

Inquiry-Based Learning for Sustainable Physics Education: A Systematic Literature Review of Senior High School Learning Outcomes

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Abstrak: This study aimed to synthesize empirical evidence on the effects of inquiry-based learning on senior high school physics learning outcomes through a Systematic Literature Review (SLR). The review followed the PRISMA 2020 guidelines. Relevant studies were identified from Google Scholar, Scopus, Springer, and ERIC using predefined search terms. Articles were selected through identification, screening, eligibility assessment, and quality appraisal based on explicit inclusion criteria. Twenty peer-reviewed studies published between 2020 and 2025 were included in the final synthesis. The findings indicate that inquiry-based learning consistently improves students' critical thinking, conceptual understanding, science process skills, learning motivation, and engagement. However, its impact on cognitive learning outcomes varies depending on teacher guidance, instructional quality, students' readiness for inquiry, learning modalities, and the integration of digital technologies such as PhET simulations and virtual laboratories. The review also identifies guided inquiry, teacher readiness, learning resources, and process-based assessment as key moderating factors influencing implementation effectiveness. Overall, inquiry-based learning is an effective instructional approach for senior high school physics when supported by appropriate instructional design, adequate learning resources, and authentic assessment practices. These findings provide evidence-based recommendations for educators, curriculum developers, and future research on inquiry-based physics education.

Keywords: Critical thinking; Inquiry-based learning; Learning outcomes; Physics education; Senior high school; Systematic literature review

Introduction

Physics learning is expected not only to develop conceptual mastery but also to strengthen scientific thinking skills such as formulating questions, designing and conducting experiments, analyzing data, and providing evidence-based explanations (Wiratman et al., 2023; Akkus et al., 2007; Pascaeka et al., 2023). The use of guided inquiry-based learning modules provides structured opportunities for students to perform scientific investigations and effectively develop science process skills (Nurfausiah et al., 2025; Yusra et al., 2021;

Purtadi et al., 2023; Widyaningsih et al., 2019). The development of guided inquiry-based electronic modules further supports this process by providing structured learning activities, investigation procedures, and interactive learning resources that facilitate students' independent scientific inquiry (Subari et al., 2022; Lestari et al., 2023; Putri & Wulandari, 2025). Previous studies have also demonstrated that guided inquiry learning plays an important role in improving students' science process skills while simultaneously enhancing their cognitive abilities through structured scientific investigation (Amiruddin et al., 2025; Yusuf et al., 2023; Hasan, 2024). Recent studies also demonstrate

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that integrating guided inquiry with blended learning environments provides students with greater opportunities to conduct investigations independently and collaboratively, resulting in significant improvements in science process skills (Bakti et al., 2023). However, recent studies continue to indicate that students' science process skills remain relatively low, particularly in physics learning environments where teacher-centered instruction still predominates (Irsyad et al., 2024; Alarcon et al., 2023). Students often perceive physics as a body of facts to be memorized rather than a process of scientific inquiry and reasoning. In contrast, when students are given opportunities to actively design experiments, collect data, analyze results, and engage in reflective discussions as in inquiry-based learning, learning outcomes show improvements in conceptual understanding, critical thinking skills, and problem-solving abilities (Tan et al., 2020; Deslauriers et al., 2011; Ertikanto et al., 2023). Previous studies have also reported that guided inquiry promotes students' creative thinking by encouraging self-directed learning, reflection, and active participation throughout the scientific inquiry process (Algiani et al., 2023). The inquiry learning model positions students as active constructors of knowledge through the integration of observation, investigation, reflection, and scientific communication activities. This model has been proven effective in improving science process skills, motivation, and higher-order thinking. A number of reviews and empirical studies support that inquiry learning is able to strengthen investigative abilities and conceptual understanding when implemented appropriately (Alarcon et al., 2023). Nevertheless, empirical evidence regarding the magnitude and consistency of the effects of inquiry learning on academic outcomes, particularly cognitive achievement, shows variation. Several meta-analyses and systematic reviews report improvements in critical thinking skills, science process skills, and conceptual understanding, although the magnitude of the effect is not always strong and depends on research design, duration of intervention, level of teacher guidance, laboratory quality, and instructional support. Thus, the effectiveness of inquiry learning appears to be contextual and influenced by various operational factors (Antonio & Prudente, 2024). Inquiry learning provides opportunities for students to formulate problems, investigate evidence, evaluate information, and construct scientific explanations, thereby improving inquiry skills (Dewi & Prodjosantoso, 2024).

Although numerous studies have demonstrated that inquiry-based learning improves conceptual understanding and higher-order thinking skills in physics education, its influence on cognitive learning outcomes remains inconsistent across senior high school contexts (Lestari, 2026). Variations have been associated

with differences in inquiry level, teacher guidance, instructional quality, and classroom implementation (Syahgiah et al., 2023; Novitra et al., 2021; Gunawan et al., 2020). The implementation of inquiry-based learning faces several significant challenges, including limited time for planning and execution, the readiness of teachers to guide students through exploratory processes, and the complexity involved in developing instructional materials (Jannah et al., 2025; Shivolo & Mokiwa, 2024; Minner et al., 2010). Many teachers report that the lack of resources—whether instructional materials, facilities, or technical support—can hinder the optimal implementation of inquiry-based learning and represents the greatest challenge that teachers will face (Muthmainah et al., 2024; Nicol, 2021). Based on this background, this article presents a Systematic Literature Review that aims to examine and summarize empirical evidence regarding the influence of the inquiry learning model on physics learning outcomes; evaluate the methodological quality of the related studies; and identify the moderating factors (levels of inquiry, duration, classroom or laboratory context, and teacher support) that affect the effectiveness of inquiry-based learning.

The results of this review are intended to provide an evidence-based foundation for educators, curriculum developers, and researchers so that the implementation of inquiry-based learning in physics education can be optimized and directed toward practices that produce meaningful impact (Strat et al., 2024; Desnita et al., 2021; Nur'aini et al., 2023). Despite the growing body of research on inquiry-based learning, existing evidence remains fragmented. Most previous studies have focused on individual classroom interventions, specific physics topics, or broad science education without providing a comprehensive synthesis of empirical evidence specifically related to senior high school physics learning. Furthermore, previous reviews have primarily emphasized overall effectiveness while paying limited attention to the learning outcome indicators most influenced by inquiry-based learning and the contextual factors that moderate its effectiveness, such as the level of teacher guidance, learning modalities, instructional quality, and the integration of digital technologies. Therefore, this study offers a novel contribution by systematically synthesizing recent empirical studies (2020–2025) focusing exclusively on senior high school physics education. In addition to evaluating the effectiveness of inquiry-based learning, this review identifies the dominant learning outcomes and analyzes the moderating variables that determine successful implementation, thereby providing a more comprehensive evidence base for instructional practice and future research.

This research is important because physics education requires instructional approaches that develop not only conceptual understanding but also critical thinking, scientific process skills, and problem-solving abilities. Although inquiry-based learning has been widely recommended, teachers and curriculum developers still lack synthesized evidence regarding the conditions under which this approach is most effective. By integrating findings from recent high-quality studies, this review provides evidence-based recommendations for teachers, curriculum developers, and policymakers in designing inquiry-oriented physics instruction that is pedagogically effective and adaptable to diverse classroom contexts. Based on these issues, this Systematic Literature Review was designed to answer the following questions:

- RQ1: How does inquiry-based learning influence learning outcomes in senior high school physics education?
- RQ2: Which learning outcome indicators (conceptual understanding, critical thinking, science process skills, cognitive achievement, motivation, and collaboration) are most consistently improved through inquiry-based learning in senior high school physics?
- RQ3: What moderating factors—including inquiry level, teacher guidance, learning modality, instructional resources, and assessment strategies—affect the effectiveness of inquiry-based learning in senior high school physics education?

Method

The conduct of this systematic review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2015). The systematic review process comprises the following stages: collection, screening, eligibility assessment, and inclusion (Myung, 2024; Philips & Barker, 2021). A systematic review is a type of evidence synthesis in which authors develop explicit eligibility criteria (Brignardello-Petersen et al., 2025).

Identification

The Google Scholar, Springer, Scopus, and ERIC databases were used in the identification process to search for relevant articles. The search in this study used keywords related to inquiry learning, physics learning, and learning strategies. After the initial search process, the results obtained were 1000 articles from Google Scholar, 350 articles from Springer, 100 articles from Scopus, and 150 articles from ERIC. However, 600 articles were removed due to duplication, leaving 1000 articles identified. To ensure that only studies that meet scientific community standards were included, the researchers focused exclusively on peer-reviewed and

indexed journal articles, and excluded non-indexed literature.

Screening

Considering the differences in databases, relevance, and feasibility of the published articles, the abstract of each article was first reviewed individually. The second stage continued with a screening process based on a set of criteria presented in Table 1. This study covers the publication period between 2020 and 2025 and focuses on inquiry in physics. A total of 20 articles did not meet these criteria, while 160 articles were accepted and passed to the next screening stage. In the next stage, the articles were reviewed based on the senior high school education level, and 18 articles did not meet the criteria. Thus, 141 articles met the established criteria.

Table 1. Screening process

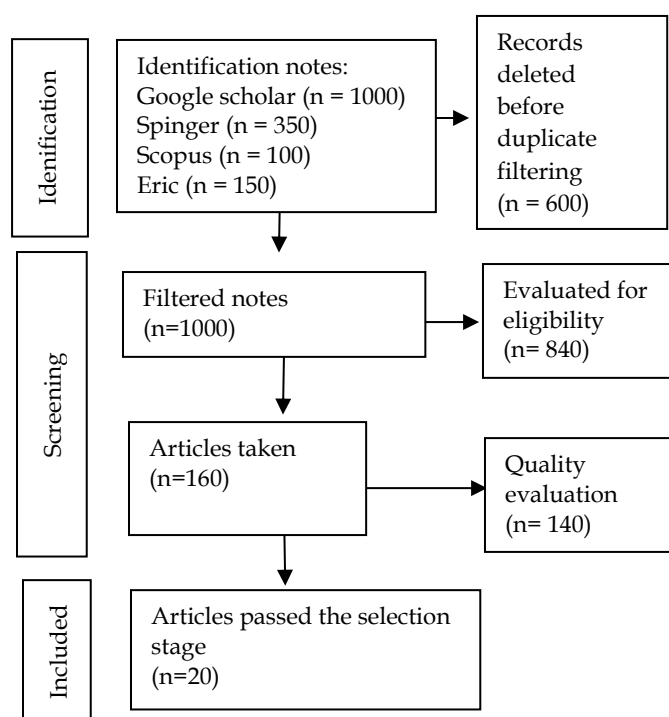
Criteria	Inclusion	Exclusion
Publication timeline	Years 2020–2025	2019 and earlier
Document type	Article	Conference proceedings; dissertations; theses; master's thesis; books; etc.
Nature of research	Concentrating on inquiry learning issues in high school	Not focused on learning problems supported by inquiry learning
Reputable articles	Published in reputable scientific journals and through a peer-review process; and indexed in credible academic databases.	Non-indexed literature and publications that have not undergone peer review such as proceedings; theses; dissertations; research reports; and books are not included to maintain the academic validity and scientific authority of the study results.

Eligibility and Inclusion in Research

Since the end of the first screening cycle, 18 articles were excluded, and 141 articles were accepted. The next step was the second-level screening, which involved assessing the quality of the articles. The criteria used as the basis for screening are presented in Table 2. It is important to determine whether the research objectives and goals have been clearly defined and subsequently implemented. Another substantial question concerns how the research was conducted. In analyzing each article, the methodology used must be taken into consideration, including methods of analysis, data collection, data presentation, qualitative and quantitative approaches, as well as how the research data are communicated and presented. It is also important to consider the target population covered by the study.

Table 2. Criteria for assessing the quality of articles

Criteria	Description
Study context	Does the article communicate the planning, implementation, and development aspects of the study effectively?
Goals and objectives	Are the aims and objectives of the research clearly articulated in the article?
Methodology	Does the article comprehensively explain the research methodology; including the framework, data collection and data analysis?
Data	Are there supporting materials such as schedules, interview transcripts; or focus group discussions; and observation feedback? Is the information presented clearly and analytically?
The research results have been validated	Are the research results validated? Did the researchers use peer review; feedback; or other mechanisms to confirm the analysis?
Sample	Does the article offer an adequate sample size for the research conducted?

**Figure 1.** Steps to a Systematic Literature Review (SLR)

The screening and selection process was divided into three main stages according to the PRISMA flow diagram (Page et al., 2021). In the first stage, only the titles and abstracts of the articles were considered. Studies were included if their abstracts aligned with the discussion of inquiry learning, physics learning, and learning strategies. Studies that used methods other than surveys, were not published in peer-reviewed academic

journals, belonged to fields other than educational research, or did not consider educational level, were excluded. After the first stage, 140 documents were excluded. From this process, a number of eligible articles were obtained for further analysis in the final synthesis stage. Overall, this process ensured that only studies meeting methodological quality standards and substantive relevance were included in the final analysis, thereby enhancing the reliability, validity, and credibility of the review findings while minimizing the risk of bias in the synthesis of evidence.

The subsequent screening step included examining the availability of the documents. Studies were excluded if they could not be accessed in full online, even after attempting to contact the authors. After multiple rounds of screening, a total of 20 studies were included.

Data Extraction and Content Analysis

After conducting a systematic review of the literature and identifying 20 relevant studies published between 2020 and 2025, the analysis of these studies was carried out using content analysis, with a focus on the substance and the way in which the research questions were addressed. In addition, each article was analyzed based on the measured learning outcome variables, the research methods used, and the effectiveness of the implementation of the inquiry learning model. The data extraction process included identifying the research objectives, sample characteristics, instructional design, evaluation instruments, and the key findings of each study. This step enabled the researchers to gain a deeper understanding of the contributions and variations in the results reported by each study. The findings from the selected studies were synthesized to provide comprehensive evidence regarding the effectiveness of inquiry-based learning in senior high school physics education, particularly in enhancing students' conceptual understanding, critical thinking, science process skills, learning motivation, and overall learning outcomes.

Results and Discussion

This study aims to map relevant publications according to the predetermined inclusion criteria. The selection process resulted in a total of 20 articles that were thoroughly analyzed. The analysis was conducted without subjective interpretive intervention, instead focusing on the distribution of data based on the year of publication.

Table 3. Summary of included articles

Year	Researchers	Findings
2020	Wale & Bishaw	Learning through inquiry-based learning can strengthen students' analytical, evaluation, and creativity skills.
2021	Mamun et al.	Guided inquiry improves the quality of interaction with content, supports deep learning, and encourages active student engagement.
2021	Sari et al.	Inquiry Mind Map is an effective inquiry-based learning strategy to improve students' critical thinking skills and learning motivation.
2020	Destino & Cunningham	Inquiry-based practicums can improve students' conceptual understanding and critical thinking skills.
2020	Palupi et al.	Guided Inquiry Learning (GIL) is more effective in improving explanatory writing skills.
2021	Novitra et al.	The inquiry learning model effectively improves 21st century skills (critical, collaborative, creative).
2020	Liu et al.	Inquiry-based mobile learning supports active engagement, collaboration, and conceptual understanding.
2021	Chen	The inquiry approach effectively improves students' work skills and collaborative mindset.
2020	Lin et al.	Inquiry programs enhance science knowledge and problem-solving skills.
2020	Prasetyo et al.	Implementation of the inquiry model effectively improves critical thinking skills.
2020	Messiou et al.	Inclusive inquiry increases student participation and inclusive awareness in schools.
2020	Gómez & Suárez	Inquiry and a positive school climate enhance science achievement and critical thinking.
2020	Kang	Effective inquiry learning combined with high instructional quality improves students' scientific literacy.
2020	Gunawan et al.	The inquiry learning model effectively improves critical thinking and problem-solving skills.
2021	Kalogeropoulos et al.	Schools that implement an inquiry approach are successful in maintaining student engagement and learning.
2020	Forbes et al.	Implementation of inquiry related to improving students' science achievement and critical thinking skills.
2021	Jong et al.	Teachers integrate digital inquiry to support student exploration, reflection, and collaboration.
2022	Tan et al.	Inquiry supports concepts and reasoning.
2022	Wang et al.	The combination of structured and open inquiry while taking into account students' epistemological beliefs significantly improves science and mathematics literacy.
2023	Alarcon et al.	Improve critical thinking skills, conceptual understanding, and student engagement.

Table 4. Distribution of articles by year of publication

Year	Number of Articles
2020	11
2021	6
2022	2
2023	1

The data show that the highest number of publications occurred in 2020, totaling 11 articles, which represents 55% of all analyzed articles. In 2021, the number of publications decreased to 6 articles, equivalent to 30%. Meanwhile, in 2022 only 2 articles were published, accounting for 10%, and the smallest number of publications was found in 2023, with 1 article representing 5% of all analyzed studies. Overall, the publication trend experienced a gradual decline from 2020 to 2023. This distribution provides an objective overview of the dynamics of scientific publications within the researched field, without initially associating it with causal factors or conceptual interpretation. The increasing number of publications between 2023 and 2025 indicates growing research interest in inquiry-based learning within senior high school physics education. This trend is likely associated with the wider adoption of student-centered learning approaches,

digital technologies, and competency-based curricula that emphasize scientific inquiry.

The analysis of the 20 articles that successfully passed the selection process indicates that student learning outcomes were evaluated using several key indicators. The main findings based on each indicator are presented as follows.

Table 5. Learning outcome indicators

Learning Outcome Indicators	Number of Articles	Percentage (%)
Conceptual understanding	4	20
Science process skills	1	5
Critical thinking skills	9	45
Cognitive learning outcomes	3	15
Motivation and learning engagement	2	10
Collaboration skills	1	5

Based on the overall data, the learning outcome indicators most frequently reported to show improvement were critical thinking skills (45%) and conceptual understanding (20%). Meanwhile, the least frequently reported indicators were collaboration skills (5%) and science process skills (5%). The results of the analysis indicate that the success of inquiry-based learning is not solely determined by the inquiry model

itself, but also by a set of moderating variables that either strengthen or weaken the learning impact.

The consistent improvement in critical thinking can be explained by constructivist learning theory, which emphasizes that knowledge is actively constructed through investigation, questioning, and evidence-based reasoning. Inquiry-based learning encourages students to formulate hypotheses, design investigations, analyze data, and draw conclusions, thereby strengthening higher-order thinking skills. These inquiry activities

reflect the principles of radical constructivism, where knowledge develops through learners' active interpretation of scientific experiences rather than passive information transfer (Ulfa et al., 2022). Guided inquiry learning encourages students to participate actively in the learning process through observation, questioning, investigation, discussion, and reflection, resulting in higher learning engagement (Sadita et al., 2025).

Table 6. Moderating variables that enhance the effectiveness of inquiry-based learning

Moderator Variables	Success indicators that are influenced	Main impact on learning outcomes
Guided inquiry level	Conceptual understanding, critical thinking	The investigation process is more focused so that learning objectives are achieved more optimally.
Quality of teacher interaction and implementation readiness	Science process skills, science literacy	Teachers are able to facilitate experiments, discussions and reflections effectively.
Learning modalities (laboratory, digital, hybrid)	Motivation to learn, involvement	Technology and experiments increase student engagement and participation
Technology and experiments increase student engagement and participation	Critical thinking, cognitive learning outcomes	Students are better able to evaluate and build knowledge
Learning resources and facilities	Science process skills, collaboration	Investigations become more optimal due to the support of physical and digital tools.
Learning process assessment strategies	Motivation, understanding of concepts	Process-based assessment encourages in-depth exploration and reflection.

Teacher guidance emerged as one of the most influential moderating factors. Guided inquiry generally produced more consistent learning outcomes than open inquiry because students received sufficient scaffolding while maintaining opportunities for independent investigation.

Guided inquiry tends to produce better outcomes compared to fully open inquiry. Previous studies have shown that guided inquiry learning has been widely implemented across science education and consistently contributes to improving students' conceptual understanding, critical thinking, and scientific investigation skills (Adaayah & Aznam, 2024). High school students still require scaffolding to ensure that the investigative process does not lose direction. Additionally, teachers trained in experimental design, guiding questions, and discussion facilitation contribute to a significant improvement in learning outcomes. Inquiry-based learning is also most effective in both offline laboratory and online environments when instruction is supported with virtual simulations, PhET, Phyphox, and experiment-based mobile learning applications (Indawati et al., 2023; Eriyanti et al., 2023).

This is in line with previous studies which assert that interactive technology is capable of compensating for the limitations of laboratory facilities and enhancing student engagement through the visualization of physics phenomena that are difficult to observe directly. Thus, inquiry-based learning assisted by technology has

been proven to be an effective solution in school contexts with limited experimental resources, without diminishing the quality of the scientific investigation process. In addition to supportive facilities and infrastructure, student characteristics are also highly important in influencing cognitive learning outcomes and critical thinking. Most importantly, the availability of laboratory equipment, inquiry-based worksheets (LKPD), and digital experimental media has a significant impact on effectiveness.

The synthesis of 20 analyzed articles shows that inquiry-based learning has high effectiveness in high school physics education because it directly involves students in the scientific process and builds knowledge through real experiences. Although many studies indicate that inquiry-based learning is effective in improving conceptual understanding and higher-order thinking skills, some studies also find that its impact on cognitive learning outcomes is not always significant. High school students still require scaffolding to manage the inquiry process, which means that they are not yet fully prepared to handle complex learning processes.

These findings from the systematic literature review (SLR) are in line with various theories and previous studies, which state that Inquiry-Based Learning (IBL) is an effective approach for enhancing students' scientific process skills. Theoretically, constructivism asserts that knowledge is constructed through active experience. In the context of physics education, the inquiry model

provides learning conditions that enable students to engage in observation, experimentation, and evidence-based reasoning. Thus, the synthesis of the research findings is consistent with the view that Inquiry-Based Learning (IBL) can facilitate the development of scientific process skills and scientific thinking.

Several studies conclude that guided inquiry tends to be more suitable for high school students compared to open inquiry, primarily because students still require scaffolding to manage the complexity of scientific stages. This study has several limitations that need to be considered when interpreting the findings. First, the number of analyzed articles is still limited to the high school (SMA) level, so generalizing the findings to other educational levels such as middle school or higher education needs to be done cautiously. Second, there is heterogeneity in assessment instruments across studies, whether in the form of cognitive assessments, scientific process skills, or scientific attitudes, which may potentially affect the consistency of comparisons among research findings. Third, most studies only evaluate the short-term impact of implementing inquiry-based learning, while reports on its long-term effects on conceptual understanding and the sustainability of scientific competence are rarely found. Therefore, further research with a broader scope, standardized assessment instruments, and a longitudinal design is highly needed to provide a more comprehensive picture of the effectiveness of inquiry-based learning.

These findings suggest that inquiry-based learning should be implemented with adequate instructional support, authentic assessment, and appropriate digital resources. For physics teachers, guided inquiry appears to be the most suitable approach for developing students' conceptual understanding and scientific reasoning while maintaining classroom feasibility. The consistent improvement in critical thinking skills identified in this review is also supported by previous studies showing that inquiry-based instruction helps students evaluate evidence, reconstruct scientific concepts, and reduce misconceptions through scientific reasoning (Julianto et al., 2023).

Conclusion

This systematic literature review concludes that inquiry-based learning is an effective instructional approach for senior high school physics, as it consistently improves students' conceptual understanding, critical thinking, science process skills, learning motivation, and engagement. However, its effectiveness is influenced by several moderating factors, including teacher guidance, instructional quality, learning modalities, and the integration of digital technologies. These findings provide evidence-

based support for implementing inquiry-based learning in physics education through well-designed instructional strategies and authentic assessment practices. Future research is recommended to examine the implementation of inquiry-based learning across different physics topics, educational contexts, and student characteristics. Further studies should also investigate the integration of emerging digital technologies and conduct broader systematic reviews or meta-analyses to strengthen the evidence regarding the effectiveness of inquiry-based learning in senior high school physics.

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Author Contributions

All authors made significant contributions to the preparation of this research. Devi Ardiantini developed the research ideas and concepts, designed the methodology, carried out data collection and analysis, and wrote the initial draft of the manuscript. Muhamad Yusup conducted the literature review, validated the research instruments, provided input on the analysis results, and performed substantive revisions of the manuscript. Sardianto Markos Siahaan provided supervision and academic guidance, conducted the final evaluation of the overall research content, and finalized the publication manuscript.

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Conflict of Interest

The authors declare that there is no conflict of interest that could influence the representation or interpretation of the research findings reported in this article. The authors have no personal or financial interests that are considered to affect the substance of this scholarly work.

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