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Cognitive Science and Science Literacy in Physics Education: A Systematic and Bibliometric Mapping of the Research Landscape

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Abstract

Physics education faces challenges in optimizing the development of high-order thinking skills and science literacy, often being trapped in the transfer of concepts and rote memorization. The integration of cognitive science and science literacy offers a potential solution to address the educational challenges of the 21st century. This research aims to conduct a Systematic Literature Review (SLR) to map the current research landscape (2015-2025) that integrates both domains in physics education. The focus is on identifying dominant trends, utilized methodologies, examined cognitive and science literacy aspects, and formulating pedagogical recommendations. The SLR method adheres to PRISMA guidelines, utilizing article searches in the Scopus database and performing bibliometric analysis with VOSviewer. Key findings indicate an increased focus on computational literacy, the role of visualization in understanding abstract concepts, strategies for developing high-order thinking skills through scientific argumentation, the importance of metacognition and epistemic cognition, as well as the effectiveness of learning approaches such as contextual and cognitive conflict-based in facilitating conceptual change. The VOSviewer analysis visualizes research theme clusters, topic evolution, and collaboration networks, reinforcing qualitative findings. The conclusions of this SLR provide significant implications for physics education practices, emphasizing the need for instructional design based on cognitive principles to achieve comprehensive science literacy, and identifying directions for further research.

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INTRODUCTION

Physics education plays a crucial role in equipping students with a deep understanding of natural phenomena and honing evidence-based scientific thinking skills (Alfiah et al., 2024; Fadliya & Huda, 2024). Physics, as one of the pillars of science, not only aims to transfer a collection of conceptual knowledge and mathematical formulas (Chaliq & Toifur, 2024), but also serves as a strategic vehicle for the development of Higher-Order Thinking Skills (HOTS) and science literacy (Salsabila et al., 2025). However, field practices show that physics learning approaches often remain focused on memorization and procedural problem solving, so that students' potential to develop a deep conceptual understanding and critical thinking skills has not been optimally explored. Consequently, the main goal of science education to produce individuals who are scientifically literate and capable of

scientific reasoning in the face of the complexities of the modern world becomes difficult to achieve.

In the context of 21st-century education, science literacy is recognized as an essential competence that every individual must possess (Rohmaya, 2022). Science literacy includes the ability to understand scientific concepts and processes, evaluate the validity of data-based information, and apply scientific knowledge in everyday decision-making and active participation in socio-scientific issues. Studies Ipi et al. (2021) show that low science literacy can hinder students' ability to solve real-life problems (Ayu et al., 2023). This is in line with the results of international assessments such as PISA, which consistently highlight the importance of science literacy and often show achievements that need to be improved in various countries (Kurniawati, 2024).

In line with efforts to improve science literacy, cognitive science offers a strong theoretical foundation for designing more effective learning (Arisanti et al., 2024). As an interdisciplinary study that examines how humans perceive, learn, remember, and think, cognitive science provides insight into the workings of students' brains during the learning process (Fajriani et al., 2024). The application of cognitive principles in physics education is expected to increase engagement, understanding, and information retention. Research has shown that learning interventions based on cognitive principles, such as the use of cognitive conflict strategies to address misconceptions (Yohanes & Dian, 2025) or the use of interactive multimedia designed in accordance with cognitive load theory and multimedia learning can have a positive impact on physics learning outcomes. Cognitive load theory, for example, emphasizes the importance of managing the amount of information processed by working memory so that it is not excessive, making learning more efficient (Rahmawati et al., 2024). Likewise, the role of working memory in physics problem-solving is crucial, where instructional strategies need to be designed to support students with various working memory capacities.

Furthermore, collaboration between cognitive science and physics education opens opportunities for curriculum development that not only focuses on content delivery (what is taught) but also explicitly trains how students learn and process information (cognitive processes) and what they are learning for (science literacy for applications in life) (Fitria & Indra, 2021). This reflects a paradigm shift from a simple knowledge transmission model to a more constructivist and functional approach (Aziz et al., 2023). Research has explored how certain learning models, such as Science-Technology-Society (STS) or contextual learning, can improve science literacy by paying attention to cognitive aspects such as learning styles or by linking subject matter to students' real-life experiences (Noviani, Farikah, et al., 2024). Other studies have also highlighted the importance of developing higher cognitive aspects such as metacognition (awareness and regulation of one's own thinking processes) and epistemic cognition (beliefs about the nature of knowledge and ways of knowing) as important components in deep physics learning and the development of understanding of the Nature of Science (NoS) (Wayudi & Santoso, 2020).

The relationship between cognitive science and science literacy is fundamentally synergistic. Cognitive science provides the theoretical framework for understanding how students perceive, learn, remember, and think, while science literacy defines the essential competencies that result from effective learning, such as understanding scientific concepts, evaluating data-based information, and applying knowledge to everyday decision-making. This connection is crucial because achieving the goals of science literacy is not merely about content acquisition; it depends directly on underlying cognitive processes. This integration is vital for several reasons. First, a student's ability to engage in complex literacy skills, such as scientific argumentation, is directly influenced by cognitive factors, including working memory capacity. Second, effective instructional strategies for

promoting conceptual change and overcoming misconceptions —a critical step toward genuine literacy —are built upon cognitive principles, such as cognitive conflict. Third, theories such as cognitive load theory are essential for designing instruction that prevents mental overload and fosters deep, efficient learning rather than superficial memorization. Higher cognitive aspects, such as metacognition, are also key, as they enable students to regulate their thinking processes, which is foundational for developing a sophisticated understanding of science.

Therefore, a holistic approach that connects cognitive principles with literacy outcomes is necessary. It moves education from a simple knowledge transmission model to a constructivist and functional one, ensuring that instructional design is not only content-rich but also cognitively informed. Although the importance of this link is clear, a comprehensive synthesis that systematically maps the connections between specific cognitive variables and the multifaceted dimensions of science literacy is still limited. There remains a need to review the landscape holistically to identify trends and formulate evidence-based pedagogical recommendations for achieving the ultimate goal of science education, which is producing scientifically literate individuals.

The novelty of this research lies in the effort to conduct an in-depth systematic literature review (SLR) with the support of bibliometric analysis using VOSviewer. The focus is on recent literature (at least from 2015) to capture the latest developments. This SLR aims to provide a more complete picture of how current physics education research bridges cognitive science and science literacy, as well as to formulate more informed and evidence-based pedagogical recommendations. Based on this background, this research aims to conduct a systematic literature review to identify, evaluate, and synthesize relevant research on the integration of cognitive science and science literacy in physics learning.

METHODS

This study employs a systematic literature review (SLR) methodology, adhering to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. The PRISMA protocol ensures a transparent and replicable process for article selection, which involves distinct stages of identification, screening, eligibility assessment, and final inclusion of studies. This structured approach is designed to systematically gather, critically appraise, and synthesize all relevant research, thereby ensuring the quality, reliability, and validity of the review's findings. The literature search was intentionally focused on a single primary scientific database, Scopus. This decision was made to ensure data consistency and integrity, which is particularly crucial for the bibliometric analysis component of this study conducted with VOSviewer. Using a single, comprehensive database prevents issues with duplicate records and metadata inconsistencies that can arise from merging data from multiple sources, thus ensuring a more accurate and reliable mapping of the research landscape. Scopus was specifically chosen for its extensive coverage of high-quality, peer-reviewed international publications across the relevant disciplines of education, physics, cognitive science, and literacy studies, making it a robust source for achieving a comprehensive and objective representation of the field. The search strategy was crafted to capture the most relevant articles using the Boolean search string: ('cognitive' AND 'science' AND 'literacy' AND 'physics') within the article title, abstract, and keywords columns. To ensure the findings reflect the current state of research, the search was restricted to articles published between January 1, 2015, and April 30, 2025.The PRISMA SLR flow is shown in Figure 1.

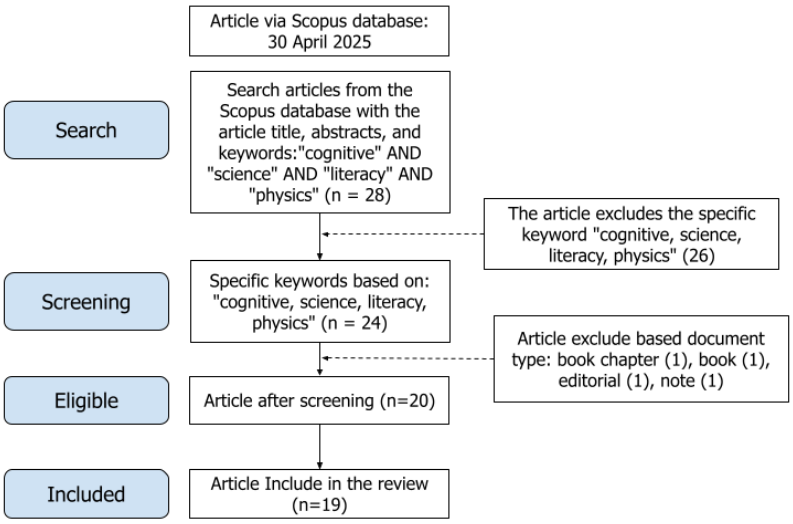

Figure 1 SLR flow PRISMA

The article selection process for this systematic literature review followed the PRISMA framework, beginning with an initial search of the Scopus database for publications from 2015 to April 30, 2025. In the identification stage, the search string ('cognitive' AND 'science' AND 'literacy' AND 'physics') was applied to the title, abstract, and keywords, yielding an initial pool of 28 articles. The selection of the keywords 'cognitive,' 'science,' 'literacy,' and 'physics' was methodologically deliberate. This specific combination was designed to precisely target the core constructs of the research question, ensuring that the initial search results were highly focused on the intersection of cognitive principles and science literacy within the specific domain of physics education. Following the initial screening of titles and abstracts, the remaining 24 articles were advanced to the eligibility assessment stage. During this phase, the primary exclusion criterion was the document type to ensure the review was based on peer-reviewed journal articles. Consequently, four publications were excluded because they were identified as a book chapter, a book, an editorial, and a note, respectively. This step yielded 20 articles deemed eligible for full-text review. The final and most critical stage involved a thorough full-text analysis of these 20 articles to verify their direct relevance. Each article was read in its entirety to confirm that its research objectives, methodology, and findings aligned with the specific scope of this review. One article was excluded at this stage because, upon detailed examination, its content did not sufficiently address the nuanced integration of cognitive science and science literacy that was the central focus of this study. This rigorous verification process resulted in the final inclusion of 19 articles for the comprehensive analysis.

RESULTS AND DISCUSSION

Results of Systematic Literature Review (SLR)

Following a rigorous PRISMA selection process, 19 articles were included in the final review for in-depth analysis. The main characteristics of the key reviewed articles are presented in Table 1. An analysis of the publications shows a sustained and increasing research interest in the integration of cognitive science and science literacy within physics education, particularly from 2020 onwards. This trend indicates an evolution in the field, likely driven by technological advancements and a deeper understanding of cognitive processes. The main characteristics of the reviewed articles are presented in Table 1.

Table 1 State of the art

No	Author	Title	Main Research Objective	Focus on Cognitive Aspects	Focus of Science Literacy Aspects	Findings
1.	Ramaila & Reddy, 2020	South African science students' perceptions of physics as a fundamental discipline	To identify the perceptions of first-year science students toward physics as a fundamental discipline, including cognitive and affective aspects.	Cognitive and affective factors in physics learning (e.g., anxiety related to experiments, mathematics, and problem-solving).	Scientific literacy (development of scientific skills).	Acquisition of physics skills is highly dependent on the blend of cognitive and affective factors that are an integral part of the learning process.
2.	Poernomo et al., 2021	Development of HOTS-Based Instruments with a Science Literacy Approach to Measure Students' High-Level Thinking Ability	To develop and test the validity of open multiple-choice instruments based on HOTS with a science literacy approach to measure high-level thinking abilities.	Higher-Order Thinking Skills (HOTS) (analyzing, evaluating, creating).	Science literacy (approach in instrument development).	The developed HOTS instrument is valid and reliable. The majority of students' high-level thinking abilities fall into the less category.
3	Kampa et al., 2021	The relation between science achievement and general cognitive abilities in large-scale assessments	To analyze the relationship between standards-oriented and literacy-based science assessments with general cognitive abilities (GCA).	General cognitive abilities (GCA).	Science literacy (PISA model), standards-oriented science achievement (biology, chemistry, physics).	Science assessments (literacy & standards) share variance with GCA but also have specific variance. Factors of science literacy and standards-oriented factors are identified.
4	Bancong et al., 2023	Nature of Science: A Comparative Analysis of the High School Physics Textbooks in Indonesia and Korea	To comparatively analyze the representation of NoS in high school physics textbooks in Indonesia and Korea.	Cognitive-epistemic aspects of NoS.	Nature of Science (NoS), socio-institutional aspects of NoS.	Korean physics textbooks contain more NoS elements than Indonesian textbooks. NoS representation is more present in the main text in both countries.

No	Author	Title	Main Research Objective	Focus on Cognitive Aspects	Focus of Science Literacy Aspects	Findings
5	Emilya & Mufit, 2023	Validity of E-module Based on Cognitive Conflict Integrated Augmented Reality for Improving Students Physics Science Literacy	To develop and test the validity of an e-module based on cognitive conflict integrated Augmented Reality (AR) to improve students' physics science literacy.	Cognitive conflict, learning with AR.	Physics science literacy.	The developed e-module is valid and has the potential to improve students' physics science literacy through cognitive conflict facilitated by AR.
6	Sartika et al., 2023	The scientific literacy profile of senior high school student based on science competence dimension	To analyze the scientific literacy profile of senior high school students based on PISA science competency dimensions.	-	Science competencies (explaining phenomena, evaluating & designing investigations, interpreting data & evidence).	Students' science literacy in all three indicators of science competence (explaining phenomena, evaluation & design of investigations, data interpretation) is very low.
7	Wang & Wei, 2024	Analysis of visual-based physics questions of the senior high school entrance examination in China	To examine the level of visual cognition in visual-based physics questions in the high school entrance examination in China using the Visualization Blooming Tool.	Visual cognition (applying, analyzing, evaluating, creating), interpretation vs. construction of visual representations.	Scientific visual literacy.	The exam emphasizes interpretation over visual construction, and application/analysis levels more than evaluation/creation.
8	Ulu & Yerdelen-Damar, 2024	Metacognition and epistemic cognition in physics are related to physics identity through the mediation of physics self-efficacy	To investigate the relationship between metacognition, epistemic cognition, physics self-efficacy, and physics identity in undergraduate students.	Metacognition, epistemic cognition, self-efficacy (as cognitive-affective constructs).	-	Metacognition and epistemic cognition are related to physics identity through the mediation of physics self-efficacy.

No	Author	Title	Main Research Objective	Focus on Cognitive Aspects	Focus of Science Literacy Aspects	Findings
9	Triananda et al., 2025	Argumentation Skills in Physics Implementation: A Systematic Literature Review	To conduct an SLR to identify trends, methods, and the impact of implementing argumentation skills in physics learning.	Cognitive processes in argumentation.	Scientific argumentation skills as part of science literacy.	The implementation of argumentation in physics shows a positive impact on conceptual understanding and critical thinking skills, with various learning models used.
10	Xie et al., 2025	Representations of Nature of Science in Chinese Physics Curriculum Standards over the Past Two Decades	To investigate how the Nature of Science (NoS) is represented in Chinese physics curriculum standards over two decades using FRA and ENA frameworks.	Cognitive-epistemic NoS system.	Nature of Science (NoS) as part of science literacy, socio-institutional NoS system.	Socio-institutional NoS system is less represented, although there is an increasing trend. Connections between NoS categories increase, more in the cognitive-epistemic system.
11	Odden & Zwickl, 2025	How physics students build computational literacy by creating computational literature	To analyze how physics students build computational literacy through reflective practices and the creation of "computational literature."	Discipline-based learning through computation, cognitive aspects of computational literacy.	Computational literacy (material, cognitive, social), epistemic and communicative aspects of computational literature.	Students utilize and deepen computational literacy by engaging in the creation of computational literature, adopting the practices of computational scientists.

An analysis of the distribution of articles published between 2015 until 2025, as detailed in Table 1, reveals a sustained and increasing research interest in the integration of cognitive science and science literacy within physics education. While foundational work was established prior to this period, this review intentionally focuses on publications from 2020 onwards to capture the most recent trends. This period appears to mark an accelerated evolution in the field, likely driven by advances in educational technology and a deeper understanding of cognitive processes. To empirically map this development, this study utilizes the overlay visualization feature of VOSviewer. This bibliometric technique provides a visual trajectory of the field's focus by analyzing temporal patterns in keyword usage. In the overlay map, keywords are color-coded based on their average year of publication; older, more established topics typically appear in blue, while newer, emerging research fronts appear in shades of green and yellow. Therefore, a shift in keyword coloration directly reflects a corresponding shift in thematic priorities or methodological innovation over time. For instance, the emergence of a cluster of yellow-colored keywords linked to specific pedagogical strategies would indicate a recent move towards applied classroom research, whereas a network of blue-colored foundational terms represents the

established conceptual core of the field. This temporal analysis allows for a data-driven interpretation of how the research conversation has evolved, highlighting the development trajectory from foundational concepts to contemporary applications.
The Overlay Visualization is shown in Figure 2.

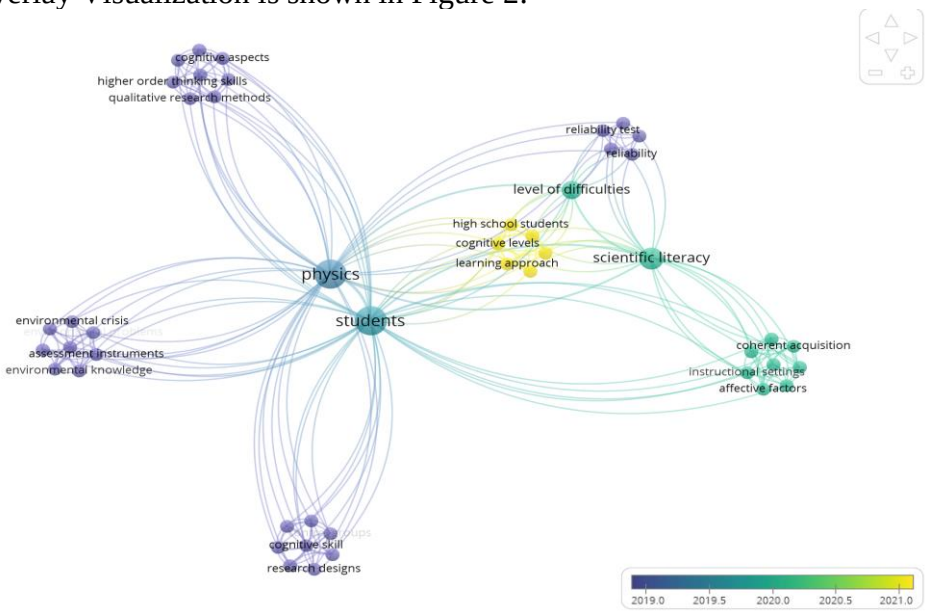

Figure 2 Overlay visualization

The VOSviewer overlay visualization maps the network of research keywords, where the color of each keyword indicates the trend of its appearance in scientific publications between 2019 and 2021. More yellow or light green colors signify newer topics (around 2020-2021), while blue or purple colors indicate older topics (around 2020-2021). Central keywords such as "students" and "physics" show the main focus of the research, with many linkages to various other concepts. Several main clusters are identified, such as the "physics" cluster connected to cognitive aspects and qualitative research methods that tend to appear earlier. The "scientific literacy" cluster shows development with supporting topics such as "high school students" and "learning approach," which are colored more yellow, indicating newer trends. On the other hand, topics related to the environmental crisis and assessment instruments appear as earlier research focuses. This visualization effectively illustrates the evolution and relationships between research topics in the analyzed time period.

In Figure 3, several high-density areas are visible. The most prominent and brightest (yellow) area is centered around the keywords "students" and "physics," indicating that this is the core of the densest research cluster. Other high-density areas are seen around "scientific literacy" which also includes "level of difficulties," "high school students," "cognitive levels," and "learning approach." In addition, there is also a significant concentration around "cognitive aspects," "higher order thinking skills," and "qualitative research methods," as well as smaller but still visible areas around "environmental crisis," "assessment instruments," and "environmental knowledge," and also "cognitive skill" along with "research designs." This indicates that these topics are the main focus and most discussed in the analyzed literature.

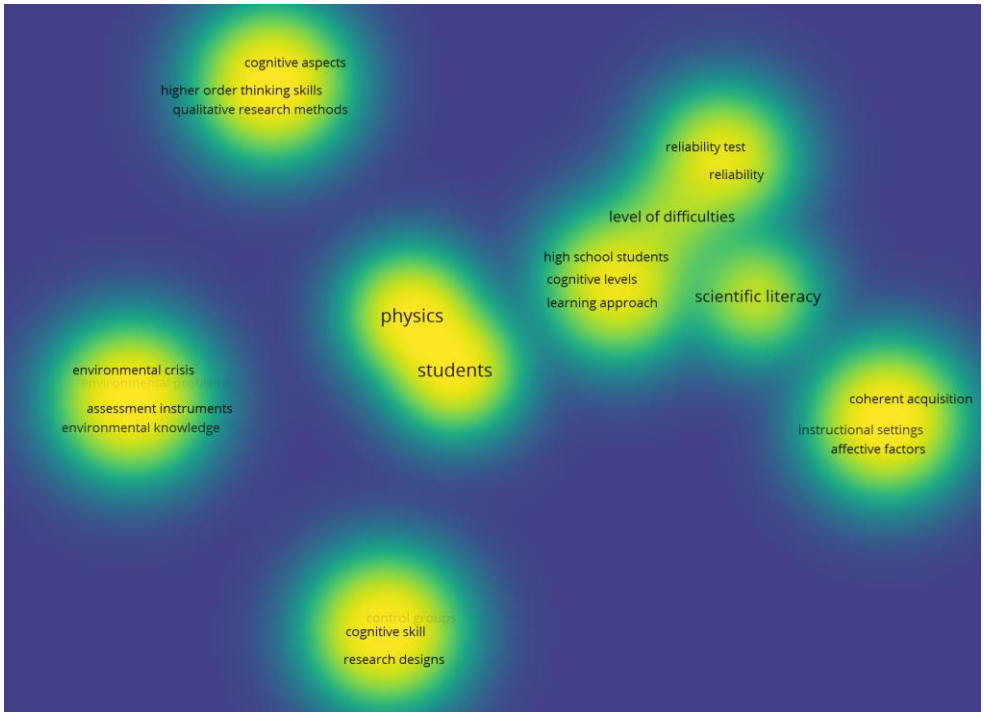

Figure 3 Density visualization

Network visualization with co-occurrence is shown in Figure 4.

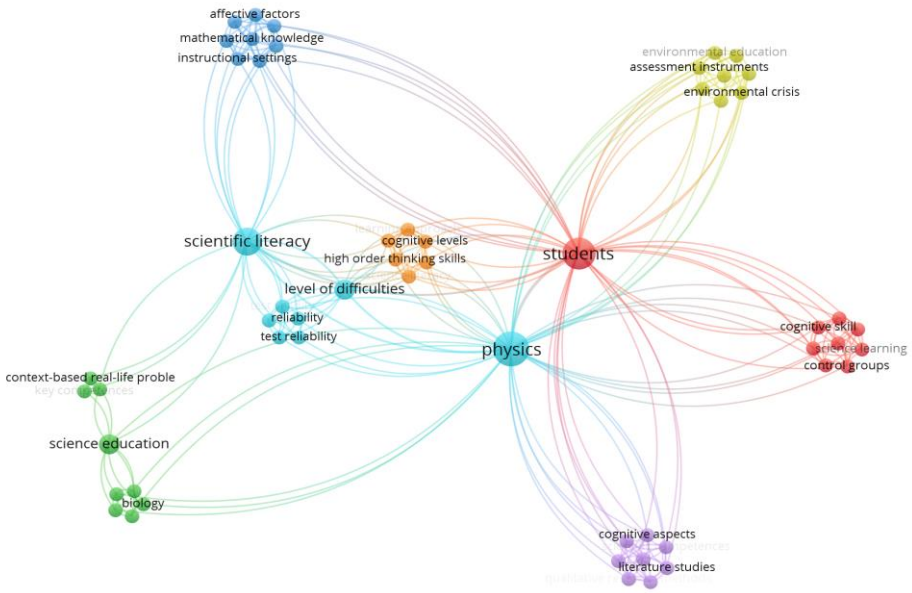

Figure 4 Network visualization by co-occurrence

The network visualization in Figure 4, based on keyword co-occurrence, enhances methodological transparency by mapping the structural relationships between dominant research themes. The analysis of these clusters reveals several key findings with significant implications for advancing the integration of cognitive science and scientific literacy. A

prominent cluster (cyan) centers on 'scientific literacy' and 'physics,' which is strongly connected to the central 'students' cluster (red) that also links to 'cognitive skill'. This structure suggests that the student experience is the primary nexus where these fields intersect. Furthermore, smaller but distinct clusters for 'cognitive aspects' (purple) and 'higher order thinking skills' (orange) appear to function as critical bridging themes. This implies that research is actively using specific cognitive functions as the primary mechanisms to connect physics instruction with the broader goal of achieving science literacy. The analysis also identifies a significant cluster focused on 'environmental education,' linked to 'environmental crisis' and 'assessment instruments' (yellow). The pedagogical relevance of this theme can be further explored as a powerful context for integrating cognitive processes into physics education. Environmental topics often serve as complex, 'context-based real-life problems' that require the application of physics principles (e.g., energy, climate modelling) and the activation of higher-order cognitive skills such as systems thinking, critical data evaluation, and evidence-based decision-making. Exploring this link more deeply could clarify how to use socio-scientific issues to make abstract physics concepts tangible while simultaneously cultivating the cognitive competencies foundational to science literacy. Collectively, the visualization illustrates that while a holistic integration is the goal, current research often investigates the components in distinct but interconnected clusters. It highlights that specific cognitive skills and compelling real-world contexts, such as environmental education, are the primary avenues being explored to bridge the gap between physics instruction and the development of a functionally literate citizents.

The findings from this SLR have several important theoretical implications. Firstly, this research reinforces the view that effective physics learning cannot be separated from a deep understanding of how students process information and construct knowledge. The integration of cognitive science provides an essential framework for explaining why and how various learning strategies succeed or fail. Secondly, this SLR highlights the multifaceted nature of science literacy, which goes beyond mere content mastery and includes competencies, understanding of NoS, and application skills in real contexts. This encourages the need for more comprehensive theoretical models that can explain the dynamic interactions between various cognitive processes and various dimensions of science literacy. Thirdly, the finding regarding the importance of computational literacy and visualization suggests that traditional learning theories may need to be expanded to accommodate the mediating role of technology and multimodal representations in the construction of physics knowledge, leading to the need for the development of theoretical frameworks that explicitly integrate "digital cognition" or "visual-spatial cognition" in the context of physics learning.

CONCLUSION

This systematic literature review has mapped the current research landscape (2015-2025) regarding the integration of cognitive science and science literacy in physics education. The key findings indicate a shift in focus in physics education, from merely transferring content to a deep understanding of how students learn (cognitive aspects) and for what purpose they are learning (applications of science literacy in life). The dominant research trends identified include the increased role of digital technology and computational literacy, the application of cognitive science principles (such as cognitive load theory, working memory, and multimedia learning) in instructional design, the focus on developing higher-order thinking skills (HOTS) and scientific argumentation, the recognition of the importance of metacognition and epistemic cognition (including understanding the nature

of science), the utilization of visualization and multimodal representations, and the effectiveness of contextual and local culture-based learning approaches.

The main contribution of this SLR is a comprehensive synthesis that provides a holistic view of current trends and translates them into evidence-based pedagogical recommendations. These identified trends have direct implications for practical improvements in classroom instruction. For instance, the focus on computational literacy and visualization informs the design of technology-enhanced learning environments that help students grasp abstract concepts. Similarly, the emphasis on higher-order thinking skills and scientific argumentation encourages a shift towards inquiry-based activities where students construct and defend scientific claims. By applying principles like cognitive load theory, educators can create more effective instructional materials, while contextual learning approaches can root physics in real-world problems, thereby increasing student engagement and motivation. Despite these contributions, the study has several limitations that affect the generalizability of its findings. First, its reliance solely on the Scopus database, while ensuring a high standard of peer-reviewed quality, may introduce selection bias. This focus likely excludes valuable research published in other major databases, regional journals, or non-English languages, potentially skewing the results toward trends prevalent in international Anglophone scholarship. Second, like all literature reviews, this study is susceptible to publication bias, where studies reporting positive or significant findings are more likely to be published, possibly leading to an overestimation of the effectiveness of certain interventions. These factors mean that while the identified trends are robust within the scope of the selected literature, they may not fully represent the entire global landscape of physics education research.

For future research, it is suggested that there be further exploration of the long-term impact of various learning interventions on science literacy and knowledge retention. More in-depth studies on the interaction between affective factors and cognitive processes in physics learning are also needed. The development and validation of assessment instruments that can comprehensively measure the integration of cognitive aspects and science literacy simultaneously is another important area. The suggestion for research that tests the effectiveness of interventions that integrate various cognitive principles holistically, not just one or two isolated aspects, implicitly acknowledges that much current research may still be partial.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest regarding the research, authorship, and/or publication of this article.

AUTHOR CONTRIBUTIONS STATEMENT

All authors contributed to the preparation and publication of this research.

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