expected to increase in 2024. As of August 2024, there are 15 articles researching scientific literacy (see Fig. 3).

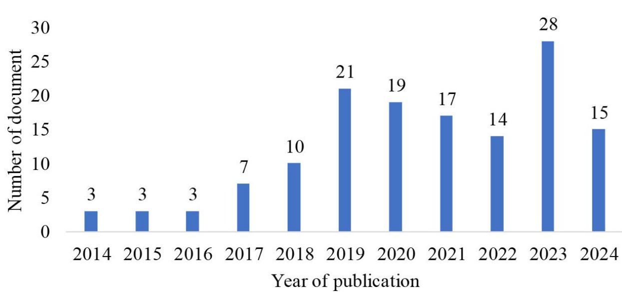

FIGURE 3. Year of publication (2014-2024).

3.1.3. Scope of scientific literacy

The scope of scientific literacy shows the mapping of scientific fields that are relevant to scientific literacy. Based on the findings, there are 11 mappings including science literacy, health literacy, energy literacy, climate literacy, environmental literacy, earth science literacy, COVID literacy, biological literacy, chemical literacy, physics literacy, and biochemistry literacy (see Fig. 4). We believe that aspects of scientific literacy in the PISA framework include content, context, and competence [19]. The content is defined as the knowledge studied in science learning. Meanwhile, context is related to issues or problems in personal, local, and global contexts. Competence is the center of these aspects or is an achievement that is realized in scientific literacy. However, we tried to determine the extent to which research had developed or investigated the topic of scientific literacy based on article search results through screening titles and abstracts related to the topic.

The topic of scientific literacy in general, or science literacy, is discussed the most (47.00%) while the topic of biochemistry literacy and earth science literacy is still minimally discussed (1.00%). When viewed from the scientific field of science, biological literacy receives the highest attention (12.00%) compared to chemical literacy (10.00%), physics literacy (7.00%), and earth science literacy (1.00%). Topics outside the scientific field of science focus on context aspects such as health literacy, COVID-19 literacy, environmental literacy, energy literacy, and climate literacy (see Fig. 4). These studies also explain aspects of competency in its application. These findings provide opportunities for future research to conduct research on scientific literacy in terms of holistic content, context, and competency aspects.

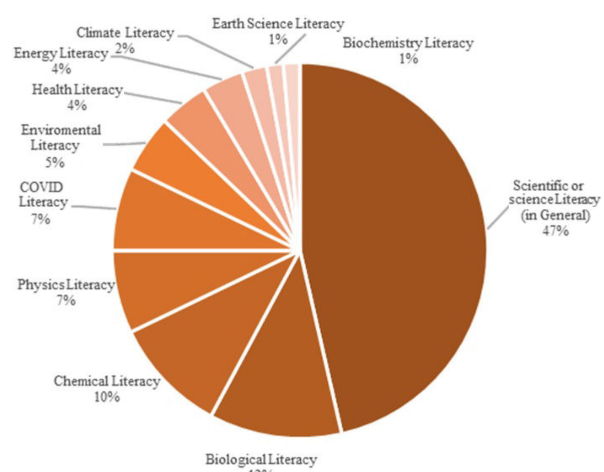

FIGURE 4. Scope of scientific literacy.

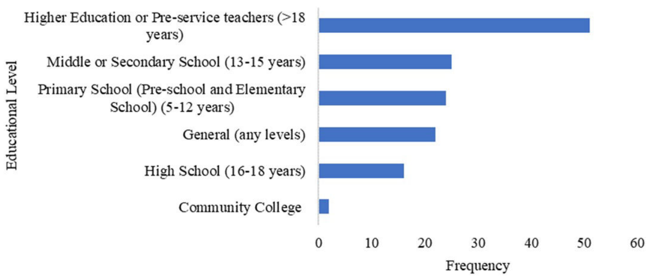

FIGURE 5. Educational level on implementation of scientific literacy.

3.1.4. *Educational level on implementation of scientific literacy*

The application of scientific literacy at the educational level appears diverse. Most research carried out is at the tertiary level or targeted at students as prospective teachers. Meanwhile, research on scientific literacy at the secondary education level (students aged 13-15 years) and basic education (students aged 5-12 years) tends to be equivalent, but the numbers are still superior to research at the higher education level (students aged 16-18 years old) (see Fig. 5). What needs to be highlighted from these findings is that the PISA assessment was carried out at the age of 15 years of students or in Indonesia the equivalent of class VIII of junior high school, but the research still focused on preparing prospective science teachers. This means that to develop students' scientific literacy, there needs to be teachers who have good scientific literacy so that it can be applied in science learning. Apart from that, the findings show that the application of scientific literacy is carried out not only in formal education but also at community colleges [32,33]. This is an opportunity to implement science, apart from formal education, but also through non-formal education.

3.2. Trend research on empirical studies

3.2.1. *Learning strategies to enhance scientific literacy*

The ten strategies most widely used in research to increase scientific literacy include focusing on teaching materials or media, STEM/STEAM learning, contextual learning, problem-based learning, distance or online learning, project-based learning, guided inquiry learning, socio-scientific issues, STS or SETS or STSE learning, and authentic inquiry learning (see Table III).

TABLE III. Learning strategies to enhance scientific literacy.

Learning Strategy	%	Author (Year)
Teaching Material or Media	15.93	Fakhriyah *et al.* (2019); Fitria, Alwi *et al.* (2023) ; Gu *et al.*, (2019); Heliawati *et al.* (2020, 2022); Listianingsih *et al.* (2021); Liu *et al.* (2022); Prastiwi *et al.* (2020); Rehorek and Dafoe (2018); Rokhmah *et al.* (2017); Rubini *et al.* (2018); Rusilowati *et al.* (2016); Smyth *et al.* (2022); Stockwell (2016); Tomas and Ritchie (2015); Uslan *et al.* (2024); Winarni and Purwandari, (2019); Pursitasari *et al.* (2019)
STEM/STEAM learning	7.08	Adriyawati *et al.* (2020); Asiyah *et al.* (2024); Chambers *et al.* (2019); Gertner *et al.* (2023); Herlanti *et al.* (2019); Rokhimawan *et al.* (2022); Suryanti *et al.* (2021); Wahyu *et al.* (2020)
Context-based approach(CBA) or contextual learning	6.19	Cigdemoglu *et al.* (2017); Cigdemoglu and Geban (2015); Dewi *et al.* (2021); Doshi *et al.* (2024); Kähler *et al.* (2020); Thummathong and Thathong (2018); Tsoumanis *et al.* (2023)
Problem-based Learning (PBL)	4.42	Fitria, Malik, *et al.* (2023); Kristiantari *et al.* (2022); Paristiowati *et al.*, 2019; Parmin and Fibriana (2019); Ratini *et al.* (2018)
Distance or Online Learning	4.42	Ahied *et al.* (2020); Anderson *et al.* (2020); Cabreja-Castillo *et al.* (2023); Kohen *et al.* (2020); Ramachandran *et al.* (2021)
Project-based Learning (PjBL)	3.54	Auerbach and Schussler (2017); Queiruga-Dios *et al.* (2020); Sholahuddin *et al.* (2023); Vogelzang *et al.* (2020)
Guided Inquiry Learning	3.54	Aiman *et al.* (2020); Buteyn *et al.* (2019); Saefullah *et al.* (2017); Taylor (2020)
Socio-scientific Issue (SSI)	3.54	Bay *et al.* (2017); Chen and Liu (2018); Saija *et al.* (2022); Widodo *et al.* (2020)
STS or SETS or STSE Learning	3.54	Calado *et al.* (2015); Herlanti *et al.* (2019); Mahlianurrahman *et al.* (2023); Ratini *et al.* (2018)
Authentic Scientific Inquiry	2.65	Ambrosino and Rivera (2022); Bórquez-Sánchez (2024); Georgiou and Kyza (2023)

TABLE IV. Assessment for scientific literacy.

Type of Assessment	%	Author (Year)
Multiple-Choice Test	51.16	Adnan *et al.* (2021); Agustina *et al.* (2022); Ahied *et al.* (2020); Aiman *et al.* (2020); Ambrosino and Rivera (2022); Anderson *et al.*, (2020); Angraini *et al.* (2023); Archila *et al.*, (2021); Asiyah *et al.*, (2024); Auerbach and Schussler (2017); Bahtiar *et al.* (2022); Bórquez-Sánchez (2024); Buteyn *et al.* (2019); Cabreja-Castillo *et al.*(2023); Chambers *et al.* (2019); Chang *et al.* (2024); Chen and Liu, (2018); Cigdemoglu *et al.* (2017); Cigdemoglu and Geban (2015); Dewi *et al.* (2021); Ekantini and Wilujeng (2018); Eymur and Çetin (2024); Fakhriyah *et al.* (2019); Fausan *et al.* (2021); Fitria, Alwi, *et al.* (2023); Fitria, Malik, *et al.* (2023); Gu *et al.* (2019); Günaydin and Başaran (2022); Heliawati *et al.* (2020, 2022); Herlanti *et al.*, (2019); Homer and Ryder (2015); Jufrida *et al.* (2024); Kähler *et al.* (2020); Kristiantari *et al.* (2022); Lestari *et al.* (2024); Listianingsih *et al.* (2021); Liu *et al.* (2022); Mahlianurrahman *et al.* (2023); Muzayanah *et al.* (2023); Pahrudin *et al.* (2019); Paristiowati *et al.* (2019); Podgornik *et al.* (2017); Ratini *et al.* (2018); Rokhimawan *et al.* (2022); Saefullah *et al.* (2017); Şahin and Ateş (2020); Shaffer *et al.* (2019); Sholahuddin *et al.* (2021, 2023); Stylos *et al.* (2023); Suárez-Mesa and Gómez (2024); Subali *et al.* (2023); Sultan *et al.* (2018); Thummathong and Thathong (2018); Uslan *et al.* (2024); Vogelzang *et al.* (2020); Wahyu *et al.* (2020); Wang *et al.* (2022); Widodo *et al.* (2020); Winarni *et al.* (2020); Winarni and Purwandari (2019); Xie *et al.* (2023); Zhang *et al.* (2023); Kreher *et al.* (2021); Cartwright *et al.*(2020); Fırat and Köksal (2019)
Questionnaire or Survey	20.93	Arthurs and Van Den Broeke (2016); Bay *et al.* (2017); Buteyn *et al.*, (2019); Coppi *et al.* (2024); Georgiou and Kyza (2023); Kohen *et al.*, (2020); Kotuláková (2019); Kristiantari *et al.* (2022); Mahmudah *et al.* (2020); Monk and Newton (2018); Motoki *et al.* (2021); Pan *et al.* (2018); Pujawan *et al.* (2022); Pursitasari *et al.* (2019); Queiruga-Dios *et al.* (2020); Ramachandran *et al.* (2021); Ratini *et al.* (2018); Rubini *et al.* (2018); Saija *et al.* (2022); Surpless *et al.* (2014); Suwono *et al.* (2022); Thummathong and Thathong (2018); Torres-Giner *et al.* (2022); Tsoumanis *et al.* (2023); Umar and Sukarno (2022); Woodham *et al.* (2016); Yang *et al.* (2021)
Interview (Open-ended question)	10.85	Adriyawati *et al.* (2020); Allison and Goldston (2018); Bay *et al.* (2017); Dewi *et al.* (2019); Díez-Palomar *et al.* (2022); Eymur and Çetin (2024); Fakhriyah *et al.* (2019); Günaydin and Başaran (2022); Kohen *et al.* (2020); Pahrudin *et al.* (2019); Pan *et al.* (2018); Taylor (2020); Thummathong and Thathong (2018); Tomas and Ritchie (2015)
Written test or Essay	5.43	Afifa *et al.* (2024); Jufrida *et al.* (2024); Parmin and Fibriana (2019); Rehorek and Dafoe (2018); Stockwell (2016); Thummathong and Thathong (2018), Chang *et al.* (2024)
Portfolio	3.88	Dye (2023); Gertner *et al.* (2023); Goodwin *et al.* (2023); Prastiwi *et al.*, (2020); Smyth *et al.* (2022)
Observation	3.88	Allison and Goldston (2018); Bay *et al.* (2017); Dewi *et al.* (2019); Díez-Palomar *et al.* (2022); Doshi *et al.* (2024)
Textbook Analysis	2.33	Calado *et al.* (2015); Rokhmah *et al.* (2017); Rusilowati *et al.* (2016)
Focus Group Discussion	1.55	Allison and Goldston (2018); Buteyn *et al.* (2019)

Apart from the learning models shown in Table III, there are still learning models that can be integrated, such as ethnoscience [34,35]; ethnoSTEM [36]; coaching model [37], Qur'an-based science [38]; scaffolding [39,40]; laboratory courses [41-43]; reading comprehension [44]; argument-driven inquiry [45,46]; discovery learning [47,48]; constructivist learning [6,14]; scientific dialogue gatherings [49]; education for environmentally sustainable development [50]; and the CREATE(S) model [51]. These findings indicate that scientific literacy can be integrated into various learning strategies, including models, methods, approaches, and teaching materials aimed at scientific literacy. Both become the focus of empirical research on the development of students' scientific literacy.

3.2.2. *Assessment for assessing scientific literacy*

Many studies have developed scientific literacy in various countries with various strategies related to the type of assessment used. Assessments to measure scientific literacy based on these findings obtained seven types of assessments including multiple-choice tests, questionnaires or surveys, interviews with open-ended questions, written tests or essays, portfolios, observation, textbook analysis and focus group discussions (see Table IV). The most widely used assessment is the multiple-choice test with various types of instruments such as the Test of Scientific Literacy Skills (TOSLS), Scientific Literacy Assessment (SLA), Test of Basic Scientific Literacy (TBSL), and Scientific Literacy Test (SLT).

3.2.3. *Country conducting empirical studies*

Empirical research on scientific literacy has been carried out in various countries across continents. The eight countries that conducted the most research include Indonesia (N=48.67% United States (N=21.24%), Turkey (N=5.30%), Taiwan (N=5%), China (N=4%), Germany (N =2.65%), Spain (N=2.65%) and Greece (N=2.65%) (see Fig. 6) (made up by percentages). The Indonesian government has recognized the importance of scientific literacy in fostering critical thinking and problem-solving skills among students, and encourages research initiatives in this area. The United States benefits from a well-established academic infrastructure and funding for educational research. This environment facilitates a wide range of research on scientific literacy, reflecting the country's emphasis on STEM (science, technology, engineering, and mathematics) education.

Countries such as Turkey, Taiwan, and China, with less research, may still appear on their research agendas but are showing increasing interest in understanding and improving scientific literacy. Apart from these countries, some countries are starting to conduct empirical research on scientific literacy, such as the United Kingdom, Portugal, Israel, Slovenia, the Netherlands, New Zealand, Japan, England, and Slovakia (see Fig. 6).

3.3. **Trend of research on article review**

Apart from empirical research, review research is also developed by various researchers to investigate the extent to which scientific literacy has been implemented. Several methods are used in reviewing articles such as content analysis, systematic review, scoping review, critical review, bibliometric analysis, thematic analysis, quantitative review, innovation essay, and book review (see Table V).

An article review of the findings of this research was carried out through document analysis from the year of publication in the 1940s [31,52] to the most recent until 2022 [53-55]. Since the scientific literacy assessment was carried out by PISA starting in 2000, review documents on scientific literacy have begun to develop [56,57]. Scientific literacy topics develop according to the research context and issues of existing natural phenomena, such as climate change issues [58,59], the environment [53,60] and the COVID-19 pandemic also inspired research to develop COVID-19 literacy that began in 2019 [33,61-64]. This finding supports previous findings regarding the large amount of empirical research that has been applied in science education.

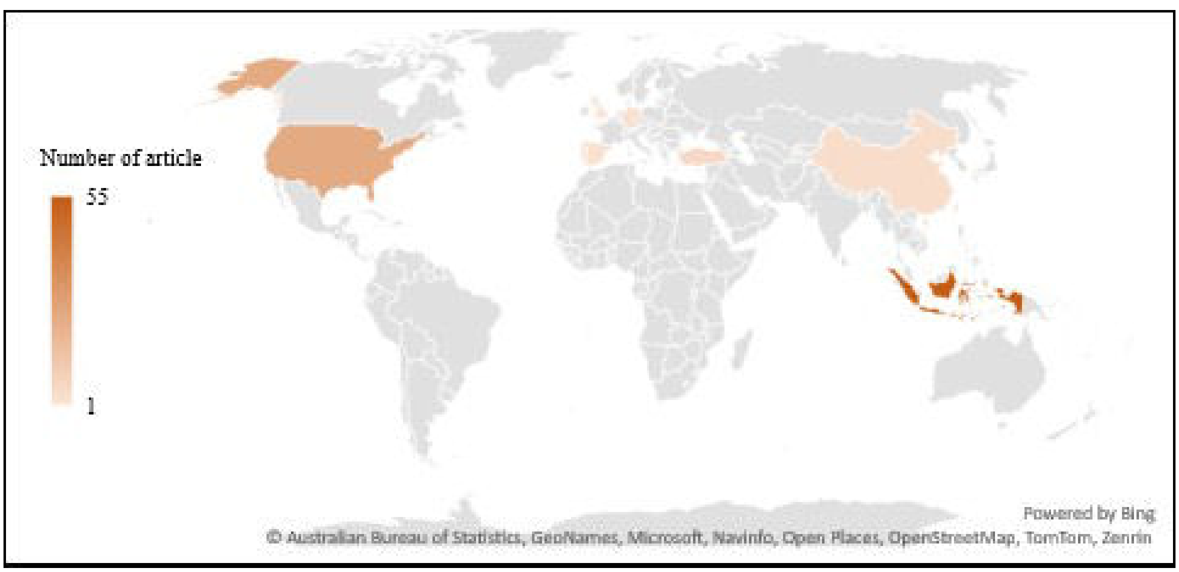

FIGURE 6. Distribution of countries developing scientific literacy.

TABLE V. The methods used in article review.

Review Methods	%	Author (Year)
Systematic Review	29.63	Busch and Rajwade (2024); Istyadji and Sauqina, (2023); Kumar *et al.* (2024); Mittenzwei *et al.*, (2019); Santillán and Cedano (2023); Sarsale *et al.*, (2024); Semilarski and Laius (2021); Torrijos-Muelas *et al.* (2023)
Content Analysis	29.63	Azevedo and Marques (2017); Broietti *et al.* (2019); Cansiz and Cansiz (2019); Rivera and Caceres (2014); Sarvary and Ruesch (2023); Serpa *et al.* (2021); Valladares (2021); Winarni and Purwandari (2019)
Innovation Essay	11.1	Owens and Sadler (2024); Ratnayake and Ashok (2023); Rudolph (2024)
Scoping Review	7.41	Choudhry *et al.* (2019); Romanova *et al.* (2024)
Bibliometric Analysis	7.41	Li and Guo (2021), Murni *et al.* (2023)
Critical Review	3.70	Guerrero and Sjöström (2024)
Thematic Analysis	3.70	Norambuena-Meléndez *et al.* (2023)
Quantitative Review	3.70	O'toole *et al.* (2020)
Book Review	3.70	Stadtländer (2022)

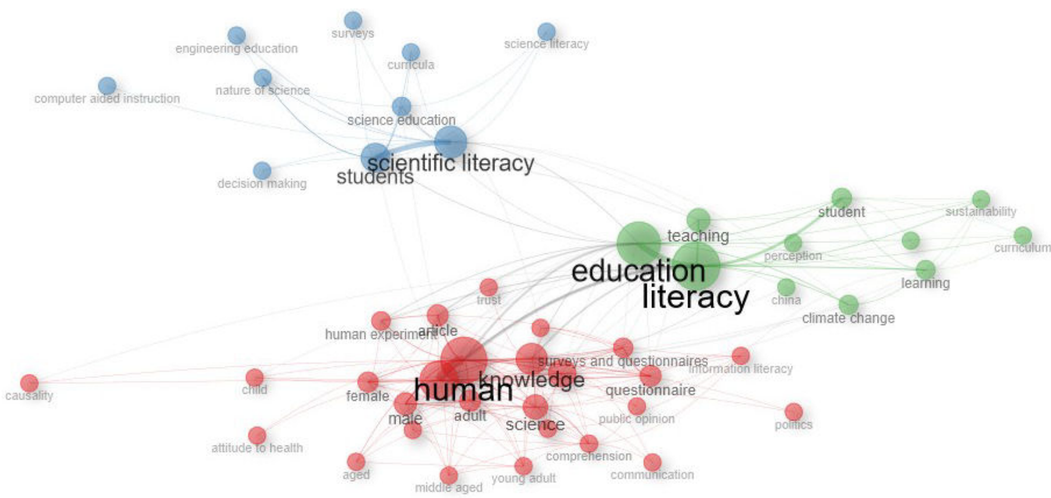

FIGURE 7. Co-occurrence network analysis from output Biblioshiny.

3.4. Network analysis

3.4.1. Co-occurrence

The scientific literacy research topic is viewed from network analysis based on BibTeX data obtained from the Scopus database connected to several co-occurrences and three clusters, namely educational literacy, scientific literacy, and human (see Fig. 7). Each cluster has keywords that describe research developed in that cluster. The education literacy cluster has keywords such as teaching, student, perception, China, sustainability, learning, climate change, and curriculum. In the scientific literacy cluster, there are keywords including students, science education, decision-making, science literacy, nature of science, engineering education, surveys, and computer-aided instruction. In the human cluster, there are keywords including trust, human experiment, articles, surveys and questionnaires, information literacy, politics, public opinion, questionnaire, science, adult, female, child, causality, knowledge, attitude to health, aged, middle-aged, young adult, comprehension, and communication.

3.4.2. Thematic map

We also investigated previous research using a thematic map. Research that has developed (see Fig. 8) in the motor theme groups emphasizes scientific literacy in science education using the context of environmental issues. Meanwhile, in the niche themes group, scientific literacy research develops based on public understanding or opinion viewed from a social aspect. In the emerging or declining themes group,

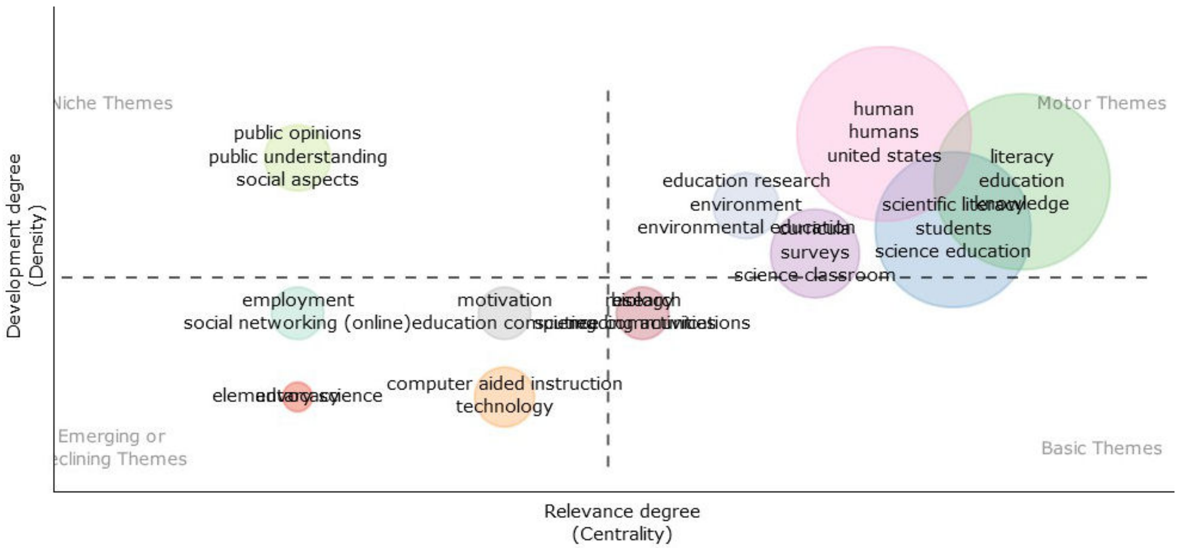

FIGURE 8. Thematic map from output Biblioshiny.

scientific literacy research is associated with motivation, social networking, computer-aided instruction, and the use of technology. In the basic themes group, scientific literacy research is still limited to improving students' cognitive abilities. These themes can still be developed in-depth concerning the implications of teachers' learning strategies for increasing scientific literacy and the nurturing effects that can be improved from scientific literacy in science education.

4. Discussion

The findings of this review can be summarized in a word cloud like in Fig. 9. Various studies have been carried out focusing on discussing literacy, specifically scientific literacy in education. This involves human knowledge, in this case, students and educators, by studying topics or aspects of scientific literacy such as climate change, sustainability, and the nature of science. Various strategies and assessments have been developed in research to increase scientific literacy in various countries.

Three aspects of scientific literacy are mapped in the findings of the research that has been conducted, including content, context, and competency. We created a visual representation between scopes of scientific literacy as in Fig. 10. This pattern was inspired by Semilarski and Laius (2021) and Azevedo and Marques (2017) articles. What differentiates the two from the visual representation of these findings is the relationship between content and context in scientific literacy. In Semilarski and Laius (2021) research, a biological literacy model is part of scientific literacy with various aspects, while Azevedo and Marques (2017) research correlates earth science literacy with environmental literacy in various contexts such as the ocean, climate, weather, and energy literacy. We found that scientific literacy includes science, biological, chemical, physics, and earth science literacies. In various scopes of scientific literacy, it is found that biological liter-

FIGURE 9. Word cloud of scientific literacy studies from output Biblioshiny.

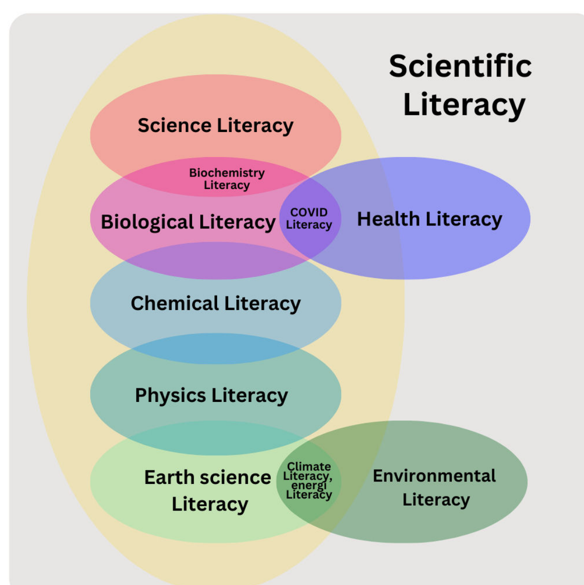

FIGURE 10. Visual representation of scientific literacy scope.

acy is related to chemical literacy, which is known as biochemical literacy. Meanwhile, outside the scope of scientific literacy, there is still health literacy and environmental literacy. Health literacy is related to biological literacy and developed to become COVID-19 literacy starting in late 2019. Meanwhile, environmental literacy is related to climate and energy literacy in the findings of this review. These findings show that research on scientific literacy continues to develop along with world developments, both in terms of content and context for achieving the desired scientific literacy competency.

5. Conclusion

The conclusion of the first research question is that there is an increasing trend of scientific literacy research in science education from 2014 to 2024 to 2023 and continues to increase in 2024. Empirical research is more often conducted than review research. The research applies aspects of scientific literacy in content, context, and competency at various levels of education, both formal and non-formal education. From the second research question, the implications of empirical research on scientific literacy in science learning have been conducted by various countries such as the United States, the European Union, the United Kingdom, and Asia, including Indonesia. They develop learning strategies and assessments of scientific literacy in various forms that are adjusted to the objectives to be achieved. From the third research question, the findings show that article reviews have been developed in science learning towards scientific literacy using various methods such as systematic reviews, coverage reviews, critical reviews, bibliometric analysis, thematic analysis, quantitative reviews, innovation essays, and book reviews. Implications for science learning can be seen from the aspects of scientific literacy emphasized in the review. Finally, the conclusion of the fourth research question is that there are three co-occurrence clusters from the bibliometric analysis, namely educational literacy, scientific literacy, and human literacy. Various thematic maps are also mapped to the areas that are the focus of scientific literacy research.

6. Further research

In the future, we can conduct empirical research that focuses on developing appropriate learning strategies and assessments to measure the scientific literacy of students in secondary education, primary education, and non-formal education. Apart from that, critical review research can also be carried out on existing research so that improvements can be made to optimize research on scientific literacy, especially in science education.

1. UNESCO, Education nine ideas for in public a post-COVID action. (UNESCO, 2020).
2. L. Valladares, Scientific Literacy and Social Transformation: Critical Perspectives About Science Participation and Emancipation, *Sci. Educ.* **30** (2021) 557, https://doi.org/10.1007/s11191-021-00205-2.
3. M. C. Oliver and M. J. Adkins, "Hot-headed" students? Scientific literacy, perceptions and awareness of climate change in 15-year olds across 54 countries, *Energy Res. Soc. Sci.* **70** (2020) 101641, https://doi.org/10.1016/j.erss.2020.101641.
4. S. A. Smith and E. T. Carbone, Health literacy and empowerment in the COVID-19 era, *Inf. Serv. Use.* **43** (2023) 89, https://doi.org/10.3233/ISU-230186.
5. M. Aristeidou and C. Herodotou, Online citizen science: A systematic review of effects on learning and scientific literacy, *Citiz. Sci. Theory Pract.* **5** (2020) 11, https://doi.org/10.5334/cstp.224.
6. M. D. Kembara *et al*., Scientific literacy profile of student teachers on science for all context, *Solid State Technol.* **63** (2020) 5844, https://solidstatetechnology.us/index.php/JSST/issue/view/49.
7. S. Amini, and P. Sinaga, Inventory of scientific literacy ability of junior high school students based on the evaluation of PISA framework competency criteria, *J. Phys. Conf. Ser.* **1806** (2021) 012017, https://doi.org/10.1088/1742-6596/1806/1/012017.
8. J. Kähler, I. Hahn, and O. Köller, The development of early scientific literacy gaps in kindergarten children, *Int. J. Sci. Educ.* **42** (2020) 1988, https://doi.org/10.1080/09500693.2020.1808908.
9. J. L. Atkinson, Are We Creating the Achievement Gap? Examining How Deficit Men talities Influence Indigenous Science Curriculum Choices, In D. J. Tippins, *et al*., eds., Cultural Studies and Environmentalism: The Confluence of EcoJustice, Place-based (Science) Education, and Indigenous Knowledge Systems, *vol. 3* (Springer Netherlands, Dordrecht, 2010) pp. 439-446, https://doi.org/10.1007/978-90-481-3929-3.
10. G. E. DeBoer, Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform, *J. Res. Sci. Teach.* **37** (2000) 582, https://doi.org/10.1002/1098-2736(200008)37:6%3C582::AID-TEA5%3E3.0.CO;2-L.
11. E. Bórquez-Sánchez, Scientific literacy in biology and attitudes towards science in the Chilean education system, *Res. Sci. Technol. Educ.* **43** (2024) 589, https://doi.org/10.1080/02635143.2024.2320104.
12. H. Semilarski and A. Laius, Exploring Biological Literacy: A Systematic Literature Review of Biological Literacy, *Eur. J. Educ. Res.* **10**(2021) 1181, https://doi.org/10.12973/eu-jer.10.3.1181.

13. C. Cigdemoglu, H. O. Arslan, and A. Cam, Argumentation to foster pre-service science teachers' knowledge, competency, and attitude on the domains of chemical literacy of acids and bases, *Chem. Educ. Res. Pract.* **18**(2017) 288, https://doi.org/10.1039/c6rp00167j.
14. A. Pahrudin, Irwandani, E. Triyana, Y. Oktarisa, and C. Anwar, The analysis of pre-service physics teachers in scientific literacy: Focus on the competence and knowledge aspects, *J. Pendidik. IPA Indones.* **8**(2019) 52, https://doi.org/10.15294/jpii.v8i1.15728.
15. L. A. Arthurs and M. S. Van Den Broeke, Novice explanations of hurricane formation offer insights into scientific literacy and the development Of expert-like conceptions, *J. Astron. Earth Sci. Educ.* **3**(2016) 1, https://doi.org/10.19030/jaese.v3i1.9686.
16. P. Turiman, J. Omar, A. M. Daud, and K. Osman, Fostering the 21st century skills through scientific literacy and science process skills, *Procedia - Soc. Behav. Sci.* **59**(2012) 110, https://doi.org/10.1016/j.sbspro.2012.09.253.
17. R. Bellová, D. Melicherčíková, and P. Tomčík, Possible reasons for low scientific literacy of Slovak students in some natural science subjects, *Res. Sci. Technol. Educ.* **36**(2018) 226, https://doi.org/10.1080/02635143.2017.1367656.
18. J. Jufrida *et al.*, Scientific literacy and science learning achievement at junior high school, *Int. J. Eval. Res. Educ.* **8**(2019) 630, https://doi.org/10.11591/ijere.v8i4.20312.
19. A. Widowati, L. Widyastuti, and E. Widodo, The profile of students' scientific literacy in competence aspect in junior high school of Yogyakarta city, *J. Phys. Conf. Ser.* **1321**(2019) 032070, https://doi.org/10.1088/1742-6596/1321/3/032070.
20. OECD, PISA 2022 results (Volume I): The state of learning and equity in education. (OECD Publishing, 2023), https://doi.org/10.1787/53f23881-en.
21. T. Neidorf, M. Stephens, A. Lasseter, K. Gattis, A. Arora, Y. Wang, S. Guile, and J. Holmes, A comparison between the Next Generation Science Standards (NGSS) and the National Assessment of Educational Progress (NAEP) frameworks in Science, Technology and Engineering Literacy, and Mathematics. (National Center for Education Statistics, 2016), https://nces.ed.gov/nationsreportcard/subject/science/pdf/ngss_naep_technical_report.pdf.
22. P. A. Archila *et al.*, Towards COVID-19 literacy: Investigating the literacy levels of university students in Colombia, *Sci. Educ.* **30**(2021) 785, https://doi.org/10.1007/s11191-021-00222-1.
23. M. Cabreja-Castillo *et al.*, COVID-19 Scientific Literacy in Medical and Nursing Students, *J. Microbiol. Biol. Educ.* **24** (2023) e00219, https://doi.org/10.1128/jmbe.00219-22.
24. K. Motoki, T. Saito, and Y. Takano, Scientific literacy linked to attitudes toward COVID-19 vaccinations: A pre-registered study, *Front. Commun.* **6** (2021) 707391, https://doi.org/10.3389/fcomm.2021.707391.
25. J. P. Higgins *et al.*, Cochrane Handbook for Systematic Reviews of Interventions (John Wiley & Sons, Ltd, 2019), https://doi.org/10.1002/9781119536604.fmatter.
26. A. Z. Ilma *et al*., A Systematic Literature Review of STEM Education in Indonesia (2016-2021): Contribution to Improving Skills in 21st Century Learning, *Pegem Egit. ve Ogr. Derg.*, **13** (2023) 134, https://doi.org/10.47750/pegegog.13.02.17.
27. L. Guan, J. M. Merigó, R. E. Löfstedt, and J. K. Wardman, Twenty-five years of the Journal of Risk Research: a bibliometric overview, *J. Risk Res.*, **27** (2024) 857, https://doi.org/10.1080/13669877.2024.2377093.
28. J.M. Merigó, A.M. Gil-Lafuente, F. Kydland, L. Amiguet, V. Vivoda, G. Campbell, Y. Lei, and D. Fleming-Muñoz, 50 years of Resources Policy: A bibliometric analysis, *Resour. Policy.* **96** (2024) 105229, https://doi.org/10.1016/j.resourpol.2024.105229.
29. M. Wakid, H. Sofyan, A. Widowati, and A. Zaida Ilma, Learning-oriented assessment: a systematic literature network analysis, *Cogent Educ.* **11** (2024) 2366075, https://doi.org/10.1080/2331186X.2024.2366075.
30. M. J Page, J. E. McKenzie, P. M. Bossuyt, I. Boutron, T. C. Hoffmann, C. D Mulrow, L. Shamseer, J. M. Tetzlaff, E. A Akl, S. E Brennan, R. Chou, J. Glanville, J. M. M. Grimshaw, A. Hróbjartsson, M. M. Lalu, T. Li, E. W. Loder, E. Mayo-Wilson, and S. McDonald, L. A McGuinness, L. A. Stewart, J. Thomas, A. C. Tricco, V. A. Welch, P. Whiting, and D. Moher, The PRISMA 2020 statement: An updated guideline for reporting systematic reviews, *BMJ* **372** (2021) 1, https://doi.org/10.1136/bmj.n71.
31. R. Randles and A. Finnegan, Guidelines for writing a systematic review, *Nurse Educ. Today* **125** (2023) 105803, https://doi.org/10.1016/j.nedt.2023.105803.
32. J. L. Rudolph, Scientific literacy: Its real origin story and functional role in American education, *J. Res. Sci. Teach.* **61** (2024) 519, https://doi.org/10.1002/tea.21890.
33. D. Gertner, N. Xu, H. Porter-Morgan, and J. Brashears, Developing students' scientific literacy through an e-portfolio project at a community college gateway science course, *J. Biol. Educ.* **57** (2023) 129, https://doi.org/10.1080/00219266.2021.1877782.
34. M. J. Tuttle, D. Kang, F. Muchaamba, B. Goncarovs, Y. Ozakman, F. Aziz, and A. Orelle , Promoting science literacy and awareness across the globe: the role of scientists as science ambassadors, *J. Microbiol. Biol. Educ.* **24** (2023) 71, https://doi.org/10.1128/jmbe.00041-23.
35. F. Fakhriyah, S. Masfuah, and D. Mardapi, Developing scientific literacy-based teaching materials to improve students' computational thinking skills, *J. Pendidik. IPA Indones.* **8** (2019) 482, https://doi.org/10.15294/jpii.v8i4.19259.
36. X. Gu, C. Wang, and L. Lin, Examining scientific literacy through new media, *Eurasia J. Math. Sci. Technol. Educ.* **15** (2019) em1785, https://doi.org/10.29333/ejmste/109948.
37. L. Heliawati, B. Rubini, and R. Firmayanto, The effectiveness of content and language integrated learning-based teaching material in the topic of the nature of matter on scientific literacy, *J. Educ. Gift. Young Sci.* **8** (2020) 1061, https://doi.org/10.17478/JEGYS.736654.

38. M. Listianingsih *et al.*, Android-Based Comics: An Alternative Media to Improve Scientific Literacy, *J.Penelit. dan Pembelajaran IPA.* **7** (2021) 105, https://doi.org/10.30870/jppi.v7i1.8636.

39. C.-C. Liu *et al*., Augmenting the effect of virtual labs with "teacher demonstration" and "student critique" instructional designs to scaffold the development of scientific literacy, *Instr. Sci*. **50** (2022) 303, https://doi.org/10.1007/s11251-021-09571-4.

40. M. S. Prastiwi, B. Kartowagiran, and E. Susantini, Assessing using technology: Is electronic portfolio effective to assess the scientific literacy on evolution theory, *Int. J. Emerg. Technol. Learn.* **15** (2020) 230, https://doi.org/10.3991/ijet.v15i12.12227.

41. S. J. Rehorek, and N. J. Dafoe, The Art of Referencing as an Often Overlooked Aspect of Scientific Literacy: Study of a Classroom Intervention, *Am. Biol. Teach.* **80** (2018) 423, https://doi.org/10.1525/abt.2018.80.6.423.

42. A. Rokhmah, W. Sunarno, and M. Masykuri, Science Literacy Indicators in Optical Instruments of Highschool Physics Text books Chapter, *J. Pendidik. Fis. Indones.* **13** (2017) 19, https://doi.org/10.15294/jpfi.v13i1.8391.

43. D. S. Smyth *et al.*, How Getting Friendly with Bacteria Can Promote Student Appreciation of Microbial Diversity and Their Civic Scientific Literacy, *J. Microbiol. Biol. Educ.* **23** (2022) e00055, https://doi.org/10.1128/jmbe.00055-22.

44. B. Rubini, A. Permanasari, and W. Yuningsih, Learning Mul timedia Based on Science Literacy on the Lightning Theme, *J. Penelit. dan Pembelajaran IPA.* **4** (2018) 89, https://doi.org/10.30870/jppi.v4i2.3926.

45. A. Rusilowati, S. E. Nugroho, and S. M. Susilowati, Development of Science Textbook Based on Scientific Literacy for Secondary School, *J. Pendidik. Fis. Indones.* **12** (2016) 98, https://doi.org/10.15294/jpfi.v12i2.4252.

46. S. B. Stockwell, A Progressive Reading, Writing, and Artistic Module to Support Scientific Literacy, *J. Microbiol. Biol. Educ.* **17** (2016) 93, https://doi.org/10.1128/jmbe.v17i1.990.

47. L. Tomas and S. M. Ritchie, The Challenge of Evaluating Students' Scientific Literacy in a Writing-to-Learn Context, *Res. Sci. Educ.* **45** (2015) 41, https://doi.org/10.1007/s11165-014-9412-3.

48. Uslan, N. Abdullah, M. K. W. Imami, and U. Aiman, The Effectiveness of the Local Knowledge-Based Module (Lkbm) To Improve Students' Scientific Literacy and Thinking Skills, *J. Pendidik. IPA Indones.* **13** (2024) 147, https://doi.org/10.15294/jpii.v13i1.47561.

49. E. W. Winarni and E. P. Purwandari, The effectiveness of turtle mobile learning application for scientific literacy in elementary school, *J. Educ. e-Learning Res.* **6** (2019) 156, https://doi.org/10.20448/journal.509.2019.64.156.161.

50. I. D. Pursitasari, E. Suhardi, and T. Putikah, Fun Science Teaching Materials on the Energy Transformation to Promote Students' Scientific Literacy, *J. Penelit. dan Pembelajaran IPA.* **5** (2019) 155, https://doi.org/10.30870/jppi.v5i2.4008.

51. Y. Fitria *et al*., Graphic Organizer-Based Science Literacy Learning Models in Elementary Schools, *J. Pendidik. IPA Indones.* **12** (2023) 123, https://doi.org/10.15294/jpii.v12i1.41004.

52. L. Heliawati, L. Lidiawati, P. N. A. Adriansyah, and E. Herlina, Ethnochemistry-Based Adobe Flash Learning Media Using Indigenous Knowledge To Improve Students' Scientific Literacy, *J. Pendidik. IPA Indones.* **11** (2022) 271, https://doi.org/10.15294/jpii.v11i2.34859.

53. Adriyawati, E. Utomo, Y. Rahmawati, and A. Mardiah, STEAM-project-based learning integration to improve elementary school students' scientific literacy on alternative energy learning, *Univers. J. Educ.* **8** (2020) 1863, https://doi.org/10.13189/ujer.2020.080523.

54. Asiyah *et al.*, Measuring the Impact of Islamic Values-Based Scientific Literacy on Scientific Competency of Madrasah Teachers, *Int. J. Learn. Teach. Educ. Res.* **23** (2024) 476, https://doi.org/10.26803/ijlter.23.4.25.

55. B. Chambers, A. Salter, and L. Muldrow, Getting past the gateway: An exploratory case on using utilitarian scientific literacy to support first-year students at-risk of leaving STEM, *Educ. Sci.* **9** (2019) 265, https://doi.org/10.3390/educsci9040265.

56. Y. Herlanti, Y. Mardiati, R. Rahmawati, A. M. K Putri, N. Jamil, M. Miftahuzzakiyah, A. Sofyan, Z. Zulfiani, and S. Sugiarti, Finding Learning Strategy in Improving Science Literacy, *J. Penelit. dan Pembelajaran IPA.* **5** (2019) 59, http://dx.doi.org/10.30870/jppi.v5i1.4902.

57. M. A. Rokhimawan, F. Yuliawati, I. Kamala, and S. Susilawati, Prospective Madrasah Teachers' Scientific Competencies Integrated With Scientific Literacy Through the Stem Approach, *J. Pendidik. IPA Indones.* **11** (2022) 91, https://doi.org/10.15294/jpii.v11i1.32983.

58. Suryanti, M. Nursalim, N. L. Choirunnisa, and I. Yuliana, STEAM-Project-Based Learning: A Catalyst for Elementary School Students' Scientific Literacy Skills, *Eur. J. Educ. Res.* **13** (2021) 1, https://doi.org/10.12973/eu-jer.13.1.1.

59. Y. Wahyu, I. W. Suastra, I. W. Sadia, and N. K. Suarni, The effectiveness of mobile augmented reality assisted STEM-based learning on scientific literacy and students' achievement, *Int. J. Instr.* **13** (2020) 343, https://doi.org/10.29333/iji.2020.13324a.

60. C. Cigdemoglu, and O. Geban, Improving students' chemical literacy levels on thermochemical and thermodynamics concepts through a context-based approach, *Chem. Educ. Res. Pract.* **16** (2015) 302, https://doi.org/10.1039/c5rp00007f.

61. C. A. Dewi *et al*., Effect of contextual collaborative learning based ethnoscience to increase student's scientific literacy ability, *J. Turkish Sci. Educ.* **18** (2021) 525, https://doi.org/10.36681/tused.2021.88.

62. A. Doshi, S. Weinert, and M. Attig, Self-regulatory abilities as predictors of scientific literacy among children in preschool and primary school years, *Learn. Individ. Differ.* **114** (2023) 102515, https://doi.org/10.1016/j.lindif.2024.102515.

63. K. G. Tsoumanis, G. Stylos, and K. T. Kotsis, A Comparative Study between Greek Pre-service Teachers and Primary School Students' Scientific Literacy Levels, Science Education Inter national, *Sci. Educ. Int.* **34** (2023) 121, https://doi.org/10.33828/sei.v34.i2.6.

64. R. Thummathong, and K. Thathong, Chemical literacy levels of engineering students in Northeastern Thailand, *Kasetsart J. Soc. Sci.* **39** (2018) 478, https://doi.org/10.1016/j.kjss.2018.06.009.

65. Y. Fitria *et al*., Digital comic teaching materials: It's role to enhance student's literacy on organism characteristic topic, *Eurasia J. Math. Sci. Technol. Educ.* **19** (2023) em2333, https://doi.org/10.29333/ejmste/13573.

66. M. G. R. Kristiantari, I. Wayan Widiana, N. K. D. Tristiantari, and N. N. Rediani, Impact of Prezi Media-Assisted Problem-Based Learning on Scientific Literacy and Independence of Elementary School Students, *J. Educ. e-Learning Res.* **9** (2022) 184, https://doi.org/10.20448/jeelr.v9i3.4185.

67. M. Paristiowati, U. Cahyana, and B. I. S. Bulan, Implementation of Problem-based Learning- Flipped Classroom Model in Chemistry and Its Effect on Scientific Literacy. *Univers. J. Educ.* **7** (2019) 56, http://doi.org/10.13189/ujer.2019.071607.

68. P. Parmin and F. Fibriana, Prospective Teachers' Scientific Literacy through Ethnoscience Learning Integrated with the In digenous Knowledge of People in the Frontier, Outermost, and Least Developed Regions, *J. Penelit. dan Pembelajaran IPA.* **5** (2019) 142, https://doi.org/10.30870/jppi.v5i2.6257.

69. H. Ratini, M. A. Suparman, A. H. Tamuri, and E. Susanto, The influence of learning models and learning reliance on students' scientific literacy, *J. Pendidik. IPA Indones.* **7** (2018) 458, https://doi.org/10.15294/jpii.v7i4.12489.

70. M. Ahied, L. K. Muharrami, A. Fikriyah, and I. Rosidi, Improving students' scientific literacy through distance learning with augmented reality-based multimedia amid the covid-19 pandemic, *J. Pendidik. IPA Indones.* **9** (2020) 499, https://doi.org/10.15294/jpii.v9i4.26123.

71. A. E. Anderson, L. B. Justement, and H. A. Bruns, Using real-world examples of the COVID-19 pandemic to increase student confidence in their scientific literacy skills, *Biochem. Mol. Biol. Educ.* **48** (2020) 678, https://doi.org/10.1002/bmb.21474.

72. Z. Kohen, O. Herscovitz, and Y. J. Dori, How to promote chemical literacy? On-line question posing and communicating with scientists, *Chem. Educ. Res. Pract.* **21** (2020) 250, https://doi.org/10.1039/c9rp00134d.

73. R. Ramachandran *et al*., Imparting Scientific Literacy through an Online Materials Chemistry General Education Course, *J. Chem. Educ.* **98** (2021) 1594, https://doi.org/10.1021/acs.jchemed.1c00138.

74. A. J. Auerbach, and E. E. Schussler, Curriculum alignment with vision and change improves student scientific literacy, *CBE Life Sci. Educ.* **16** (2017) ar29, https://doi.org/10.1187/cbe.16-04-0160.

75. M. A. Queiruga-Dios *et al*., Citizen science for scientific literacy and the attainment of sustainable development goals in formal education, *Sustain.* **12** (2020) 155, https://doi.org/10.3390/su12104283.

76. A. Sholahuddin, N. Anjuni, Leny, and C. Falkhamta, Project-Based and Flipped Learning in the Classroom: A Strategy for Enhancing Students' Scientific Literacy, *Eur. J. Educ. Res.* **12** (2023) 239, https://doi.org/10.12973/eu-jer.12.1.239.

77. J. Vogelzang, W. F. Admiraal, and J. H. Van Driel, Effects of Scrum methodology on students' critical scientific literacy: The case of Green Chemistry, *Chem. Educ. Res. Pract.* **21** (2020) 940, https://doi.org/10.1039/d0rp00066c.

78. U. Aiman, S. Hasyda, and Uslan, The influence of process oriented guided inquiry learning (POGIL) model assisted by realia media to improve scientific literacy and critical thinking skill of primary school students, *Eur. J. Educ. Res.* **9** (2020) 1635, https://doi.org/10.12973/EU-JER.9.4.1635.

79. N. Buteyn, Y. I. Oh, J. Knott, P. Bokach, J. Konyndyk, J. Tenney, A. Wilstermann, H. Fynewever, and D. Koetje, Exploring nutraceuticals to enhance scientific literacy: Aligning with vision and change, *Am. Biol. Teach.* **81** (2019) 176, https://doi.org/10.1525/abt.2019.81.3.176.

80. A. Saefullah, U. Samanhudi,L Nulhakim, L. Berlian, A. Rakhmawan, B. Rohimah, R. A. Z El Islami, Efforts to Improve Scientific Literacy of Students through Guided Inquiry Learning Based on Local Wisdom of Baduy's Society, *J. Penelit. dan Pembelajaran IPA* **3** (2017) 84, https://doi.org/10.30870/jppi.v3i2.2482.

81. A. T. Taylor, Integrating scientific literacy skills into a biochemistry course for nonscience majors, *Biochem. Mol. Biol. Educ.* **48** (2020) 54, https://doi.org/10.1002/bmb.21313.

82. J. L. Bay *et al*., Adolescents as agents of healthful change through scientific literacy development: A school-university partnership program in New Zealand, *Int. J. STEM Educ.* **4** (2017) 15, https://doi.org/10.1186/s40594-017-0077-0.

83. S. Y. Chen, and S. Y. Liu, Reinforcement of scientific literacy through effective argumentation on an energy-related environmental issue, *Eurasia J. Math. Sci. Technol. Educ.* **14** (2018) em1625, https://doi.org/10.29333/ejmste/95171.

84. M Saija, S Rahayu, F Fajaroh, and S Sumari, Enhancement of High School Students' Scientific Literacy Using Local-Socioscientific Issues in Oe3C Instructional Strategies, *J. Pendidik. IPA Indones.* **11** (2022) 11, https://doi.org/10.15294/jpii.v11i1.33341.

85. W. Widodo *et al*., The effectiveness of gadget-based interactive multimedia in improving generation z's scientific literacy, *J. Pendidik. IPA Indones.* **9** (2020) 248, https://doi.org/10.15294/jpii.v9i2.23208.

86. F. M. Calado, F. J. Scharfenberg, and F. X. Bogner, To what extent do biology textbooks contribute to scientific literacy? Criteria for analysing science-technology-society-environment issues, *Educ. Sci.* **5** (2015) 255, https://doi.org/10.3390/educsci5040255.

87. Mahlianurrahman, I. W. Lasmawan, I. M. Candiasa, and I. W. Suastra, The Effect of Nyerayo Based SETS Learning on Student's Scientific Literacy. *Pegem Egit. ve Ogr. Derg.* **13** (2023) 79, https://doi.org/10.47750/pegegog.13.02.10.

88. C. M. Ambrosino, and M. A. J. Rivera, Using ethological techniques and place-based pedagogy to develop science literacy in Hawaii's high school students, *J. Biol. Educ.* **56** (2022) 3, https://doi.org/10.1080/00219266.2020.1739118.

89. Y. Georgiou, and E. A. Kyza, Fostering Chemistry Students' Scientific Literacy for Responsible Citizenship through Socio-Scientific Inquiry-Based Learning (SSIBL), *Sustain.* **15** (2023) 6442, https://doi.org/10.3390/su15086442.

90. C. A. Dewi, Y. Khery, and M. Erna, An ethnoscience study in chemistry learning to develop scientific literacy, *J. Pendidik. IPA Indones.* **8** (2019) 279, https://doi.org/10.15294/jpii.v8i2.19261.

91. Jufrida, W. Kurniawan, and F. R. Basuki, Ethnoscience learning: how do teacher implementing to increase scientific literacy in junior high school, *Int. J. Eval. Res. Educ.* **13** (2024) 1719, https://doi.org/10.11591/ijere.v13i3.26180.

92. B. Subali, E. Ellianawati, Z. Faizah, and M. Sidiq, Indonesian national assessment support: Can RE-STEM Android app improve students' scientific literacy skills?, *Int. J. Eval. Res. Educ.* **12** (2023) 1399, https://doi.org/10.11591/ijere.v12i3.24794.

93. U. Muzayanah, A. G. Santoso, S. Saimroh, and T. I Fauzah, Strengthening students' scientific literacy through scientific coaching programs, *Int. J. Eval. Res. Educ.* **12** (2023) 1467, https://doi.org/10.11591/ijere.v12i3.25206.

94. M. Umar and S. Sukarno, The influence of fiqh insights and science literacy on student ability in developing Quran-based science, *Int. J. Eval. Res. Educ.* **11** (2022) 954, https://doi.org/10.11591/ijere.v11i2.22012.

95. J. M. Monk and G. Newton, Use of a scaffolded case study assignment to enhance students' scientific literacy skills in undergraduate nutritional science education: Comparison between traditional lecture and distance education course formats, *Int. J. High. Educ.* **7** (2018) 95, https://doi.org/10.5430/ijhe.v7n2p95.

96. I. M. Tegeh, I. G. Astawan, I. K. Sudiana, and M. G. R. Kristiantari, Murder Learning Model Assisted By Metacognitive Scaffolding To Improve Students' Scientific Literacy and Numeracy Skills Through Science Studies in Elementary Schools, *J. Pendidik. IPA Indones.* **10** (2021) 618, https://doi.org/10.15294/jpii.v10i4.32926.

97. B. Surpless, M. Bushey, and M. Halx, Murder Developing scientific literacy in introductory laboratory courses: A model for course design and assessment, *J. Geosci. Educ.* **62** (2014) 244, https://doi.org/10.5408/13-073.1.

98. S. Torres-Giner, A. Yuste, and C. González-Martínez, Improving the Scientific Literacy of Food Engineering Students in Electrohydrodynamic Processing by Means of Zein Solutions, *Educ. Sci.* **12** (2022) 503, https://doi.org/10.3390/educsci12080503.

99. H. Woodham *et al.*, Enhancing Scientific Literacy in the Undergraduate Cell Biology Laboratory Classroom, *J. Microbiol. Biol. Educ.* **17** (2016) 458, https://doi.org/10.1128/jmbe.v17i3.1162.

100. Y. Günaydin and M. Basaran, The Predictive Power of Reading Comprehension, Attitude Toward Sciences, Test Technique, And Science Subject Matter Knowledge In Predicting Pisa Scientific Literacy Test Total Score, *Particip. Educ. Res.* **9** (2022) 206, http://dx.doi.org/10.17275/per.22.136.9.6.

101. G. Eymur and P. S. Çetin, Investigating the role of an inquiry-based science lab on students' scientific literacy, *Instr. Sci.* **52** (2024) 743, http://dx.doi.org/10.1007/s11251-024-09672-w.

102. Bahtiar, Ibrahim, and Maimun, Analysis of students' scientific literacy skill in terms of gender using science teaching materials discovery model assisted by PhET simulation, *J. Pendidik. IPA Indones.* **11** (2022) 371, http://dx.doi.org/10.15294/jpii.v11i3.37279.

103. E. W. Winarni, D. Hambali, and E. P. Purwandari, Analysis of Language and Scientific Literacy Skills for 4th Grade Elementary School Students through Discovery Learning and ICT media, *Int. J. Instr.* **13** (2020) 213, http://dx.doi.org/10.20448/journal.509.2019.64.156.161.

104. J. Díez-Palomar, M. F. Palomar, A. Aubert, and C. Garcia-Yeste, Dialogic Scientific Gatherings: The Promotion of Scientific Literacy Among Children, *SAGE Open* **12** (2022) 21582440221121783, http://dx.doi.org/110.1177/21582440221121783.

105. A. Ekantini, and I. Wilujeng, The development of science student worksheet based on education for environmental sustainable development to enhance scientific literacy, *Univers. J. Educ. Res.* **6** (2018) 1339, http://dx.doi.org/10.13189/ujer.2018.060625.

106. E. C. Goodwin *et al.*, Synthesizing Research Narratives to Reveal the Big Picture: a CREATE(S) Intervention Modified for Journal Club Improves Undergraduate Science Literacy, *J. Microbiol. Biol. Educ.* **24** (2023) 1, http://dx.doi.org/10.1128/jmbe.00055-23.

107. W. Agustina, I. N. S. Degeng, H. Praherdhiono, and S. R. Lestaric, The Effect of Blended Project-Based Learning for Enhancing Student's Scientific Literacy Skills: An Experimental Study in University, *Pegem Egit. ve Ogr. Derg.* **13** (2022) 223, https://doi.org/10.47750/pegegog.13.01.24.

108. E. Angraini, S. Zubaidah, and H. Susanto, TPACK-based Active Learning to Promote Digital and Scientific Literacy in Genetics, *Pegem Egit. ve Ogr. Derg.* **13** (2023) 50, https://doi.org/10.47750/pegegog.13.02.07.

109. T. C. Chang, Y. M. Lyu, H. C. Wu, and K. W. Min, Introduction of Taiwanese literacy-oriented science curriculum and development of an aligned scientific literacy assessment, *Eurasia J. Math. Sci. Technol. Educ.* **20** (2024) em2380, https://doi.org/10.29333/ejmste/13930.

110. M. M. Fausan *et al.*, The scientific literacy performance of gifted young scientist candidates in the digital age, *Cakrawala Pendidik.* **40** (2021) 467, https://doi.org/10.21831/cp.v40i2.39434.

111. M. Homer and J. Ryder, The Impact of a Science Qualification Emphasising Scientific Literacy on Post-compulsory Science Participation: An analysis using national data, *Int. J. Sci. Educ.* **37** (2015) 1364, https://doi.org/10.1080/09500693.2015.1036151.

112. D. P. Lestari, P. Paidi, and S. Suwarjo, Effect of the inquiry-based nature of science argumentation instructional model in scientific literacy skills, *J. Educ. Learn.* **18** (2024) 734, https://doi.org/10.11591/edulearn.v18i3.21024.

113. B. B. Podgornik, D. Dolničar, and S. A. GlaÅ$\frac{3}{4}$ar, Does the information literacy of university students depend on their scientific literacy? *Eurasia J. Math. Sci. Technol. Educ.* **13** (2017) 3869, https://doi.org/10.12973/eurasia.2017.00762a.

114. F. Sahin, and S. Ates, Examination of the relationship between seventh-grade students' scientific literacy among certain cognitive variables, *Egit. ve Bilim* **45** (2020) 63, https://doi.org/10.15390/EB.2020.8552.

115. J. F. Shaffer, J. Ferguson, and K. Denaro, Use of the test of scientific literacy skills reveals that fundamental literacy is an important contributor to scientific literacy, *CBE Life Sci. Educ.* **18** (2019) ar31, https://doi.org/10.1187/cbe.18-12-0238.

116. A. Sholahuddin, E. Susilowati, B. K. Prahani, and E. Erman, Using a cognitive style-based learning strategy to improve students' environmental knowledge and scientific literacy, *Int. J. Instr.* **14** (2021) 791, https://doi.org/10.29333/iji.2021.14445a.

117. G. Stylos, O. Siarka, and K. T. Kotsis, Assessing Greek preservice primary teachers' scientific literacy, *Eur. J. Sci. Math. Educ.* **11** (2023) 271, https://doi.org/10.30935/scimath/12637.

118. A. M. Suárez-Mesa and R. L. Gómez, Does teachers' motivation have an impact on students' scientific literacy and motivation? An empirical study in Colombia with data from PISA 2015, *Large-Scale Asses. Educ.* **12** (2024) 1, https://doi.org/10.1186/s40536-023-00190-8.

119. Y. Xie, J. Wang, S. Li, and Y. Zheng, Research on the influence path of metacognitive reading strategies on scientific literacy, *J. Intell.* **11** (2023) 78, https://doi.org/10.3390/jintelligence11050078.

120. L. Zhang, X. Liu, and H. Feng, Development and validation of an instrument for assessing scientific literacy from junior to senior high school, *Discip. Interdiscip. Sci. Educ. Res.* **5** (2023) 21, https://doi.org/10.1186/s43031-023-00093-2.

121. N. M. Cartwright *et al*., Assessing scientific literacy skill perceptions and practical capabilities in fourth year undergraduate biological science students, *Int. J. High. Educ.* **9** (2020) 64, https://doi.org/10.5430/ijhe.v9n6p64.

122. E. Açıkgül Fırat and M. S. Köksal, Development and Validation of the Biotechnology Literacy Test, *Biochem. Mol. Biol. Educ.* **47** (2019) 179, https://doi.org/10.1002/bmb.21216.

123. Adnan, U. Mulbar, Sugiarti, and A. Bahri, Scientific literacy skills of students: Problem of biology teaching in junior high school in South Sulawesi, Indonesia, *Int. J. Instr.* **14** (2021) 847, https://doi.org/10.29333/iji.2021.14349a.

124. H. H. Wang *et al.*, The role of structured inquiry, open inquiry, and epistemological beliefs in developing secondary students' scientific and mathematical literacies, *Int. J. STEM Educ.* **9** (2022) 14, https://doi.org/10.1186/s40594-022-00329-z

125. S. A. Kreher, I. V. Pavlova, and A. Nelms, An Active Learning Intervention Based on Evaluating Alternative Hypotheses Increases Scientific Literacy of Controlled Experiments in Introductory Biology, *J. Microbiol. Biol. Educ.* **22** (2021) e00172-21, https://doi.org/10.1128/jmbe.00172-21.

126. M. Coppi, I. Fialho, and M. Cid, Validity evidence based on internal structure of a pilot scientific literacy assessment instrument, *Meta Aval.* **16** (2024) 364, https://doi.org/10.22347/2175-2753v16i51.4330.

127. K. Kotuláková, Importance of Teachers' Beliefs in Development of Scientific Literacy, *Chem. Didact. Ecol. Metrol.* **24** (2019) 77, https://doi.org/10.2478/cdem-2019-0006.

128. Y. T. Pan, K. K. Yang, Z. R. Hong, and H. S. Lin, The effect of interest and engagement in learning science on adults' scientific competency and environmental action. *Eurasia J. Math. Sci. Technol. Educ.* **14** (2018) em1609, https://doi.org/10.29333/ejmste/94225.

129. U. Mahmudah, M. Chamdani, T. Tarmidzi, and S. Fatimah, Robust regression for estimating the impact of student's social behaviors on scientific literacy. *Cakrawala Pendidik.* **39** (2020) 293, https://doi.org/10.21831/cp.v39i2.29842.

130. I. G. Pujawan *et al.*, Revised Bloom Taxonomy-Oriented Learning Activities To Develop Scientific Literacy and Creative Thinking Skills, *J. Pendidik. IPA Indones.* **11** (2022) 47, https://doi.org/10.15294/jpii.v11i1.34628.

131. H. Suwono *et al.*, The Development and Validation of an Instrument of Prospective Science Teachers' Perceptions of Scientific Literacy, *Eurasia J. Math. Sci. Technol. Educ.* **18** (2022) em2068, https://doi.org/10.29333/EJMSTE/11505.

132. X. Yang *et al.*, The effects of scientific self-efficacy and cognitive anxiety on science engagement with the 'question-observation-doing-explanation' model during school disruption in COVID-19 pandemic, *J. Sci. Educ. Technol.* **30** (2021) 380, https://doi.org/10.1007/s10956-020-09877-x

133. E. Allison and M. J. Goldston, Modern Scientific Literacy: A Case Study of Multiliteracies and Scientific Practices in a Fifth Grade Classroom, *J. Sci. Educ. Technol.* **27** (2018) 270, https://doi.org/10.1007/s10956-017-9723-z.

134. M. Afifa, R. Khoirunnisa, S. M. V. Pratiwi, and D. Meitaza, Utilizing Rasch Model to Analyze A Gender Gap in Students' Scientific Literacy on Energy, *J. Pendidik. Fis. Indones.* **20** (2024) 85, https://doi.org/10.15294/jpfi.v20i1.44472.

135. K. Dye, Developing scientific literacy with a cyclic independent study assisted CURE detecting SARS-CoV-2 in wastewater, *J. Microbiol. Biol. Educ.* **24** (2023) e00147-23, https://doi.org/10.1128/jmbe.00147-23.

136. K. C. Busch and A. Rajwade, Conceptualizing community scientific literacy: Results from a systematic literature review and a Delphi method survey of experts, *Sci. Educ.* **108** (2024) 1231, https://doi.org/10.1002/sce.21871.

137. M. Istyadji, and Sauqina, Conception of scientific literacy in the development of scientific literacy assessment tools: a systematic theoretical review, *J. Turkish Sci. Educ.* **20** (2023) 281, https://doi.org/10.36681/tused.2023.016.

138. V. Kumar, S. K. Choudhary, and R. Singh, Environmental socio-scientific issues as contexts in developing scientific liter acy in science education: A systematic literature review, *Soc. Sci. Humanit. Open.* **9** (2024) 100765, https://doi.org/10.1016/j.ssaho.2023.100765.

139. D. Mittenzwei, T. Bruckermann, J. Nordine, and U. Harms, The energy concept and its relation to climate literacy, *Eurasia J. Math. Sci. Technol. Educ.* **15** (2019) em1703, https://doi.org/10.29333/ejmste/105637.

140. O. S. Santillán and K. G. Cedano., Energy Literacy: A Systematic Review of the Scientific Literature, *Energies.* **16** (2023) 7235, https://doi.org/10.3390/en16217235.

141. J. Sarsale, D. Alonzo, A. Caseñas, C. Z. Oo, F. A. Sy, and P. I. Yepes, Assessing literacy practices and futures in science and mathematics classrooms: A systematic review, *Issues Educ. Res.* **34** (2024) 719.

142. M. Torrijos-Muelas, S. González-Víllora, A. R. B. Osma, and E. Guijarro, Teachers and pre-service teachers' scientific competencies: a methodological development for a systematic review, *Int. J. Sci. Educ.* **45** (2023) 1182, https://doi.org/10.1080/09500693.2023.2190851.

143. S. Serpa *et al*., COVID-19 and Scientific Literacy, *J. Educ. Soc. Res.* **11** (2021) 1, https://doi.org/10.36941/jesr-2021-0024.

144. M. A. Sarvary and J. M. Ruesch, A Multistep Science Lit eracy Training Framework in an Introductory Biology Class room: Teaching How to Find, Evaluate, Comprehend, and Cite Scientific Evidence, *J. Microbiol. Biol. Educ.* **24** (2023) 22, https://doi.org/10.1128/jmbe.00197-22.

145. M. E. U. Rivera, and I. O. Caceres, Study programs and texts schoolchildren for secondary education in Chile: what oppor tunities for scientific literacy do they offer?, *Sci. Teach.* **32** (2014) 37.

146. M. Cansiz, and N. Cansiz, Reconceptualizing and field testing the scientific literacy framework by exploring the aspect of scientific literacy in Turkish science curriculum, *J. Balt. Sci. Educ.* **18** (2019) 681, https://doi.org/10.33225/jbse/19.18.681.

147. F. C. D. Broietti, P. Dos Santos Nora, and S. L. R. Costa, Dimensions of science learning: A study on PISA test questions involving chemistry content, *Acta Sci.* **21** (2019) 95, https://doi.org/10.17648/acta.scientiae.v21iss1id4947.

148. J. Azevedo and M. Marques, Climate literacy: A systematic review and model integration, *Int. J. Glob. Warm* **12** (2017) 414, https://doi.org/10.1504/IJGW.2017.084789.

149. D. C. Owens, and T. D. Sadler, Socio-scientific issues instruction for scientific literacy: 5E Framing to enhance teaching practice, *Sch. Sci. Math.* **124** (2024) 203, https://doi.org/10.1111/ssm.12626.

150. A. W. Ratnayake, and A. Ashok, Investigating Anti-Vaccination Stances on Social Media: an Assignment To Promote Science Literacy, *J. Microbiol. Biol. Educ.* **24** (2023) 22, https://doi.org/10.1128/jmbe.00171-22.

151. A. Romanova, S. Rubinelli, and N. Diviani, Improving health and scientific literacy in disadvantaged groups: A scoping review of interventions, *Patient Educ. Couns.* **122** (2024) 108168, https://doi.org/10.1016/j.pec.2024.108168.

152. F. R. Choudhry *et al.*, Health literacy studies conducted in australia: A scoping review, *Int. J. Environ. Res. Public Health.* **16** (2019) 1112, http://dx.doi.org/10.3390/ijerph16071112.

153. Y. Li and M. Guo, Scientific Literacy in Communicating Science and Socio-Scientific Issues: Prospects and Challenges, *Front. Psychol.* **12** (2021) 1, https://doi.org/10.3389/fpsyg.2021.758000.

154. A. W. Murni, Suryanti, and N. Suprapto, Use of bibliometric software to explore the relationship between scientific literacy and socio-scientific issues, *E3S Web Conf.* **450** (2023) 03009, https://doi.org/10.1051/e3sconf/202345003009.

155. G. Guerrero, and J. Sjöström, Critical scientific and environmental literacies: a systematic and critical review, *Stud. Sci. Educ.* **61** (2024) 41, http://dx.doi.org/10.1080/03057267.2024.2344988.

156. M. Norambuena-Meléndez, G. R. Guerrero, and C. González Weil, What is meant by scientific literacy in the curriculum? A comparative analysis between Bolivia and Chile. *Cult. Stud. Sci. Educ.* **18** (2023) 937, https://doi.org/10.1007/s11422-023-10190-3.

157. J. M. O'toole, K. McKoy, M. Freestone, and J. A. Osborn, Scientific Literacy': An Exercise in Model Building. *Educ. Sci.* **10** (2020) 204, https://doi.org/10.3390/educsci10080204.

158. C. T. K.-H. Stadtländer, Beyond a Textbook: a Captivating Popular Nonfiction Book on Virology for Enhancing Science Literacy, *J. Microbilogy Biol. Educ.* **24** (2022) e00020, https://doi.org/10.1128/jmbe.00020-23.