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Review Article

From Variables to Conclusions: Analysis Three Indicators of Science Process Skills in High School Physics Learning

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ABSTRACT

Purpose of the study: This study aims to analyze the development of Science Process Skills (SPS) in high school physics learning through a systematic review of international research published between 2017 and 2025.

Methodology: This study employed a Systematic Literature Review (SLR) design guided by the PRISMA. Data were collected through a structured literature search of two international academic databases, Taylor & Francis Online and SpringerLink. Using purposive sampling based on predefined inclusion and exclusion criteria, a total of 30 peer-reviewed journal articles were selected for analysis from an initial pool of 300 identified records. Data were analyzed using qualitative thematic analysis to identify research trends, dominant SPS indicators, and instructional approaches applied in high school physics education.

Main Findings: The synthesis reveals that inquiry-based learning, project-based learning, and virtual laboratory approaches are the most consistently reported strategies for enhancing students' science process skills. Among the three SPS indicators, identifying variables and analyzing data are most frequently emphasized, while drawing conclusions remains less explicitly developed. Strengthening SPS through these approaches improves students' scientific reasoning, experimental accuracy, learning engagement, and motivation in physics learning.

Novelty/Originality of this study: This study provides an updated and systematic synthesis of global research on science process skills development in physics education up to 2025. By mapping instructional strategies and SPS indicators across international contexts, this review offers new conceptual insights into how inquiry-based and technology-supported learning can foster sustainable scientific thinking and support students' readiness to meet 21st-century learning demands.

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1. INTRODUCTION

Physics education at the high school level is widely recognized as a medium for developing students' scientific thinking through inquiry, experimentation, and evidence-based reasoning. Various countries have adopted different instructional approaches to foster these competencies. In Finland, physics learning is implemented through a phenomenon-based approach that situates scientific concepts within real-world contexts, encouraging students to critically analyze natural phenomena and construct explanations based on empirical evidence [1]. In Japan, physics instruction emphasizes structured laboratory activities designed to strengthen students' psychomotor skills and analytical thinking through systematic experimentation [2]. Meanwhile, studies from South Korea indicate that although students are often engaged in data analysis and explanatory tasks, opportunities for conducting independent investigations remain limited, which constrains the comprehensive development of science process skills (SPS) [3]. In Indonesia, physics education is expected to play a central role in developing SPS; however, existing learning practices still tend to prioritize conceptual understanding over the explicit cultivation of scientific processes such as inquiry, reflection, and scientific communication [4].

Science process skills (SPS) are defined as a set of cognitive and psychomotor abilities that enable students to generate, test, and validate scientific knowledge through systematic procedures. Prior studies consistently identify SPS as a key determinant of students' scientific reasoning and conceptual understanding. Specifically, identifying variables, analyzing data, and drawing conclusions are recognized as the core indicators of SPS at the high school level. Zainuddin et al., [5] emphasize that SPS encompass formulating hypotheses, identifying and operationally defining variables, designing data tables, analyzing experimental results, and drawing conclusions. Similarly, cross-level studies report that experimental activities inherently require students to identify and control variables as well as interpret data accurately [6]. Research conducted in chemistry education further supports these findings, indicating that the abilities to analyze data and draw conclusions represent the highest indicators of students' SPS mastery [7]. Collectively, these studies demonstrate that SPS are essential for fostering logical, evidence-based thinking; however, they also reveal that these skills are cognitively demanding and require deliberate instructional support.

Despite the growing body of research on SPS, existing studies predominantly focus on measuring students' SPS levels or examining the effectiveness of specific instructional models in isolation. Longitudinal and comparative perspectives remain limited. Historical analyses suggest that during the 1990s, physics instruction in many educational contexts, including Indonesia, was largely teacher-centered, positioning students as passive recipients of information. A gradual paradigm shift occurred in the early 2000s with the introduction of inquiry-based and discovery learning approaches, which encouraged students to actively construct knowledge through experimentation [8]. More recent studies from the 2010s onward highlight the increasing adoption of project-based learning and problem-based learning models, which promote students' engagement in scientific processes, particularly in identifying variables, analyzing data, and drawing conclusions [9]. Furthermore, the integration of digital technologies such as virtual laboratories and data analysis tools has been reported to enhance students' SPS across various educational contexts [10].

However, a critical examination of the literature reveals several unresolved issues. First, while numerous studies report positive effects of inquiry-based, project-based, and technology-enhanced learning on SPS, the findings are fragmented and context-specific, making it difficult to draw general conclusions about long-term trends in SPS development. Second, most studies emphasize outcomes rather than instructional trajectories, providing limited insight into how teachers' strategies for developing SPS have evolved over time in physics education. Third, although identifying variables, analyzing data, and drawing conclusions are frequently cited as key SPS indicators, evidence indicates that these skills often remain underdeveloped among students. For example, studies show that students commonly struggle with identifying and controlling variables and interpreting experimental data [11], while integrated SPS such as constructing tables and graphs, describing relationships among variables, and synthesizing conclusions are considered complex and challenging to master [12].

These gaps highlight the need for a systematic and critical synthesis of existing research to clarify how instructional strategies have been used to foster SPS in high school physics learning. Therefore, this study aims to systematically review the development of science process skills in high school physics education through a Systematic Literature Review (SLR) using the PRISMA method. Specifically, this review seeks to address the following research questions: (1) How have instructional strategies in high school physics evolved in supporting students' science process skills? (2) Which instructional approaches are most consistently reported to enhance students' abilities in identifying variables, analyzing data, and drawing conclusions?

The significance of this study lies in its contribution to organizing and critically evaluating dispersed findings across different countries and instructional approaches. By synthesizing evidence on the evolution of teachers' strategies and mapping dominant trends and persistent challenges in SPS development, this research provides both theoretical and practical contributions to physics education. The findings are expected to inform educators, curriculum developers, and policymakers in designing more effective learning environments that explicitly support the development of science process skills, particularly within the context of Indonesian high school physics education.

2. RESEARCH METHOD

This study employed a Systematic Literature Review (SLR) design guided by the PRISMA 2020 statement [13]. The SLR approach was selected to systematically identify, evaluate, and synthesize empirical evidence related to the development of Science Process Skills in high school physics learning [14]. Unlike survey-based studies, this research did not involve primary data collection through questionnaires or direct respondents. Instead, the unit of analysis consisted of peer-reviewed research articles, making SLR an appropriate and rigorous methodological choice. The review focused on three core SPS indicators: identifying variables, analyzing data, and drawing conclusions, which are widely recognized as essential components of students' scientific reasoning in physics education [15]. Through a PRISMA-based process, this study aimed to map research trends, instructional strategies, and empirical findings related to these indicators in a transparent and replicable manner.

Data were obtained from two reputable international academic databases: Taylor & Francis Online and SpringerLink, selected due to their credibility and strong focus on science and physics education research. The sampling technique used was purposive sampling, based on predefined inclusion and exclusion criteria aligned with the research objectives. The inclusion criteria were:

1. Articles published between 2017 and 2025,
2. Studies focusing on high school physics learning,
3. Research explicitly addressing Science Process Skills or their indicators,
4. Peer-reviewed journal articles written in English.

Exclusion criteria included non-empirical opinion papers, studies conducted outside the secondary education level, and articles that did not explicitly discuss SPS indicators. The document selection process followed PRISMA stages: identification, screening, eligibility, and inclusion. All references were managed using Mendeley, while screening and categorization were conducted using Microsoft Excel. The article selection flow is presented in Figure 1.

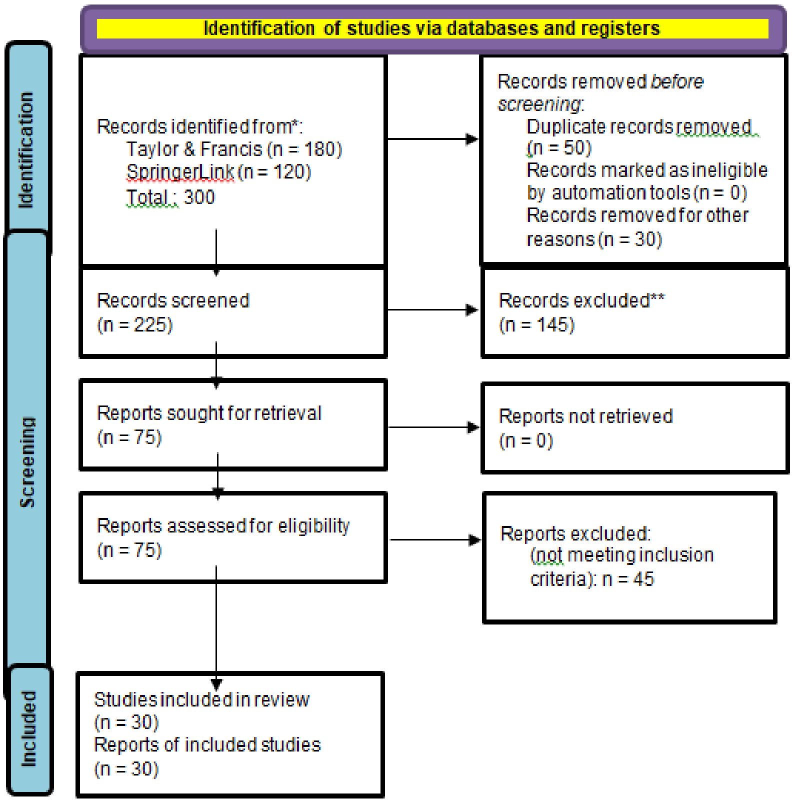

Figure 1. Researh Flow

Data analysis was carried out using a qualitative thematic analysis method. Each article that passed the inclusion stage was analyzed in depth to identify patterns, trends, and directions of research development related to the three main indicators of Science Process Skills, namely:

1. Identifying variables within the context of physics learning,
2. Analyzing experimental data using a scientific approach, and
3. Drawing conclusions based on empirical findings.

The analysis process was conducted through three main stages:

1) Initial coding: marking keywords, methods, and results relevant to the three SPS indicators.
2) Categorization: grouping the coded results into broader themes such as teacher strategies, learning models, and student achievements for each SPS indicator.
3) Data synthesis: compiling the findings into descriptive narratives and thematic tables that illustrate annual research trends and the development of SPS strengthening strategies from 2017 to 2025.

This analysis was performed triangulatively by comparing findings across articles to ensure data consistency. The results are expected to provide a comprehensive overview of the development of SPS indicators in high school physics learning and serve as a foundation for developing more effective and sustainable learning strategies.

3. RESULTS AND DISCUSSION

Based on a systematic search conducted in the Taylor & Francis Online and SpringerLink databases, a total of 300 articles published between 2017 and 2025 were initially identified. After removing duplicates and screening titles and abstracts, 220 articles were retained for eligibility assessment. Following full-text evaluation based on predefined inclusion and exclusion criteria, 75 articles met the eligibility requirements. From these, 30 articles were selected as the most relevant and directly aligned with the research focus on Science Process Skills (SPS) in high school physics learning.

The analysis of the selected articles indicates a consistent increase in research attention toward SPS development in high school physics education over the reviewed period. Most studies explicitly emphasize three core SPS indicators: identifying variables, analyzing data, and drawing conclusions. These indicators are predominantly embedded within inquiry-oriented instructional designs and experimental learning environments. Various instructional approaches were reported to support SPS development. Inquiry-based learning, project-based learning, and problem-based learning emerged as the most frequently implemented strategies. In addition, the growing use of virtual laboratories and technology-enhanced experiments was identified as a major trend, particularly after 2020. Several studies reported that the integration of combined real and virtual laboratory activities resulted in more consistent improvements across all three SPS indicators compared to the use of a single approach. Table 1 presents a detailed summary of the contribution of each reviewed article to the three main SPS indicators in high school physics learning.

Table 1. Summary of Reviewed Articles on Science Process Skills in Physics Learning

No.	Author(s) & Year	Article Title	Journal & Full URL	SPS Indicators	Main Findings
1	Mutlu, A. (2020) [16]	Evaluation of students' scientific process skills through practical work	*International Journal of Science Education* https://www.tandfonline.com/doi/full/10.1080/14623943.2020.1736999	Identifying variables, analyzing data, drawing conclusions	Practical work enhances students' ability to identify variables and analyze results in physics labs.
2	Chen, K-F., Hwang, G-J., & Chen, M-R. (2024) [17]	Effects of concept mapping-guided virtual laboratory learning on students' SPS	*Educational Technology Research & Development* https://link.springer.com/article/10.1007/s11423-024-10348-y	Analyzing data, drawing conclusions	Concept mapping with virtual labs improves reasoning and analytical accuracy.
3	Stender, A., et al. (2018) [18]	Making inquiry-based science learning visible	*International Journal of Science Education* https://www.tandfonline.com/doi/abs/10.1080/09500693.2018.1504346	Identifying variables, analyzing data	Inquiry-based learning strengthens recognition of variables and data evaluation.
4	Van Vo, D. (2021) [19]	Development of scientific reasoning test measuring control variables in	*International Journal of Science Education* https://www.tandfonline.com/doi/ab	Identifying variables	Improves ability to define and manipulate control variables during experimentation.

No.	Author(s) & Year	Article Title	Journal & Full URL	SPS Indicators	Main Findings
		physics	s/10.1080/09500693.2021.1957515		
5	Pavlou, Y. (2023) [20]	Using Physical and Virtual Labs for Experimentation in Education	*Springer Education Review* https://link.springer.com/chapter/10.1007/978-3-031-44792-1_1	Analyzing data, drawing conclusions	Combines virtual and physical labs to enhance SPS through practical experience.
6	Elmoazen, R. (2023) [21]	Learning analytics in virtual laboratories: a systematic review	*Smart Learning Environments* https://slejournal.springeropen.com/articles/10.1186/s40561-023-00244-y	Analyzing data	Virtual labs increase analytical engagement and interpretation accuracy.
7	Banda, H.J. (2023) [22]	The Impact of PhET Simulations on Science Process Skills	*Journal of Science Education and Technology* https://link.springer.com/article/10.1007/s10956-022-10010-3	Analyzing data, drawing conclusions	PhET simulations strengthen data analysis and evidence-based reasoning.
8	Zhuang et al. (2021) [23]	Comparison of nature of science representations in five Chinese high school physics textbooks	*International Journal of Science Education* https://www.tandfonline.com/doi/full/10.1080/09500693.2021.1933647	Identifying variables, analyzing data	Reveals how SPS indicators appear in modern science curricula.
9	Daniel et al (2023) [24]	Modified guided-discovery methods in physics laboratories: Pre-service teachers' conceptual and procedural knowledge, views of nature of science, and motivation	*Cogent Education* https://www.tandfonline.com/doi/full/10.1080/2331186X.2023.2267937	Identifying variables, drawing conclusions	Guided discovery improves independent inquiry and reasoning.
10	Dziob et al (2022) [25]	Physics competition to inspire learning and improve soft skills: a case of the Chain Experiment	*International Journal of Technology and Design Education* https://link.springer.com/article/10.1007/s10798-020-09620-y	Drawing conclusions	Competitive learning enhances motivation and conclusion accuracy.
11	Sarı et al (2020) [26]	The effects of STEM education on scientific process skills and STEM awareness in simulation based inquiry learning environment	*Journal of Science Education and Technology* https://link.springer.com/article/10.1007/s10956-020-09847-9	Analyzing data	STEM-based simulations develop students' data reasoning abilities.
12	Lestari et al (2023) [27]	Effect of science virtual laboratory combination with demonstration methods on lower-secondary school	*Education and Information Technologies* https://link.springer.com/article/10.	Analyzing data	Virtual-real hybrid methods improve analytical interpretation.

No.	Author(s) & Year	Article Title	Journal & Full URL	SPS Indicators	Main Findings
		students' scientific literacy ability in a science course	1007/s10639-023-11857-8		
13	Moore et al (2024) [28]	Assessment and practical science: identifying generalizable characteristics of written assessments that reward and incentivise effective practices in practical science lessons	*International Journal of Science Education* https://www.tandfonline.com/doi/full/10.1080/09500693.2023.2253366	Identifying variables, drawing conclusions	Highlights authentic assessment aligned with inquiry-based physics.
14	Wang et al (2025) [29]	Virtual experiments in physics education: a systematic literature review	*Research in Science & Technological Education* https://www.tandfonline.com/doi/full/10.1080/10494820.2025.2475801	Analyzing data, drawing conclusions	Virtual experiments enhance analytical thinking in physics labs.
15	Lin et al. (2021) [30]	Using an inquiry-based science and engineering program to promote science knowledge, problem-solving skills and approaches to learning in preschool children	*Early Education and Development* https://www.tandfonline.com/doi/abs/10.1080/10409289.2020.1795333	Identifying variables, drawing conclusions	Reviews trends of inquiry-based SPS improvement worldwide.
16	Musengimana, T. (2025) [31]	Assessing physics students' problem-solving skills: A baseline investigation	*Discover Education* https://link.springer.com/article/10.1007/s44217-025-00640-1	Identifying variables, analyzing data	Correlates SPS and problem-solving performance in physics.
17	Meulenbroeks et al. (2024) [32]	Fostering secondary school science students' intrinsic motivation by inquiry-based learning	*Research in Science Education* *https://link.springer.com/article/10.1007/s11165-023-10139-0*	Identifying variables, drawing conclusions	Inquiry worksheets promote autonomy in identifying and concluding experimental outcomes.
18	Lavonen et al (2021) [33]	Upper secondary students' situational interest in physics learning in Finland and Chile	*International Journal of Science Education* https://www.tandfonline.com/doi/full/10.1080/09500693.2021.1978011	Analyzing data	Demonstrates link between interest and improvement in analytical SPS.
19	Lämsä et al (2018) [34]	Visualising the temporal aspects of collaborative inquiry-based learning processes in technology-	*International Journal of science education* https://www.tandfonline.com/doi/full/10.1080/095006	Identifying variables, analyzing data	Provides global evidence of SPS assessment in inquiry-based physics.

No.	Author(s) & Year	Article Title	Journal & Full URL	SPS Indicators	Main Findings
		enhanced physics learning	93.2018.1506594		
20	Morris (2025) [35]	Rethinking science education practices: Shifting from investigation-centric to comprehensive inquiry-based instruction	*Education Sciences* https://doi.org/10.3390/educsci15010073	Identifying variables, analyzing data	Highlights teacher strategies improving SPS consistency.
21	Chen, F. (2024) [36]	Technology-enhanced collaborative inquiry in K–12	*Education and Information Technologies* https://link.springer.com/article/10.1007/s11191-024-00538-8	Analyzing data	Technology-aided collaboration strengthens analytical reasoning.
22	Pols, C.F.J. (2021) [37]	Investigating students' ability to interpret empirical data	*International Journal of Science Education* https://www.tandfonline.com/doi/full/10.1080/09500693.2020.1865588	Analyzing data	Strengthens data interpretation accuracy.
23	Zhang et al (2025) [38]	Where inquiry-based science learning meets gamification: a design case of Experiverse	*Journal of Science Education* https://www.tandfonline.com/doi/full/10.1080/0144929X.2024.2433058	Identifying variables, analyzing data	Gamified inquiry enhances engagement and analytical skill.
24	Anam, R.S. (2023) [39]	The effects of teaching with real, virtual, and real-virtual experimentation modes on conceptual knowledge and science process skills among sixth-grade primary school students: a case study on concepts of electricity	*Education 3–13* https://www.tandfonline.com/doi/full/10.1080/03004279.2023.2192224	Analyzing data	Hybrid labs strengthen experimental analysis.
25	McLure, F. (2023) [40]	The thinking frames approach: Improving high school students' written explanations of phenomena in science	*Research in Science Education* https://link.springer.com/article/10.1007/s11165-022-10052-y	Drawing conclusions	Thinking Frames improve logical conclusion-making in experiments.
26	Sari et al (2025) [41]	Computational thinking in science laboratories based on the flipped	*Journal of Science Education and Technology* https://link.spring	Analyzing data	Flipped experimentation builds stronger data-processing skills.

No.	Author(s) & Year	Article Title	Journal & Full URL	SPS Indicators	Main Findings
		classroom model: Computational thinking, laboratory entrepreneurial and attitude	er.com/article/10.1007/s10956-024-10192-y		
27	Robertson et al. (2023) [42]	Identifying student conceptual resources for understanding physics: A practical guide for researchers	*Physical Review Physics Education Research* https://journals.aps.org/prper/abstract/10.1103/PhysRevPhysEducRes.19.020138	Identifying variables	Reinforces variable identification in conceptual learning.
28	Dunn. (2025) [43]	The effect of simulation-supported inquiry on South African natural sciences learners' understanding of atomic and molecular structures	*Education sciences* https://www.mdpi.com/2227-7102/10/10/280	Analyzing data, drawing conclusions	Integrates simulations for evidence-based understanding.
29	Opitz et al. (2017) [44]	Measuring scientific reasoning–a review of test instruments	*Educational Research and Evaluation* https://www.tandfonline.com/doi/abs/10.1080/13803611.2017.1338586	Identifying variables, analyzing data, drawing conclusions	Shows correlation between scientific reasoning and SPS mastery.
30	Hsin et al (2023) [45]	Implementing a project-based learning module in urban and indigenous areas to promote young children's scientific practices	*Research in Science Education* https://link.springer.com/article/10.1007/s11165-022-10043-z	Identifying variables, analyzing data	PBL improves ability to define and control variables.

Based on the analysis of 30 reviewed articles, this study found that the strengthening of Science Process Skills (SPS) in high school physics learning has shown a consistent positive trend from 2017 to 2025. Most of the reviewed studies emphasize three core SPS indicators identifying variables, analyzing data, and drawing conclusions which are predominantly developed through inquiry-based and technology-supported experimental approaches. Instructional strategies such as virtual laboratories, project-based learning, and problem-based learning are frequently reported as effective in enhancing students' analytical abilities and scientific reasoning [46]-[49]. Notably, the synthesis of findings indicates that the integration of real and virtual laboratory activities represents the most adaptive and effective strategy in responding to the demands of the digital era. Overall, the literature demonstrates that instructional practices focusing on scientific processes substantially contribute to improving the quality of students' scientific thinking in physics learning.

The findings further reveal a clear shift in recent years toward process-oriented and technology-enhanced instructional designs. This trend aligns with previous research highlighting the critical role of inquiry-based and experimental learning environments in fostering students' scientific reasoning skills. Compared to earlier studies, more recent research places stronger emphasis on structured inquiry frameworks and digital experimentation, indicating an evolution in pedagogical approaches aimed at strengthening SPS more systematically.

A closer examination of the three SPS indicators shows that identifying variables and analyzing data are the most consistently developed skills across the reviewed studies. These indicators are commonly supported through guided inquiry activities, virtual simulations, and data-driven physics experiments [50], [51]. In contrast, the skill of drawing conclusions is less explicitly addressed and often embedded implicitly within learning activities rather than supported through deliberate instructional scaffolding. This pattern suggests a persistent gap in physics instruction, particularly in guiding students to synthesize experimental evidence into well-reasoned scientific conclusions.

The review also highlights the central role of teachers in facilitating SPS development. Teachers are increasingly positioned as facilitators who guide inquiry processes, support data interpretation, and encourage reflective and evidence-based reasoning. Adaptive teaching strategies especially those combining real and virtual laboratory experiences enable teachers to address diverse learning contexts while maintaining the authenticity of scientific investigation. These findings reinforce existing literature emphasizing that effective pedagogical design is essential for strengthening students' engagement with scientific processes.

Despite providing a comprehensive synthesis of current research, this study has several limitations. First, the review was restricted to English-language articles indexed in two international databases, which may have excluded relevant regional or non-English publications. Second, as a Systematic Literature Review, this study relies on secondary data and does not empirically measure improvements in students' SPS. Future research is therefore recommended to conduct experimental and longitudinal studies examining the direct effects of specific instructional strategies on each SPS indicator, particularly the development of students' ability to draw scientific conclusions. Further studies may also explore SPS development across different cultural and curriculum contexts through comparative or cross-national research designs.

In both the short and long term, strengthening SPS has important implications for physics education. In the short term, SPS-oriented instruction enhances students' engagement and motivation in experimental activities. In the long term, it supports the development of critical, systematic, and evidence-based scientific thinking required for 21st-century learning. The key contribution of this study lies in its global mapping of instructional strategies and SPS indicators, offering synthesized empirical insights into how inquiry and technology integration can effectively strengthen science process skills. Thus, this research not only advances theoretical understanding but also provides practical guidance for physics teachers and curriculum developers seeking to improve science process-based learning in high school physics classrooms.

4. CONCLUSION

Based on a systematic review of 30 international research articles published between 2017 and 2025, this study concludes that the development of Science Process Skills (SPS) in high school physics learning has increasingly emphasized three core indicators: identifying variables, analyzing data, and drawing conclusions. The synthesis confirms that inquiry-based learning, project-based learning, and the integration of virtual laboratory activities are the most consistently reported instructional approaches for strengthening students' scientific thinking skills. This review further highlights that the effective development of SPS is strongly influenced by the pedagogical role of teachers as facilitators who guide inquiry processes, support data interpretation, and encourage evidence-based reasoning. The integration of digital tools serves as a complementary mechanism that enhances students' ability to connect theoretical concepts with experimental practices, rather than as a standalone solution. The main implication of this study is that physics learning should be intentionally designed to prioritize scientific processes alongside conceptual understanding. For physics educators and curriculum developers, these findings underscore the importance of integrating inquiry-oriented and technology-supported instructional strategies in a balanced and reflective manner to foster sustainable scientific thinking skills among students. This study also provides a qualitative conceptual framework for understanding how SPS-oriented instruction can be strengthened in high school physics education.

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AUTHOR CONTRIBUTIONS

SP designed the study, conducted the analysis, collected the data, and wrote the manuscript. D and DAK supported the availability of research data, and reviewed the research results.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

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