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A systematic review of metacognitive dynamics in secondary physics education

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ABSTRACT

Metacognitive strategies are effective in enhancing secondary school students' performance in physics, a key science, technology, engineering, and mathematics (STEM) subject that poses challenges due to its conceptual complexity and the need for higher-order thinking skills. This study systematically reviews the impact of metacognitive strategies on student performance in physics from 2014 to 2024. The research objectives include identifying trends, advantages, and challenges of these strategies. Using preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines, 25 studies were selected from databases like Web of Science (WoS) and Scopus, involving diverse respondents. Research instruments included surveys, interviews, and standardized tests to assess metacognitive awareness and academic performance. Analysis revealed a preference for quantitative methods (88%), with qualitative (8%) and mixed methods (4%) also contributing insights. Results indicate that metacognitive strategies enhance conceptual understanding, problem-solving skills, motivation, engagement, and academic performance while reducing gender gaps. However, challenges include implementation complexity, time constraints, student resistance, assessment difficulties, and variability in effectiveness. The findings underscore the need for comprehensive teacher training and innovative instructional designs to integrate metacognitive strategies effectively. These strategies hold promise for transforming physics education and promoting equitable student outcomes. Future research should focus on developing tailored approaches and innovative assessment methods to optimize the implementation of metacognitive strategies across diverse educational contexts.

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1. INTRODUCTION

In the field of education, the pursuit of effective teaching strategies that enhance student performance remains a critical objective [1]. Physics, as a foundational discipline in modern science and technology, often poses significant challenges to secondary school students [2]. These challenges arise not only from the abstract and mathematical nature of the subject but also from students' cognitive and metacognitive abilities [3], [4]. Metacognition, defined as the awareness and regulation of one's own learning processes, has emerged as a crucial factor in academic success [5]. Research suggests that fostering metacognitive skills can significantly enhance students' understanding and application of complex physics concepts [6]–[9].

Metacognition comprises two key components: metacognitive knowledge and metacognitive regulation [10]. Metacognitive knowledge involves awareness of one's cognitive processes, understanding task requirements, and selecting appropriate strategies [11]. Metacognitive regulation, on the other hand, encompasses planning, monitoring, and evaluating one's learning activities. Studies consistently demonstrate that students who employ metacognitive strategies achieve higher academic performance, as these skills enable them to become self-regulated learners capable of adapting their approaches to diverse tasks [12]–[14].

Despite the growing recognition of metacognition's importance, its application in secondary physics education remains underexplored [15]–[18]. Traditional teaching methods, which often emphasize rote memorization and procedural problem-solving, may not adequately address the cognitive and metacognitive demands of physics [8], [13], [19]. Consequently, students frequently develop misconceptions, experience anxiety, and disengage from the subject [20]–[23]. These issues underscore the need for innovative instructional approaches that integrate metacognitive strategies to enhance both cognitive and affective outcomes [24]–[26].

Empirical evidence highlights the transformative potential of metacognitive strategies in physics education [8], [19], [27], [28]. For instance, students who receive metacognitive training demonstrate improved problem-solving abilities, deeper conceptual understanding, and higher academic achievement [11], [16], [29]–[34]. However, the implementation of these strategies in secondary school curricula presents unique challenges, including limited teacher training and the complexity of aligning metacognitive practices with existing educational frameworks [35].

This systematic review aims to address these gaps by synthesizing research on metacognitive strategies in secondary physics education from 2014 to 2024. Thus, it seeks to answer three key questions:

i) What are the prevailing trends and characteristics of research on metacognitive strategies in secondary school physics education?
ii) How do these strategies enhance students' understanding and performance in physics?
iii) What challenges do educators face in integrating metacognitive strategies and how can these be addressed?

By addressing these questions, this review provides a comprehensive overview of the field and offers actionable insights for educators and researchers seeking to improve physics education through metacognitive interventions.

The novelty of this systematic review lies in its focused investigation of metacognitive strategies specifically within secondary physics education, a subject that has received limited attention in broader metacognitive research. Unlike previous studies that examine metacognition in general science, technology, engineering, and mathematics (STEM) or science education, this review synthesizes research from the past decade (2014–2024) to provide a comprehensive analysis of trends, benefits, and challenges unique to physics learning. Additionally, it highlights the role of metacognitive strategies in promoting equity by addressing gender disparities in physics performance—an area that remains underexplored. By integrating diverse methodologies and global perspectives, this study offers new insights into how metacognitive interventions can be effectively implemented in physics classrooms, ultimately contributing to a more student-centered and inclusive approach to teaching and learning.

2. METHOD

A systematic literature review (SLR) is crucial for establishing theoretical foundations, identifying research gaps, enhancing methodologies, supporting arguments, and preventing duplication of previous studies [36]. Recognized as a promising structured approach, it examines prior research comprehensively. This SLR was conducted to explore the impact of metacognitive strategies on secondary school students' performance in physics, following the preferred reporting items for systematic reviews and meta-analyses (PRISMA) 2020 guidelines [37]. These guidelines provide updated criteria for identifying, selecting, assessing, and summarizing studies to enhance clarity and effectiveness in literature reviews. The process began with a comprehensive search of multiple reputable academic databases, such as Web of Science (WoS) and Scopus, using specific keywords like "metacognitive strategies," "physics education," and "secondary school students," ensuring a broad and inclusive collection of relevant literature.

The literature review aims to detect themes, theoretical perspectives, and general issues, as well as identify theoretical concept components from recent studies. It contributes to research by synthesizing existing studies to create a future research agenda. Defined as the process of identifying, assessing, synthesizing, and interpreting studies effectively, this review relies on secondary sources, such as reputable and high-quality journal articles. The chosen database is considered a primary source due to its broad impact compared to others. Alternatively recognized as a structured literature review, the SLR emerges as a potent tool for scrutinizing previous studies, thereby strengthening the respective field. A thorough protocol has been outlined within this review, detailing the criteria for data exploration and other pertinent aspects.

The initial search results were meticulously screened to eliminate duplicates and irrelevant articles, focusing only on studies that directly addressed the research questions. Predefined inclusion criteria were applied to assess the eligibility of the remaining studies, including relevance to the research topic, methodological rigor, and publication date, ensuring that only high-quality and pertinent studies were included. The quality of the studies was further evaluated using established benchmarks to ensure the robustness of the findings. Data extraction from the eligible studies was conducted systematically, focusing on key variables such as research methods, findings, and implications for physics education. The extracted data were then analyzed to evaluate the impact of metacognitive strategies on students' performance in physics. This led to a synthesis of findings that identified trends, advantages, and challenges associated with metacognitive approaches in secondary school physics education. This review aims to contribute to the field by providing a comprehensive overview and identifying areas for future research.

2.1. Database sources

Databases are crucial as they serve as primary reservoirs of publication metadata and bibliometric metrics. Selecting an appropriate data repository is essential for assessing a study's credibility. It is imperative for a SLR to utilize multiple databases. According to existing literature, WoS and Scopus are the two predominant bibliographic databases used. These databases are widely favored in systematic review endeavors due to their global recognition, comprehensive coverage and competitive citation indexing [38].

2.2. Preferred reporting items for systematic review and meta-analysis

This SLR adheres to the PRISMA review process. Originally introduced in 2009, PRISMA has been updated to PRISMA 2020, incorporating revised reporting criteria to reflect advancements in the process of identifying. Also, enhancing the clarity and effectiveness of communication in literature reviews and meta-analyses.

2.3. Identification

To select a significant volume of relevant literature for this study, several key steps in the systematic review process were employed. Initially, keywords were selected, and associated terms were identified using dictionaries, thesauri, encyclopedias, as well as prior research. Consequently, search strings were developed with regard to the Scopus and WoS databases, from which all significant terms were selected, as presented in Table 1. In the first step of the systematic review process, 576 publications were successfully retrieved from these two databases with regard to the current research project.

Table 1. The search strings

Databases	Term for search strings
Scopus	TITLE-ABS-KEY ((metacognit* OR "self-regulation" OR "self-awareness" OR "reflective thinking") AND (physics OR "physical science" OR mechanics OR thermodynamics) AND (high OR secondary OR elementary OR middle) AND (school OR education) AND (students OR learners)) AND PUBYEAR > 2013 AND PUBYEAR < 2025 AND (LIMIT-TO (SUBJAREA , "SOCI")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (PUBSTAGE , "final")) Date of access: August 2024
WoS	(metacognit* OR "self-regulation" OR "self-awareness" OR "reflective thinking") AND (physics OR "physical science" OR mechanics OR thermodynamics) AND (high OR secondary OR elementary OR middle) AND (school OR education) AND (students OR learners) (All Fields) and 2024 or 2023 or 2022 or 2021 or 2020 or 2019 or 2018 or 2017 or 2016 or 2015 or 2014 (Publication Years) and Article (Document Types) and Education Educational Research (WoS Categories) and 6.11 Education & Educational Research (Citation Topics Meso) as well as English (Languages) Date of access: August 2024

2.4. Screening

Throughout the screening phase, the gathered research items are assessed to examine which content aligns with the predefined research questions. Typical criteria for this phase include selecting research items categorized under metacognitive approaches to enhance secondary school students' performance in physics. Duplicate papers are removed. Initially, 576 publications were excluded, while 134 papers were further examined based on the study's inclusion as well as exclusion criteria, as refer to Table 2. Note that the main criterion was research literature offering practical recommendations, such as reviews, meta-syntheses, meta-analyses, conference proceedings, chapters, book series, as well as books that were not included in the latest study. Other than that, the review concentrated on English-language publications from 2014 to 2024. In the end, 15 publications were omitted prior to duplication.

Table 2. The selection criterion is searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Time line	2014-2024	<2013
Literature type	Journal (article)	Review, book, conference
Publication stage	Final	In press
Subject area	Social science	Others

2.5. Eligibility

In the third stage, referred to as the eligibility assessment, 94 articles were gathered. Each article was meticulously reviewed for titles and content to confirm they matched the inclusion criteria, which aligned with the study's research objectives. As a result, 69 data sets, papers, and articles were eliminated for not meeting the eligibility requirements. Reasons for exclusion included being outside the study's field, having titles that did not significantly relate to the research goals, abstracts irrelevant to the study's objectives, and lacking full-text access with regard to empirical evidence. This process left 25 articles for the next review phase.

2.6. Data abstraction as well as analysis

This research utilized an integrative analysis to assess and integrate various research designs, concentrating on quantitative methods to pinpoint significant subtopics as well as topics. Note that the initial stage of theme development involved data collection. Referring to Figure 1, the authors carefully assessed 25 publications with regard to content pertinent to the study's topics. They assessed major studies on metacognitive strategies aimed at improving secondary school students' performance in physics, scrutinizing the methodologies, and results of each study. Subsequently, the authors worked together to create themes established on the evidence, keeping a detailed log during the whole of the data analysis process to document analyses, perspectives, questions, and reflections related to data interpretation. They compared their findings to spot any inconsistencies in the theme development process. Correspondingly, disagreements were resolved through discussions among the authors, as well as the themes were revised to ensure consistency. Note that the analysis selection was validated by two science education experts, who confirmed the clarity, relevance, as well as appropriateness of each subtheme by establishing domain validity.

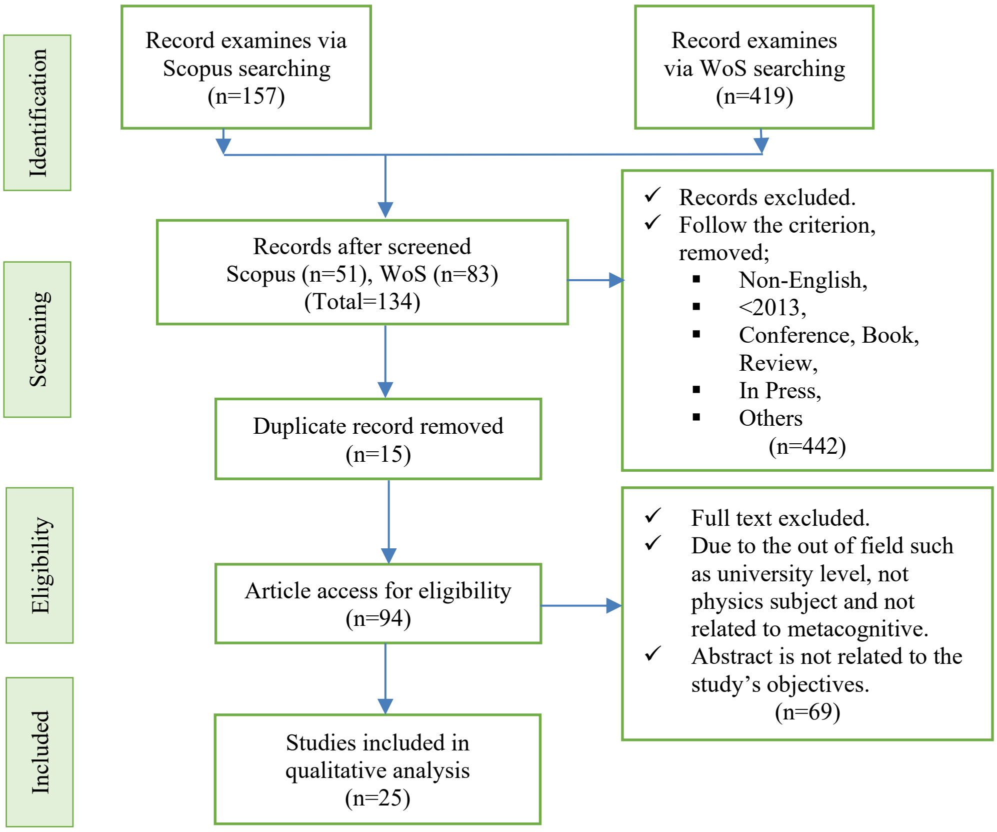

Figure 1. Flow diagram with regard to the proposed searching study [37]

3. RESULTS AND DISCUSSION

In the analysis of metacognition research in secondary school physics education from 2014 to 2024, several significant findings emerged. The research demonstrated a clear upward trend, with publications peaking in 2022, reflecting an increased focus on innovative teaching strategies, particularly post-COVID-19. This trend underscores the growing recognition of metacognition's role in enhancing student outcomes in physics. The studies predominantly employed quantitative methods (88%), highlighting a preference for objective measurement and statistical analysis, while qualitative (8%) and mixed methods (4%) provided valuable contextual insights. Geographically, Indonesia led four studies, focusing on online learning and self-regulated strategies, while the USA, Serbia, and Turkey each contributed three studies, exploring diverse metacognitive tools. This global distribution emphasizes the universal relevance of metacognitive strategies in physics education. The advantages identified include enhanced conceptual understanding, improved problem-solving skills, increased motivation and engagement, better academic performance, and reduced gender gaps. However, challenges such as implementation complexity, time constraints, student resistance, assessment difficulties, and variability in effectiveness were also noted. Addressing these challenges requires comprehensive teacher training and innovative instructional designs. Overall, the integration of metacognitive strategies holds significant promise for transforming physics education, fostering deeper understanding, and promoting equity in student outcomes.

3.1. The prevailing trends and characteristics of research on metacognitive strategies in secondary school physics education from 2014 to 2024

From 2014 to 2024, research on metacognition enhancing secondary school students' performance in physics has shown a clear upward trend. Initially, there were no articles in 2014 based on the criteria in this study, but interest began to grow, with two articles each in 2015 and 2016. After a brief hiatus in 2017, the field saw a steady increase in publications, peaking in 2022 with six articles. This surge, particularly noticeable from 2021 onwards, likely reflects the heightened focus on innovative teaching strategies necessitated by the COVID-19 pandemic. The consistent output in 2023 and 2024, with three articles each year, indicates that metacognition has become a well-established and ongoing area of research, highlighting its recognized importance in improving student outcomes in physics education. Figure 2 shows the graph of the publication of articles related to metacognition among high school students for the years 2014-2024.

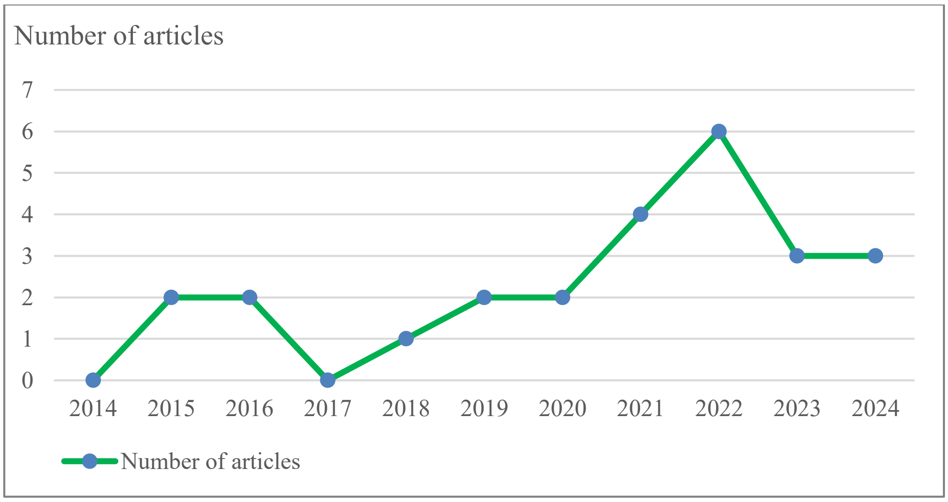

Figure 2. Number of articles

The distribution of research methodologies in studies on metacognition's impact on secondary school students' performance in physics shows a strong preference for quantitative methods (88%), which focus on objective measurement and statistical analysis to identify patterns and test hypotheses. A smaller portion of studies (8%) use qualitative methods, providing in-depth, contextual insights into students' experiences and perceptions. An even smaller fraction (4%) employs mixed methods, combining qualitative as well as quantitative approaches to provide a detailed understanding by validating numerical data with detailed, subjective insights. This distribution highlights the emphasis on measurable outcomes in the field while acknowledging the value of rich, contextual data to explain and enhance the quantitative findings. Figure 3 shows the methodology used by researchers in studying the metacognition of high school students.

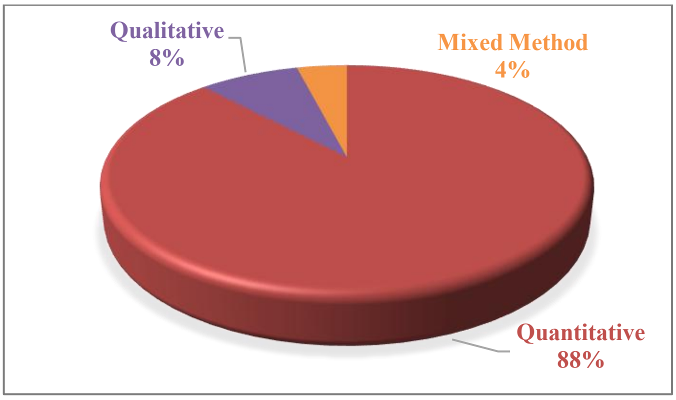

Figure 3. Methodology of studies

Figure 4 shows the distribution of countries that published articles on metacognition among high school students. The global spread of research on metacognition in physics education underscores a broad acknowledgment of its significance in improving student performance. Indonesia leads with four studies focusing on online learning and self-regulated strategies. At the same time, the USA, Serbia, and Turkey each contribute three studies exploring diverse metacognitive tools and their impact on conceptual understanding. Finland and the Philippines also show significant interest in two studies each, emphasizing collaborative learning and innovative teaching strategies. Other countries like Switzerland, Germany, the Netherlands, Austria, Malaysia, Taiwan, Uganda, and Zambia each contribute valuable insights into various aspects of metacognitive instruction, such as context-based tasks, formative feedback, and problem-solving skills. This diverse body of research underscores the universal relevance of metacognitive strategies in improving educational outcomes in physics across different educational contexts.

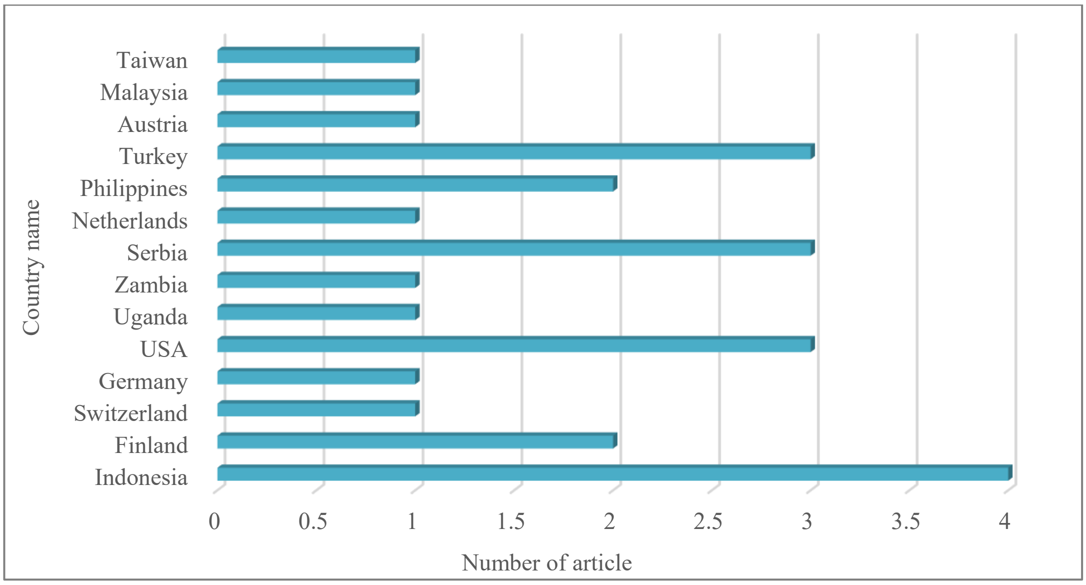

Figure 4. Number of studies based on countries

3.2. Metacognitive strategies enhance secondary school students' understanding and performance in physics

Based on the review papers, there are five advantages identified in metacognition for secondary school physics education studies. Table 3 presents a summary of the advantages. The review identified five key advantages of integrating metacognitive strategies into secondary school physics education: enhanced conceptual understanding, improved problem-solving skills, increased motivation and engagement, better academic performance, and reduced gender gaps, as shown in Table 3. These advantages highlight the transformative potential of metacognitive strategies in fostering deeper learning and equity in physics education. For instance, several studies [39], [40] demonstrated that metacognitive tools, such as self-regulated learning (SRL) and cognitively activating instruction, significantly improved students' conceptual understanding ($p<0.05$). These strategies encourage students to monitor and regulate their thought processes, leading to better comprehension and retention of complex physics concepts. Similarly, research by Wade-Jaimes *et al.* [41] emphasized the role of interactive questioning and reflection in supporting students' conceptual trajectories, moving beyond rote memorization to achieve meaningful learning outcomes.

Table 3. Summarizes the advantages

Advantages	Explanation
Enhanced conceptual understanding	Metacognitive strategies, such as SRL and cognitively activating instruction, help students develop a deeper comprehension with regard to physics concepts as well as the ability to connect ideas more effectively. By encouraging students to determine their own thinking processes, these strategies promote better comprehension and retention of complex topics.
Improved problem-solving skills	Metacognitive instruction aids in the development of effective problem-solving skills. Students learn to plan, monitor, and evaluate their approach to solving physics problems, leading to more systematic and successful problem-solving efforts. By reassuring students to monitor their thought processes as well as evaluate their approaches to problem-solving, metacognition fosters the development of more effective strategies for tackling complex physics problems.
Increased motivation and engagement	Incorporating metacognitive strategies can boost students' motivation and engagement in physics. By adopting a sense of autonomy and self-efficacy, students become more invested in their learning process. Metacognition encourages students to secure ownership of their learning process, which can lead to higher levels of motivation and engagement in physics activities.
Better academic performance	Metacognitive strategies have been linked to improved academic performance in physics. By helping students develop better study habits and self-assessment skills, these strategies contribute to higher test scores and overall academic achievement. Those who employ metacognitive strategies tend to perform better academically, as they are more aware of their learning processes and can adjust their strategies accordingly.
Reduction of gender gaps	Metacognitive instruction can help reduce gender gaps in physics education. By providing equal opportunities for both boys and girls to develop metacognitive skills, these strategies can level the playing field and promote gender equity in academic performance. Metacognitive interventions can help address disparities in self-efficacy and identity in physics, particularly among different genders, potentially leading to a reduction in the gender gap in physics education.

Improved problem-solving skills were another significant advantage identified in the review. Metacognitive scaffolding and SRL strategies were shown to enhance students' ability to plan, monitor, and evaluate their approaches to solving physics problems [42], [43]. For example, Winarti *et al.* [43] reported that problem-solving-based SRL strategies significantly boosted students' metacognitive abilities, which in turn improved their problem-solving performance (effect size=0.45). Additionally, Moser *et al.* [44] highlighted the value of metacognitive scaffolding during simulation-based learning, which resulted in better learning outcomes and more systematic problem-solving approaches. These findings align with prior research, which underscores the importance of metacognitive strategies in equipping students with the tools to tackle complex physics problems with confidence and competence.

Increased motivation and engagement in physics education were also strongly linked to the integration of metacognitive strategies. Context-based tasks, cooperative learning techniques, and formative feedback were particularly effective in fostering student interest and active participation [45]–[47]. For instance, Pozas *et al.* [47] found that problem-solving tasks based on real-world contexts significantly improved students' situational interest and metacognitive experiences, though the effects varied depending on the physics topic. Similarly, the jigsaw technique, a form of cooperative learning, was shown to boost students' motivation and metacognitive awareness, leading to improved academic performance [29]. These findings suggest that diverse, interactive, and feedback-rich educational strategies can significantly enhance student engagement and motivation in physics learning.

Better academic performance was another key outcome associated with metacognitive strategies. Previous studies [17], [48] demonstrated that direct instruction of metacognitive skills significantly improved students' motivation, learning, and ability to transfer knowledge, resulting in higher test scores and overall academic achievement. For example, study by Abdullah *et al.* [49] reported that metacognitive knowledge-based teaching materials used during online learning improved students' metacognitive analysis skills, leading to better learning outcomes compared to conventional methods ($p<0.01$). Additionally, study by Bogdanović *et al.* [18] highlighted the effectiveness of the modified know-want-learn strategy in fostering deeper understanding and retention of knowledge, particularly in mixed-gender physics classrooms. These findings underscore the importance of integrating metacognitive instruction into physics education to enhance students' academic success [50].

Finally, the review highlighted the potential of metacognitive strategies to reduce gender gaps in physics education. Cognitively activating instruction, which includes methods such as metacognitive questioning and inventing with contrasting cases, was shown to benefit female students with above-average intelligence, helping to minimize gender disparities in physics achievement [51]. Additionally, Ulu and Yerdelen-Damar [25] found that while male students scored higher in physics identity and self-efficacy, interventions aimed at improving self-efficacy among female students could help bridge these gaps. These findings emphasize the importance of employing instructional strategies that enhance metacognitive skills and self-efficacy, thereby promoting equity in educational outcomes across genders.

In conclusion, the integration of metacognitive strategies into secondary school physics education offers significant advantages, including improved conceptual understanding, problem-solving skills, motivation, academic performance, and gender equity. Compared to previous studies, this review provides a comprehensive synthesis of these benefits while also highlighting the practical challenges of implementation. By addressing these challenges and adopting evidence-based metacognitive interventions, educators can create a more inclusive and effective physics education environment that fosters deeper learning and equitable outcomes for all students.

3.3. The challenges educators face when integrating metacognitive strategies into secondary school physics curricula

According to the review papers, five challenges have been identified in the study of metacognition within secondary school physics education. Table 4 presents a summary of the challenges. Five key challenges were identified in integrating metacognitive strategies into secondary school physics education: implementation complexity, time constraints, student resistance, assessment difficulties, and variability in effectiveness (Table 4). These challenges highlight the complexities of incorporating metacognitive practices into existing curricula and underscore the need for targeted interventions to address these barriers. For instance, implementation complexity arises from the need for teachers to be well-trained in cognitively activating instruction and metacognitive questioning, which require both content expertise and pedagogical skills [51]. Previous studies [43], [49] emphasize that effective instructional designs must consistently incorporate metacognitive activities, which can be difficult to implement without adequate support and training. These findings align with prior research, which highlights the importance of comprehensive teacher training programs to ensure the successful integration of metacognitive strategies.

Table 4. Summary of the challenges

Challenges	Explanation
Implementation complexity	Implementing metacognitive strategies effectively requires careful planning and execution. Teachers need to be well-trained in these strategies and understand how to integrate them into their existing curriculum. Cognitively activating instruction requires teachers to apply complex methods, which include inventing with contrasting cases or metacognitive questions, which can be challenging without adequate support and training. Mandating that teachers possess a thorough grasp of both the content and the metacognitive processes involved. A need for effective instructional designs that incorporate metacognitive activities, which can be complex to implement consistently across different teaching contexts.
Time constraints	Incorporating metacognitive strategies often requires additional time for activities such as reflection, self-assessment, and collaborative discussions. This can be difficult to manage within the constraints of a typical school schedule. The necessity of giving students ample time to explore and develop multiple models which can be challenging in time-limited classroom settings. The limited time available in the curriculum makes it essential to balance content coverage with metacognitive instruction.
Student resistance	Students may initially resist metacognitive strategies, especially if they are accustomed to more traditional, teacher-centered approaches. The shift to SRL and metacognitive monitoring can be challenging for students who are not used to taking an active role in their learning process. Note that the effectiveness of metacognitive interactions can vary depending on students' willingness to engage in these practices. This resistance can stem from a lack of understanding of metacognitive strategies or a preference for more traditional learning methods.
Assessment challenges	Assessing metacognitive skills can be more complex than evaluating traditional academic performance, as traditional assessment methods may not adequately capture students' metacognitive awareness and strategies. Standardized tests may not adequately capture students' metacognitive abilities, requiring the development of new assessment tools and methods. There is a need for reliable and valid assessment instruments.
Variability in effectiveness	The effectiveness of metacognitive strategies can vary widely among students, relying on factors such as prior knowledge, motivation, and individual differences in cognitive and metacognitive abilities. Differences in how students used metacognitive strategies, influenced by intrinsic motivation, gender, and perceived autonomy support, suggest that a one-size-fits-all approach may be inefficient. Factors that include learning styles, prior knowledge, and individual differences can influence how well students respond to metacognitive training, leading to inconsistent outcomes.

Time constraints are another significant challenge, as incorporating metacognitive strategies often requires additional time for activities such as reflection, self-assessment, and collaborative discussions. Many classrooms face limitations in time, making it difficult to balance content coverage with metacognitive instruction [41]. For example, research by Yerdelen-Damar and Eryılmaz [52] found that integrating metacognitive instruction with explicit epistemic interventions significantly enhanced students' conceptual understanding, but this approach required sufficient time for students to engage deeply with the material. To address this challenge, educators must find innovative ways to integrate metacognitive strategies within the limited time available, such as embedding reflective practices into existing lesson plans [18], [40].

Student resistance to metacognitive strategies is another barrier, particularly among those accustomed to traditional, teacher-centered approaches. Several studies [48], [53] highlight that students' personal epistemologies, such as their beliefs about knowledge and learning, significantly influence their willingness to engage in metacognitive practices. For instance, students with rigid or simplistic views about knowledge may resist questioning and reflecting on their learning processes. Addressing this resistance requires reshaping students' epistemological beliefs and enhancing their intrinsic motivation through targeted interventions. For example, Langdon *et al.* [50] demonstrated that integrating metacognitive instruction with efforts to develop students' understanding of knowledge and learning can create a more receptive environment for metacognitive practices.

Assessment challenges also pose significant barriers, as traditional methods often fail to capture the dynamic nature of metacognitive engagement. For example, Pozas *et al.* [47] found that context-based problem-solving tasks revealed a decline in students' interest and perceived accuracy of solutions over time, suggesting that traditional assessments may not adequately reflect students' metacognitive processes. To address this issue, innovative assessment tools are needed to accurately measure students' metacognitive skills and their impact on learning outcomes [29], [54]. These tools should account for variables such as physics topics, individual differences, and the dynamic nature of metacognitive engagement, enabling educators to better understand and support students' development.

Variability in the effectiveness of metacognitive strategies highlights the need for personalized interventions. Previous studies [55], [56] identified differences in how students respond to metacognitive strategies, influenced by factors such as intrinsic motivation, gender, and perceived autonomy support. For instance, the results by Molin *et al.* [46] found that cooperative feedback significantly enhanced metacognitive skills and motivation for students with initially low metacognitive abilities, while individual feedback was more beneficial for female students. These findings suggest that a one-size-fits-all approach may be inefficient, and tailored interventions are necessary to maximize the effectiveness of metacognitive strategies. By considering individual learner characteristics, educators can design personalized approaches that address the diverse needs of students and ensure equitable outcomes.

In conclusion, the integration of metacognitive strategies into secondary school physics education involves several significant challenges, including implementation complexity, time constraints, student resistance, assessment difficulties, and variability in effectiveness. Addressing these challenges requires comprehensive teacher training, innovative instructional designs, and the development of reliable assessment tools. Additionally, personalized interventions that consider individual learner characteristics are essential to ensure that all students can benefit from metacognitive instruction. By overcoming these barriers, educators can enhance the effectiveness of metacognitive strategies, ultimately improving students' conceptual understanding, motivation, and academic achievement in physics education.

4. CONCLUSION

This systematic review highlights the significant potential of metacognitive strategies to address the challenges posed by the conceptual complexity of physics education for secondary school students. By analyzing 25 studies from 2014 to 2024, this review identifies key trends, advantages, and challenges associated with these strategies. The findings demonstrate that metacognitive strategies significantly enhance students' conceptual understanding, problem-solving skills, motivation, engagement, and academic performance, while also helping to reduce gender gaps. Despite these benefits, challenges such as implementation complexity, time constraints, student resistance, assessment difficulties, and variability in effectiveness must be addressed. To maximize the impact of metacognitive strategies in physics education, it is essential to provide comprehensive teacher training and develop innovative instructional designs. Future research should focus on creating tailored approaches and developing innovative assessment methods to optimize the implementation of metacognitive strategies across diverse educational contexts. By doing so, educators can transform physics education, making it more accessible and equitable for all students, ultimately leading to improved educational outcomes.

However, the study has several limitations. One of the limitations are the scope of the literature may affect the representation of each aspect studied, as some relevant literature might have been missed despite rigorous search and selection methods. Besides that, there is potential for assessment bias in evaluating the quality of the included literature, as the assessment remains subjective despite consistent application of quality criteria. Limited time resources may have impacted the depth of analysis and synthesis also. Future studies should focus on identifying essential elements that optimize to incorporating metacognitive strategies into secondary school physics education and examining internal and external influencing factors.

Researchers should also explore the potential impact of metacognitive strategies by focusing on teaching methods that enhance students' conceptual understanding, enabling them to grasp physics concepts more deeply and connect ideas, which leads to better comprehension and retention. This includes selecting and using suitable instructional models to encourage metacognitive strategies. These findings provide actionable insights for educators, researchers and policymakers by emphasizing the need for comprehensive teacher training, innovative instructional designs, and tailored interventions to address implementation challenges, while also promoting equity in physics education through strategies that reduce gender gaps and enhance student outcomes.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
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R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

No conflicts of interest, whether financial, personal or professional related to this manuscript.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

REFERENCES

[1] J. M. Cardino and R. A. O.-D. Cruz, "Understanding of learning styles and teaching strategies towards improving the teaching and learning of mathematics," *LUMAT: International Journal on Math, Science and Technology Education*, vol. 8, no. 1, pp. 19–43, May 2020, doi: 10.31129/LUMAT.8.1.1348.

[2] D. Wangchuk, D. Wangdi, S. Tshomo, and J. Zangmo, "Exploring students' perceived difficulties of learning physics," *Educational Innovation and Practice*, vol. 6, pp. 1–11, May 2023, doi: 10.17102/eip.6.2023.03.

[3] Z. Abulhul, "Teaching strategies for enhancing student's learning," *Journal of Practical Studies in Education*, vol. 2, no. 3, pp. 1–4, Apr. 2021, doi: 10.46809/jpse.v2i3.22.

[4] O. Yalçin and F. Sadik, "Examining the cognitive and affective changes in students through the implementation process of the physics curriculum based on an interdisciplinary context-based learning approach," *Thinking Skills and Creativity*, vol. 54, p. 101672, Dec. 2024, doi: 10.1016/J.TSC.2024.101672.

[5] H. Özçakmak, "The effect of metacognitive awareness on academic success," *African Educational Research Journal*, vol. 9, no. 2, pp. 434–448, May 2021, doi: 10.30918/AERJ.92.21.020.

[6] I. Z. Bogdanovic, D. D. Rodic, T. N. Roncevic, J. D. Stanisavljevic, and Z. A. M. Zouhor, "The relationship between elementary students' physics performance and metacognition regarding using modified know-want-learn strategy," *International Journal of Science and Mathematics Education*, vol. 20, no. 8, pp. 1907–1926, 2022, doi: 10.1007/s10763-021-10231-9.

[7] H. Sapulete, F. Sopacua, and V. Sopacua, "The analysis of students' metacognitive skills in physics through problem-solving strategies in physics education students," *Jurnal Penelitian Pendidikan IPA*, vol. 10, no. 7, pp. 4453–4460, Jul. 2024, doi: 10.29303/jppipa.v10i7.7102.

[8] E. Dessie, D. Gebeyehu, and F. Eshetu, "Enhancing critical thinking, metacognition, and conceptual understanding in introductory physics: The impact of direct and experiential instructional models," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 19, no. 7, p. em2287, 2023, doi: 10.29333/ejmste/13273.

[9] S. Rahayu and E. Hertanti, "Students' metacognitive awareness and physics problem solving ability and correlation between them," *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, vol. 9, no. 2, pp. 207–215, Oct. 2020, doi: 10.24042/jipfalbiruni.v9i2.6009.

[10] G. Schraw and R. S. Dennison, "Assessing metacognitive awareness," *Contemporary Educational Psychology*, vol. 19, no. 4, pp. 460–475, 1994, doi: 10.1006/ceps.1994.1033.

[11] M. B., M. Abd. Malik, and Badaruddin, "The effectiveness of metacognitive-based learning model," *Journal of Physics: Conference Series*, vol. 1028, no. 1, pp. 7–11, 2018, doi: 10.1088/1742-6596/1028/1/012084.

[12] S. Avargil, R. Lavi, and Y. J. Dori, "Students' Metacognition and Metacognitive Strategies in Science Education," in *Cognition, Metacognition and Culture in STEM Education*, Y. J. Dori, Z. R. Mevarech, and D. R. Baker, Cham: Springer International Publishing, 2018, pp. 33–64, doi: 10.1007/978-3-319-66659-4_3.

[13] W. Nurhidayat, E. Surahman, and E. Sujarwanto, "The effect of conceptual understanding procedures learning model on students' higher level thinking skills," *JPI (Jurnal Pendidikan Indonesia)*, vol. 12, no. 2, pp. 386–394, Jun. 2023, doi: 10.23887/jpiundiksha.v12i2.58709.

[14] J. D. Stanton, A. J. Sebesta, and J. Dunlosky, "Fostering Metacognition to Support Student Learning and Performance," *CBE—Life Sciences Education*, vol. 20, no. 2, pp. 1–7, Jun. 2021, doi: 10.1187/cbe.20-12-0289.

[15 C. Wider and W. Wider, "Effects of metacognitive skills on physics problem-solving skills among form four secondary school students," *Journal of Baltic Science Education*, vol. 22, no. 2, pp. 357–369, 2023, doi: 10.33225/jbse/23.22.257.

[16] V. Džinović, R. Dević, and I. Derić, "The role of self-control, self-efficacy, metacognition, and motivation in predicting school achievement," *Psihologija*, vol. 52, no. 1, pp. 35–52, 2019, doi: 10.2298/PSI180202027D.

[17] I. Bogdanović, D. Ž. Obadović, S. Cvjetićanin, M. Segedinac, and S. Budić, "Students' metacognitive awareness and physics learning efficiency and correlation between them," *European Journal of Physics Education*, vol. 6, no. 2, pp. 18–30, 2015, doi: 10.20308/ejpe.96231.

[18] I. Z. Bogdanović, J. D. Stanisavljević, D. D. Rodić, T. N. Rončević, and Z. A. M. Zouhor, "The impact of using the modified Know-Want-Learn strategy in physics teaching on students' metacognition," *South African Journal of Education*, vol. 42, no. 4, pp. 1–14, 2022, doi: 10.15700/saje.v42n4a2096.

[19] E. Dessie, D. Gebeyehu, and F. Eshetu, "Motivation, conceptual understanding, and critical thinking as correlates and predictors of metacognition in introductory physics," *Cogent Education*, vol. 11, no. 1, p. 2290114, 2024, doi: 10.1080/2331186X.2023.2290114.

[20] G. Liu and N. Fang, "Student misconceptions about force and acceleration in physics and engineering mechanics education," *International Journal of Engineering Education*, vol. 32, no. 1(A), pp. 19–29, 2016, doi: 10.1080/08957347.2011.554604.

[21] R. A. Hidayati and M. R. A. Taqwa, "Computer based recitation program development with feedback in Newton's law topic," *International Journal of Education and Teaching Zone*, vol. 2, no. 1, pp. 113–129, Feb. 2023, doi: 10.57092/ijetz.v2i1.49.

[22] T. Neidorf, A. Arora, E. Erberber, Y. Tsokodayi, and T. Mai, "An Introduction to Student Misconceptions and Errors in Physics and Mathematics," in *Student Misconceptions and Errors in Physics and Mathematics: Exploring Data from TIMSS and TIMSS Advanced*, T. Neidorf, A. Arora, E. Erberber, Y. Tsokodayi, and T. Mai, Eds., Cham: Springer International Publishing, 2020, pp. 1–10, doi: 10.1007/978-3-030-30188-0_1.

[23] T. N. Diyana, Sutopo, and Sunaryono, "The effectiveness of web-based recitation program on improving students' conceptual understanding in fluid mechanics," *Jurnal Pendidikan IPA Indonesia*, vol. 9, no. 2, pp. 219–230, Jun. 2020, doi: 10.15294/jpii.v9i2.24043.

[24] M. Modi, "Meta-cognition-Driven Problem Solving in Physics Education," *Graduate Journal of Interdisciplinary Research, Reports and Reviews*, vol. 2, no. 2, pp. 110–118 2024, doi: 10.34256/gjir3.v2i02.32.

[25] Y. Ulu and S. Yerdelen-Damar, "Metacognition and epistemic cognition in physics are related to physics identity through the mediation of physics self-efficacy," *Physical Review Physics Education Research*, vol. 20, no. 1, p. 010130, 2024, doi: 10.1103/PhysRevPhysEducRes.20.010130.

[26] A. M. Amin and R. Adiansyah, "Identification of preservice biology teachers' metacognitive awareness and metacognitive skills," in *Journal of Physics: Conference Series*, vol. 1511, no. 1, 2020, p. 012029, Mar., doi: 10.1088/1742-6596/1511/1/012029.

[27] Haeruddin, Z. K. Prasetyo, and Supahar, "The development of a metacognition instrument for college students to solve physics problems," *International Journal of Instruction*, vol. 13, no. 1, pp. 767–782, 2020, doi: 10.29333/iji.2020.13149a.

[28] A. Reinhard, A. Felleson, P. C. Turner, and M. Green, "Assessing the impact of metacognitive postreflection exercises on problem-solving skillfulness," *Physical Review Physics Education Research*, vol. 18, no. 1, p. 010109, Jun. 2022, doi: 10.1103/PhysRevPhysEducRes.18.010109.

[29] B. K. Blajvaz, I. Z. Bogdanović, T. S. Jovanović, J. D. Stanisavljević, and M. V. Pavkov-Hrvojević, "The Jigsaw technique in lower secondary physics education: Students' achievement, metacognition and motivation," *Journal of Baltic Science Education*, vol. 21, no. 4, pp. 545–557, 2022, doi: 10.33225/jbse/22.21.545.

[30] J. Willison *et al.*, "Metacognitively ALERT in science: literature synthesis of a hierarchical framework for metacognition and preliminary evidence of its viability," *Studies in Science Education*, 2023, vol. 60, no. 2, pp. 153–189, doi: 10.1080/03057267.2023.2207147.

[31] H. Hamzah, M. I. Hamzah, and H. Zulkifli, "Systematic literature review on the elements of metacognition-based higher order thinking skills (HOTS) teaching and learning modules," *Sustainability (Switzerland)*, vol. 14, no. 2, p. 813, 2022, doi: 10.3390/su14020813.

[32] D. S. Fleur, B. Bredeweg, and W. van den Bos, "Metacognition: ideas and insights from neuro- and educational sciences," *Nature Partner Journals Science of Learning*, vol. 6, no. 1, p. 13, 2021, doi: 10.1038/s41539-021-00089-5.

[33] N. S. Wilson and H. Bai, "The relationships and impact of teachers' metacognitive knowledge and pedagogical understandings of metacognition," *Metacognition and Learning*, vol. 5, no. 3, pp. 269–288, 2010, doi: 10.1007/s11409-010-9062-4.

[34] M. X. Zhang, J. Morphew, and T. Stelzer, "Impact of more realistic and earlier practice exams on student metacognition, study behaviors, and exam performance," *Physical Review Physics Education Research*, vol. 19, no. 1, p. 010130, 2023, doi: 10.1103/PhysRevPhysEducRes.19.010130.

[35] U. Rasheed and J. M. Zafar, "Effect of metacognitive strategies on secondary school students to achieve sustainable learning skills," *Academy of Education and Social Sciences Review*, vol. 3, no. 4, pp. 521–529, Nov. 2023, doi: 10.48112/aessr.v3i4.601.

[36] B. Smela, M. Toumi, K. Świerk, K. Gawlik, E. Clay, and L. Boyer, "Systematic literature reviews over the years," *Journal of Market Access and Health Policy*, vol. 11, no. 1, p. 2244305, 2023, doi: 10.1080/20016689.2023.2244305.

[37] M. J. Page *et al.*, "PRISMA 2020 explanation and elaboration: Updated guidance and exemplars for reporting systematic reviews," *The British Medical Journal*, vol. 372, p. n160, Mar. 2021, doi: 10.1136/bmj.n160.

[38] E. Schvirck, C. Lievore, P. Rubbo, J. R. H. Cantorani, and L. A. Pilatti, "Invisible publications: A study of academic productivity in the Web of Science database," *Revista Espanola de Documentacion Cientifica*, vol. 47, no. 1, p. e375, 2024, doi: 10.3989/redc.2024.1.1454.

[39] Maison, Syahrial, Syamsurizal, and Tanti, "Learning environment, students' beliefs, and self-regulation in learning physics: Structural equation modeling," *Journal of Baltic Science Education*, vol. 18, no. 3, pp. 389–403, 2019, doi: 10.33225/jbse/19.18.389.

[40] J. M. Nixson, K. Waras, S. Eddy, and Widiyanti, "Effectiveness of Matlab-based learning and thinking styles (internal-external) on students' higher order thinking skills," *International Journal of Instruction*, vol. 17, no. 2, pp. 685–706, Apr. 2024, doi: 10.29333/iji.2024.17238a.

[41] K. Wade-Jaimes, K. Demir, and A. Qureshi, "Modeling strategies enhanced by metacognitive tools in high school physics to support student conceptual trajectories and understanding of electricity," *Science Education*, vol. 102, no. 4, pp. 711–743, 2018, doi: 10.1002/sce.21444.

[42] H. S. Wang, S. Chen, and M. H. Yen, "Effects of metacognitive scaffolding on students' performance and confidence judgments in simulation-based inquiry," *Physical Review Physics Education Research*, vol. 17, no. 2, p. 020108, Dec. 2021, doi: 10.1103/PhysRevPhysEducRes.17.020108.

[43] Winarti, S. E. Ambaryani, and H. Putranta, "Improving learners' metacognitive skills with self-regulated learning based problem-solving," *International Journal of Instruction*, vol. 15, no. 2, pp. 139–154, 2022, doi: 10.29333/iji.2022.1528a.

[44] S. Moser, J. Zumbach, and I. Deibl, "The effect of metacognitive training and prompting on learning success in simulation-based physics learning," *Science Education*, vol. 101, no. 6, pp. 944–967, Nov. 2017, doi: 10.1002/sce.21295.

[45] J. Malmberg, O. Fincham, H. J. Pijeira-Díaz, S. Järvelä, and D. Gasevic, "Revealing the hidden structure of physiological states during metacognitive monitoring in collaborative learning," *Journal of Computer Assisted Learning*, vol. 37, no. 3, pp. 861–874, 2021, doi: 10.1111/jcal.12529.

[46] F. Molin, S. Cabus, C. Haelermans, and W. Groot, "Toward reducing anxiety and increasing performance in physics education: evidence from a randomized experiment," *Research in Science Education*, vol. 51, no. Suppl 1, pp. 233–249, 2021, doi: 10.1007/s11165-019-9845-9.

[47] M. Pozas, P. Loffler, W. Schnotz, and A. Kauertz, "The effects of context-based problem-solving tasks on students' interest and metacognitive experiences," *Open Education Studies*, vol. 2, no. 1, pp. 112–125, 2020, doi: 10.1515/edu-2020-0118.

[48] E. Bahufite, S. Kasonde-Ng'andu, and A. Akakandelwa, "The relationships between learners' academic achievement due to the use of constructivist methods in physical science and their self-esteem in Zambian secondary schools," *Social Sciences and Humanities Open*, vol. 8, no. 1, p. 100632, Jan. 2023, doi: 10.1016/j.ssaho.2023.100632.

[49] H. Abdullah, J. D. Malago, and K. Arafah, "The implementation of physics learning through online mode during pandemic COVID-19 using metacognitive knowledge-based materials," *Jurnal Pendidikan IPA Indonesia*, vol. 10, no. 2, pp. 220–227, 2021, doi: 10.15294/jpii.v10i2.28583.

[50] X. J. Langdon *et al.*, "Examining the effects of different teaching strategies on metacognition and academic performance," *Advances in Physiology Education*, vol. 43, no. 3, pp. 414–422, 2019, doi: 10.1152/advan.00013.2018.-The.

[51] S. I. Hofer, R. Schumacher, H. Rubin, and E. Stern, "Enhancing physics learning with cognitively activating instruction: A quasi-experimental classroom intervention study," *Journal of Educational Psychology*, vol. 110, no. 8, pp. 1175–1191, Nov. 2018, doi: 10.1037/edu0000266.

[52] S. Yerdelen-Damar and A. Eryılmaz, "Promoting conceptual understanding with explicit epistemic intervention in metacognitive instruction: Interaction between the treatment and epistemic cognition," *Research in Science Education*, vol. 51, no. 2, pp. 547–575, 2021, doi: 10.1007/s11165-018-9807-7.

[53] M. M. Alpaslan, B. Yalvac, C. C. Loving, and V. Willson, "Exploring the relationship between high school students' physics-related personal epistemologies and self-regulated learning in Turkey," *International Journal of Science and Mathematics Education*, vol. 14, no. 2, pp. 297–317, Mar. 2016, doi: 10.1007/s10763-015-9685-7.

[54] M. I. Sukarelawan, H. Kuswanto, and M. A. Thohir, "The Indonesian version of the physics metacognition inventory: Confirmatory factor analysis and Rasch model," *European Journal of Educational Research*, vol. 10, no. 4, pp. 2133–2144, 2021, doi: 10.12973/EU-JER.10.4.2133.

[55] D. Kwarikunda, U. Schiefele, C. M. Muwonge, and J. Ssenyonga, "Profiles of learners based on their cognitive and metacognitive learning strategy use: occurrence and relations with gender, intrinsic motivation, and perceived autonomy support," *Humanities and Social Sciences Communications*, vol. 9, no. 1, pp. 1–12, Dec. 2022, doi: 10.1057/s41599-022-01322-1.

[56] F. Molin, C. Haelermans, S. Cabus, and W. Groot, "The effect of feedback on metacognition - A randomized experiment using polling technology," *Computers & Education*, vol. 152, p. 103885, 2020, doi: 10.1016/j.compedu.2020.103885.

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