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Thinking About Thinking in Physics: A Systematic Review on Metacognitive Approaches for Secondary Students

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Abstract: This review examines the literature on metacognitive strategies implemented in high school physics from 2021 to 2025, using Schraw's control framework, which encompasses planning, monitoring, and evaluation. The goal is to identify structural weaknesses that hinder overall theoretical progress and practical application in the classroom. Using PRISMA principles, an article search in ERIC yielded 244 documents, 22 of which were Scopus-indexed studies that met the criteria. We outline study designs, evaluation instruments, types of interventions, participants, and study objectives. A thematic synthesis addressed three guiding questions: (1) which instructional strategies contribute to metacognitive growth, (2) which evaluative instruments were used, and (3) what implementation conditions and challenges exist. Four main intervention categories were identified. Cognitive-reflective strategies foster self-awareness and introspection. Various inquiry methods combine metacognitive control with scientific investigation. Tools that aid visualization and representation of concepts, particularly simulations and concept maps, are key to organizing and maintaining coherent information. Gender-sensitive sociocultural and affective strategies foster motivation and inclusivity. All studies reported that these interventions had positive impacts on problem-solving, self-efficacy, and conceptual understanding. However, based on Schraw's hypothesis, this review identified planning as the most underdeveloped and neglected aspect of metacognitive regulation. Most studies relied heavily on self-reporting, leaving limited opportunities for task-embedded or multimodal assessments. Most designs were quasi-experimental or survey-based, and very few included mixed-methods or technology-mediated assessments. This research suggests combining structured insights, including goal setting, preemptive questioning, and activity design, with authentic assessments such as portfolios and think-aloud rubrics. Using these approaches within an equity-centered and culturally responsive pedagogy can foster active and self-directed learning in physics. Future research should aim to expand planning elements, diversify assessment techniques, and use educational technology to enhance and simplify metacognitive instruction in instructional design.

Keywords: metacognition, physics education, high school students, systematic literature review, thinking awareness.

▪ INTRODUCTION

Students are expected to take greater ownership of their learning in the challenging scientific areas post-pandemic (Cardino & Cruz, 2020; Wangchuk et al., 2023). In this situation, learning autonomy is a necessary competency for grasping more abstract and complex constructs, especially in subjects like physics. Metacognition, in its simplest form, is the most powerful tool for developing autonomy (Schraw & Dennison, 1994; Özçakmak, 2021). A student with strong cognitive awareness will choose their strategies purposefully, isolate and fix the major problematic areas, and engage in critical analysis of the learning process.

The field of physics presents complex abstractions and multi-representational reasoning, which result in unique cognitive challenges for learners. These included

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reasoning that cannot be represented with a diagram and widespread misconceptions (Neidorf et al., 2020; Abulhul, 2021). In fact, students appear to struggle with learning the fundamentals of physics due to a lack of self-regulated learning, particularly in the cognitive processes of planning, monitoring, and controlling (Bogdanovic et al., 2022; Yalcin & Sadik, 2024). This is indeed the reason that the focus in science education has been directed towards the development of self-regulatory skills. In recent years, the educational framework has purported to reduce the need for other prompts (e.g., singing) as it is common for students to demonstrate some post-task self-regulation (Willison et al., 2023; Dessie et al., 2023). Nonetheless, it is the planning and control regulatory that remains deficient (Langdon et al., 2019; Liu & Fang, 2016).

A valuable way to investigate how people utilize metacognitive skills is Schraw's metacognitive regulation framework, which includes three aspects: planning, monitoring, and evaluation (Schraw & Moshman, 1995). This three-part model is especially relevant to science education because, in addition to strategically designing and selecting appropriate methods, students formulate and assess a plan to track conceptual progress and determine how to revise their methods in response to the outcome. Within the field of physics education, the framework has been used to investigate how specific pedagogical approaches, such as inquiry-based learning, concept mapping, and guided problem-solving, target particular areas of metacognitive regulation (Reinhard et al., 2022; Wade-Jaimes et al., 2018). Sadly, the most foundational phase, planning, continues to be the most underrepresented (Ulu & Yerdelen-Damar, 2024).

Research on metacognition in physics education still relies heavily on the Metacognitive Awareness Inventory (MAI) and self-report methods (Stanton et al., 2021; Abulhul, 2021). Despite the growing use of qualitative approaches, such as the think-aloud method and reflective journals (Zhang et al., 2023; Reinhard et al., 2022), these approaches still struggle to capture real-time regulatory processes and demonstrate inconsistent application across different teaching settings. In addition to the aforementioned issues, disparate study designs and variations in curriculum standards, as well as combinations of instructional modalities (e.g., online, hybrid, and traditional classroom), add even more to the difficulty of assessing and teaching metacognitive strategies (Dessie et al., 2023; Malmberg et al., 2021).

Frequently, reviews within the literature focus on instructional methods or evaluation techniques in a somewhat disjointed manner, stemming from the absence of robust, cohesive connections among metacognitive theory integration (Willison et al., 2023; Bogdanovic et al., 2022). A significant portion of the literature remains concentrated on the evaluation and monitoring phases of metacognition, largely ignoring the planning level of metacognition, which is essential for attaining conceptual understanding in physics (Yalçin & Sadik, 2024; Langdon et al., 2019). This creates a gap in knowledge regarding the extent to which certain teaching methods implement other levels of metacognition, and whether the respective and appropriate assessment methods enable and capture such levels. Additionally, there is a gap in the reviews that explore the interplay between educational context, specifically the technological modalities of instructional design, teaching methods, and the development of metacognition (Wang et al., 2021; Dessie et al., 2023).

The recently published systematic reviews, synthesising studies from 2021 to 2025, do show an increasing focus on the area, but point to three main and significant gaps. The first gap is that, while there is a focus on inquiry and problem-solving, there is little evidence of instruction and teaching that focuses on the planning phase of metacognition. The second gap is that most assessments still heavily rely on self-report instruments such as the MAI. At the same time, there remains a lack of studies that deploy novel instruments designed to capture real-time metacognitive monitoring and other self-regulatory processes. The third gap is that the vast majority of research designs are still predominantly quasi-experimental, situated in traditional classrooms, and largely unexplored remain hybrid or technology-mediated instructional contexts.

This systematic review, focusing on the years 2021–2025, seeks to fill the gaps in the literature based on the following three research questions: (RQ1) What learning strategies have been used to build metacognitive skills in the discipline of physics education? (RQ2) Among these studies, in what way have metacognitive skills been evaluated, and what assessment tools have been used? (RQ3) What are the described research designs, educational contexts, and challenges within implementation, and what effect do these have on the teaching of metacognition in physics?

This review aims to provide a comprehensive overview of the field and offers practical suggestions for educators and researchers seeking to enhance metacognitive practices in the physics classroom. This systematic review is the first of its kind to study metacognitive practices in the literature on secondary physics education specifically. This is an important step to take, given the scarce literature on metacognition in secondary education physics. This is a departure from most literature, which typically positions metacognition within the broader context of science, technology, engineering, and mathematics (STEM) education or the broader field of science education. This review analyzes literature specifically in the field of physics education to identify trends, advantages, and challenges from 2021 to 2025. This research expands the understanding of how to incorporate metacognitive strategies into physics instruction, moving toward a more research-focused and inclusive approach to teaching and learning.

▪ METHOD

This systematic review was directed to explore the impact of metacognitive strategies on the performance of high school students in learning physics, following the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 (Page et al., 2021). PRISMA delivers the latest standards in the process of identification, selection, assessment, and synthesis of articles, so that transparency and accuracy in the study library are increased.

This study aims not only to synthesize empirical evidence on metacognitive strategies in physics learning but also to highlight the methodological rigor and thematic patterns emerging from recent research. The review aligns with contemporary trends emphasizing the integration of metacognition into science education curricula to enhance learning outcomes and transparency in systematic reviews. This is in line with the contemporary trend study emphasizing the integration of science education and metacognition in the curriculum (Yalçin & Sadik, 2024; Sapulete, Sopacua, & Sopacua, 2024; Wider & Wider, 2023). Thus, this SLR becomes a structured process for identifying, evaluating, and interpreting studies that enrich development learning in physics, as well as for developing a future research agenda (Dessie, Gebeyehu, & Eshetu, 2023; Stanton, Sebesta, & Dunlosky, 2021).

Database Source

The primary search was conducted using the Education Resources Information Center (ERIC) database (https://eric.ed.gov/). ERIC was selected for its broad coverage of education-related studies, including physics education. This excellence is why ERIC is relevant for the systematization of research focused on learning physics at the high school level (Bogdanović, Obadović, Cvjetićanin, Segedinac, & Budić, 2015; Liu & Fang, 2016). After retrieval, all articles were manually cross-checked in Scopus to confirm their indexing status and verify the journal's quality. Only studies published in Scopus-indexed journals were retained for synthesis.

Identification

The initial search was conducted using the following keywords: metacognition, physics, high school, and metacognitive. The search was then refined using the filters shown in the following table:

Table 1. The search strings

Database	Search string (Boolean operators and wildcards)	Filters applied	Records identified
ERIC (Education Resources Information Center)	(metacognit* OR "self-regulation" OR "self-regulated learning" OR "reflective thinking" OR "planning" OR "monitoring" OR "evaluation") AND (physics) AND ("high school" OR "secondary school" OR "senior high school" OR "upper secondary")	• Publication date: since 2021 • Education level: High School Students / High Schools • Subject: Physics • Document type: Journal Articles, Research Reports	244

The first stage of the search produced 244 articles. The greatest distribution was from Physical Review Physics Education Research (49 articles), Physics Education (17 articles), Journal of Technology and Science Education (10 articles), Journal of Turkish Science Education (10 articles), Journal of Education and Learning (9 articles), Research in Science Education (7 articles), and several other international journals, each with a smaller number of articles (3-6 articles per journal).

Screening

During the screening phase, the titles and abstracts of the articles are reviewed to ensure relevance. Articles are included when the title or abstract contains explicit keywords (metacognition, metacognitive, monitoring, planning, evaluation, self-regulation, metacognitive instruction, MAI, PMI, SRL, reflective thinking, metacognitive brainstorming) or implicit keywords (strategy/method and clear learning directed at the development of metacognitive skills).

Table 2. The selection criterion is searching

Inclusion Criteria	Exclusion Criteria
The article discusses metacognition in both explicit and implicit ways.	Not relevant to metacognition

Inclusion Criteria	Exclusion Criteria
Research conducted on high school students.	Research conducted outside the high-school level**.**
The subject study should be in the context of learning physics.	Studies not within the domain of physics education**.**
Publication originates from a reputable international journal (Scopus-indexed).	Publications not from reputable peer-reviewed journals (e.g., conference proceedings or grey literature).
Available *full text* with complete empirical data.	Articles without accessible full texts**.**

As shown in Table 2, at this stage, 56 articles met the initial criteria, which included all documents sourced from the high school level (senior high school/secondary school) and centered on the teaching and learning of physics (Rahayu & Hertanti, 2020; Özçakmak, 2021).

Eligibility

In the eligibility phase, articles that successfully passed the screening stage are selected again based on the inclusion and exclusion criteria. All retrieved articles were manually verified in Scopus to confirm journal indexing and eligibility. Out of the 56 articles, 44 were confirmed to be indexed in Scopus, while the 12 articles were non-Scopus and were therefore excluded. After thoroughly reviewing the title, abstract, and the entire content, only 22 articles were retained that fulfilled all the inclusion and exclusion criteria for further analysis (Ulu & Yerdelen- Damar, 2024; Sukarelawan, Kuswanto, & Thohir, 2021; Yerdelen-Damar & Eryılmaz, 2021). This is more clearly illustrated in the following tables.

Table 3. Eligibility process

Exclusion category	Number of articles	Explanation
Non-Scopus journals	12	Excluded because not indexed in Scopus (quality criterion).
Not addressing metacognition in physics education (RQ1–RQ3)	22	Excluded because they did not describe strategies to develop metacognition (RQ1), did not use/mention assessment tools (RQ2), or were outside the senior high school physics context (RQ3).
Total excluded from eligibility	34	–

The articles that did not match the inclusion criteria were eliminated from the synthesis. The selection process at each stage is detailed in Figure 1 (PRISMA 2020 Flow Diagram), which displays the total number of articles identified, screened, excluded, and included in the synthesis.

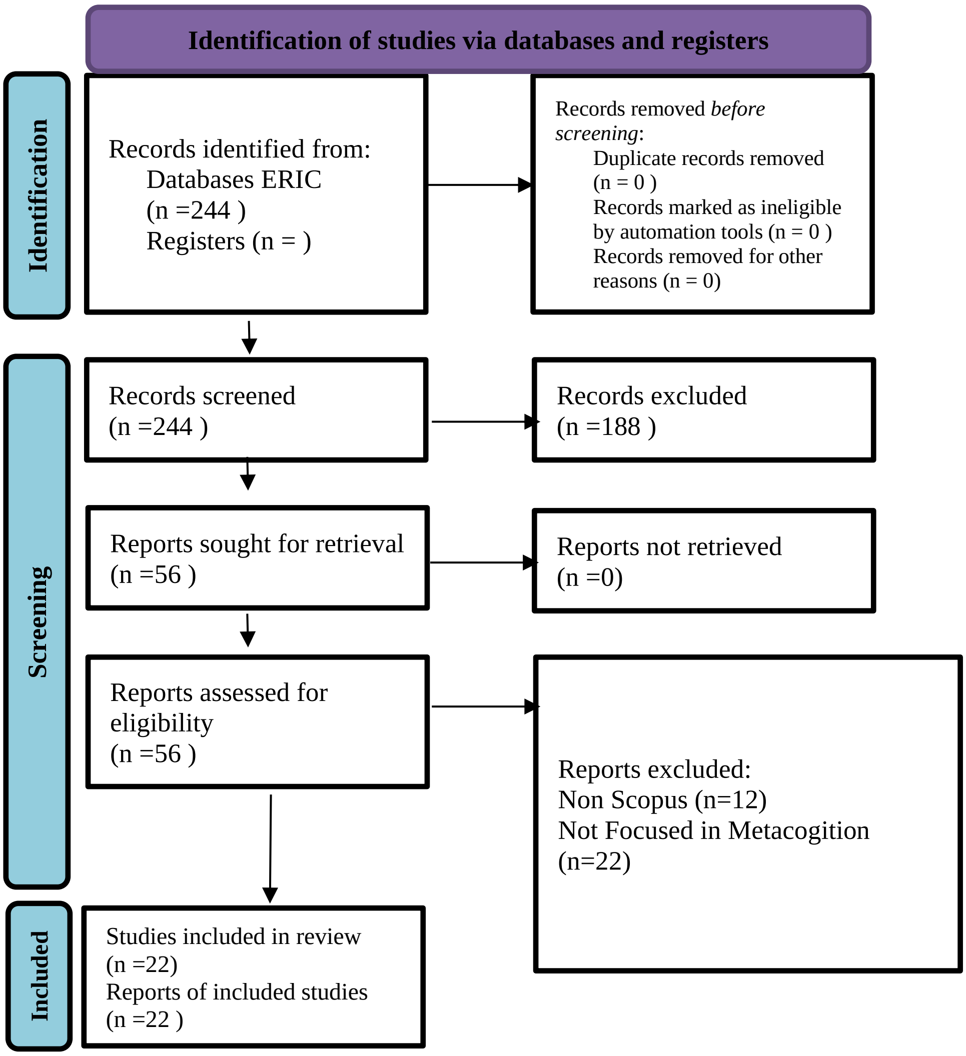

Figure 1. Diagram of the article selection process

Data Extraction and Synthesis

Data extraction for the 22 articles that met the inclusion criteria was conducted systematically. The extracted data included the research objectives, methods, participant numbers, the metacognitive strategies focused on (RQ1), assessment instruments used (RQ2), as well as the research design, educational context, and challenges to implementation (RQ3)

The synthesis involved direct thematic analysis related to the third research question (RQ1–RQ3). Such analyses helped identify trends in learning strategies with respect to metacognitive variations, the assessment instruments used, and the impact of research design and educational context on the integration of metacognition in physics teaching. The synthesized results aimed to provide a detailed description, while also outlining a recommendation for future research focus (Avargil, Lavi, & Dori, 2018; Malmberg, Fincham, Pijeira-Díaz, Järvelä, & Gašević, 2021).

▪ RESULT AND DISSCUSSION

Identifying key themes within metacognitive research on secondary school physics education between 2021 and 2025 highlighted several significant issues. Study output followed an upward trend during this period, peaking in 2022, which correlates with the introduction of novel post-COVID-19 teaching innovations, prompting an additional research focus during this time. Furthermore, this trend suggests an increasing prominence and value of metacognitive strategies aimed at enhancing students' performance in learning physics.

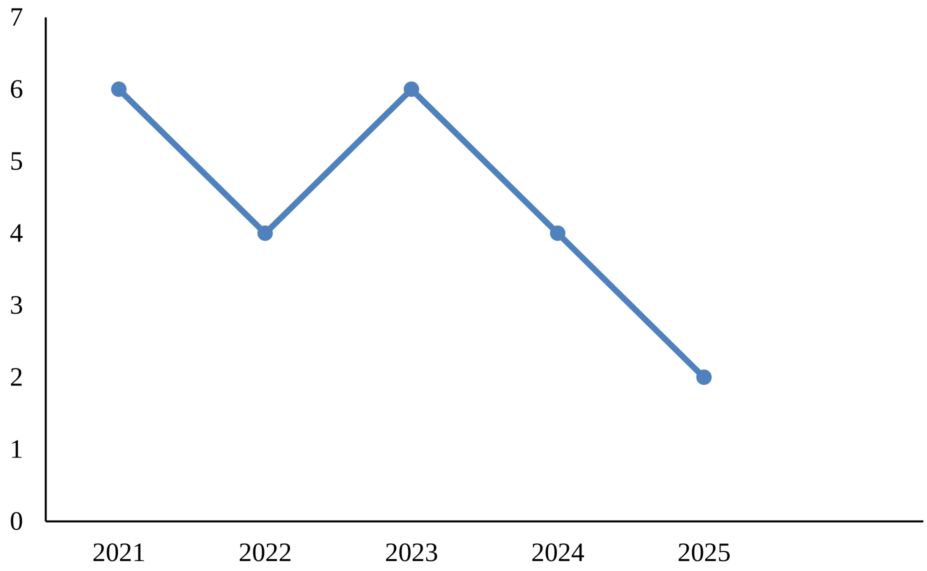

Figure 2. Number of Metacognitive articles by year

The majority of research conducted within this field has relied on quantitative methods, primarily through surveys and quasi-experimental frameworks. This has been indicative of an overreliance on statistical data within the field. Nevertheless, qualitative case studies and more recent convergent research lent valuable contextual data and analysis on the interplay within the teaching and learning milieu, the roles of educators, and the metacognitive processes articulated by learners.

Table 4. Number of metacognitive articles by method

Method	Number of Articles	Percentage
Quantitative	19	86%
Qualitative	2	9%
Mixed-methods	1	5%
Total	22	100%

From a geographical perspective, the range of studies was particularly diversity and international range in the studies reviewed. The United States published the greatest number of studies (7), with Turkey next (3); Indonesia, the Philippines, and Israel each published two studies. One study each came from Italy, Finland, India, Iran, China, and Bosnia and Herzegovina. This worldwide distribution suggests that metacognitive and inquiry-based frameworks in physics education attract scholarly attention in both developed and developing educational contexts. There is, however, increasing international use of metacognitive frameworks to improve student cognitive control and reasoning in secondary school physics.

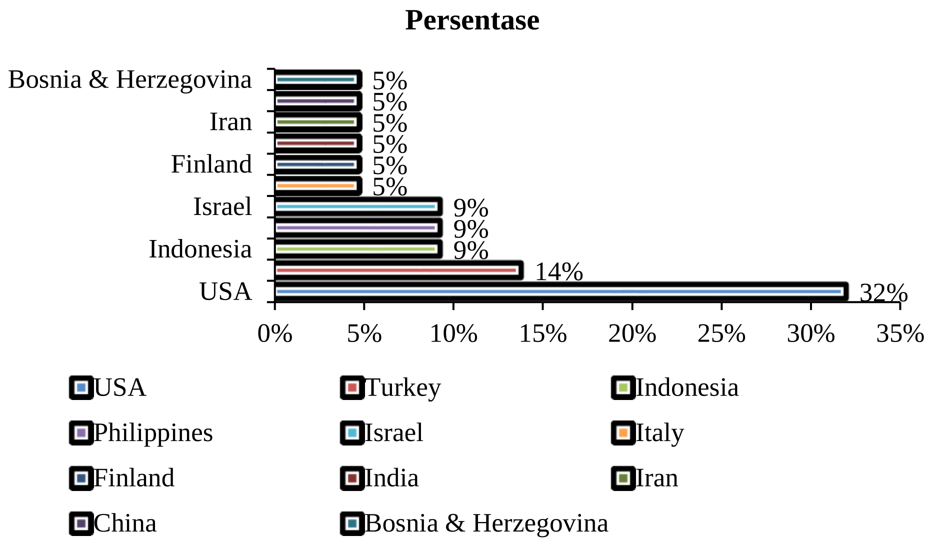

Figure 3. Number of metacognitive articles by country of origin

The integration of metacognitive strategies in various studies underscores a range of advantages, including improved conceptual understanding, enhanced problem-solving skills, increased student motivation, and increased engagement in learning physics. However, the complexity of implementing reflective and inquiry strategies, time limitations within typical classroom cycles, challenges related to assessments, and student resistance or lack of familiarity with self-regulated learning are persistent challenges.

The overall picture these studies paint illustrates the areas of metacognitive strategies that hold the most promise for driving change in the physics classroom. With proper teacher training and instructional metacognitive design, deep understanding, resilient problem-solving, and improved equity in student achievement are all within reach.

RQ1. Strategies for Enhancing Metacognition in Physics Education

A methodical examination of 22 curated studies revealed a range of strategies employed to enhance metacognitive skills in secondary school physics education. These strategies can be categorized into four primary groups: cognitive-reflective strategies, inquiry- and experimentation-based methodologies, representation and visualization tools, and sociocultural/affective supports. Each cluster highlights distinct elements of Schraw’s metacognitive regulation model (planning, monitoring, evaluation), indicating varying levels of comprehensiveness and efficacy.

Cognitive Reflective Techniques

Numerous studies employed methodologies aimed at rendering students' cognitive processes transparent through reflection and self-evaluation. For example, Dulger and Ogan-Bekiroglu (2025) employed think-aloud protocols and rubric-based evaluations to allow students to articulate their thoughts and track their reasoning as they worked on open-ended problems. Safadi and Saadi (2021) implemented self-diagnosis activities in geometric optics, enabling students to recognize their errors and juxtapose them with worked examples, thereby enhancing both the monitoring and evaluation phases. Carroll et al. (2023) similarly found that using ePortfolios in high school physics helped students learn how to self-regulate by setting goals, tracking their progress, and writing in a reflective journal. These methods typically enhance monitoring and evaluation, but research indicates that planning remains underdeveloped without clear support.

Inquiry and Experimentation-Based Methodologies

Another prominent cluster encompassed guided inquiry and experimentation tasks that actively involved students in scientific reasoning cycles. Padios & Tobia (2023) demonstrated that distance laboratories, whether virtual, physical, or a combination of both, enabled students to plan experiments, track their progress, and analyze their results. Cai et al. (2021) utilized augmented reality environments to enhance conceptual understanding of wave–particle duality, emphasizing the significance of interactive simulations in facilitating planning (via experiment design) and monitoring (by tracking results). Yerdelen-Damar and Eryılmaz (2021) demonstrated that the incorporation of explicit epistemic interventions into metacognitive instruction enhanced the conceptual understanding of mechanics. These results suggest that inquiry-based strategies are particularly effective when they incorporate all three metacognitive phases, aligning closely with Schraw’s model.

Tools for Representation and Visualization

A smaller but important group of studies has focused on external cognitive tools, such as simulations and concept maps. Rugh et al. (2023) presented Dynamic Interactive Mathematical Expression (DIME) maps, facilitating students' interactive exploration of conceptual interrelations. These tools helped students plan by organizing their knowledge structures and tracking their progress through visualizing connections. However, the evaluation phase was not always addressed as well. Similarly, simulation-based homework (Mešić et al., 2022) helped students learn how to self-regulate by encouraging them to think ahead, perform, and reflect on their own work, even though it was challenging to do so. These strategies demonstrate that visualization tools can alleviate cognitive load and indirectly enhance metacognition; however, they necessitate reflective prompts to facilitate deeper evaluative engagement.

Sociocultural and Emotional Support

A significant subset of studies emphasized the influence of classroom climate, equity, and affective factors in facilitating metacognitive engagement. Mathis, Southerland, & Jaber (2025) characterized politicized care, including encompassing social, epistemic, and academic care, as a culturally responsive pedagogy that fosters secure environments for students from marginalized communities to reflect on and manage their learning. Stoeckel and Roehrig (2021) investigated gender disparities in AP Physics classrooms, demonstrating how guided inquiry labs and feedback methodologies influenced students' self-efficacy and propensity for self-regulation. These strategies, although not direct cognitive interventions, serve as facilitating conditions, enhancing the efficacy of metacognitive scaffolds by promoting motivation, identity validation, and equitable engagement.

Table 5 summarizes the main points of the 22 eligible articles, providing a comprehensive overview of the studies reviewed. The table outlines the types of metacognitive strategies, assessment tools, research design, and educational context that form the empirical basis for the analysis that follows.

Table 5. Types of metacognitive strategies, assessment tools, research design, and educational context

No	Strategy Type	Example Intervention	Metacognitive Phase Targeted	Key Outcome	Reference
1	Cognitive–reflective	Think-aloud protocols & rubrics during problem-solving	Monitoring, Evaluation	Better error detection, deeper reflection	Dulger & Ogan-Bekiroglu (2025)
2	Cognitive–reflective	Self-diagnosis + worked examples	Monitoring, Evaluation	Improved conceptual repair in optics	Safadi & Saadi (2021)
3	Cognitive–reflective	ePortfolio reflection & self-assessment	Planning, Monitoring, Evaluation	Strengthened SRL, goal-setting	Carroll et al. (2023)
4	Inquiry / Experimentation	Distance labs (virtual + physical) with guided inquiry	Planning, Monitoring, Evaluation	Improved achievement & metacognition	Padios & Tobia (2023)
5	Inquiry / Experimentation	Augmented reality inquiry tasks	Planning, Monitoring	Improved conceptual understanding	Cai et al. (2021)
6	Inquiry / Experimentation	Explicit epistemic metacognitive instruction	Monitoring, Evaluation	Improved force & motion understanding	Yerdelen-Damar & Eryılmaz (2021)
7	Visualization tools	Dynamic Interactive Concept Maps (DIME Maps)	Planning, Monitoring	Improved self-efficacy & knowledge connections	Rugh et al. (2023)
8	Visualization tools	Simulation-based homework (PhET)	Planning, Reflection	Enhanced problem-solving and reflection	Mešić et al. (2022)
9	Sociocultural / Affective	Politicized care pedagogy	Motivation, Monitoring, Identity	Engagement of underserved students	Mathis et al. (2025)
10	Sociocultural / Affective	Classroom experiences (gender-sensitive)	Self-efficacy, Monitoring	Narrowed confidence gap in AP Physics	Stoeckel & Roehrig (2021)

Table 5 shows that the strategies range from reflective practices to inquiry-driven interventions and sociocultural supports. In most cases, however, strategies focus primarily on monitoring and evaluation, with fewer directly targeting planning. This pattern suggests that students are often encouraged to reflect on and evaluate their learning, but they are less frequently provided with guidance on planning and anticipating tasks. This leaves a gap in the full cycle of Schraw's (1995) metacognitive regulation model.

Figure 4 illustrates a typology of metacognitive interventions that helps organize these findings conceptually. The figure illustrates how each cluster aligns with different stages of metacognitive regulation (planning, monitoring, evaluation), while the table provides details about each study. This mapping reveals that studies are not balanced, highlighting the importance of developing strategies that more clearly incorporate the planning phase.

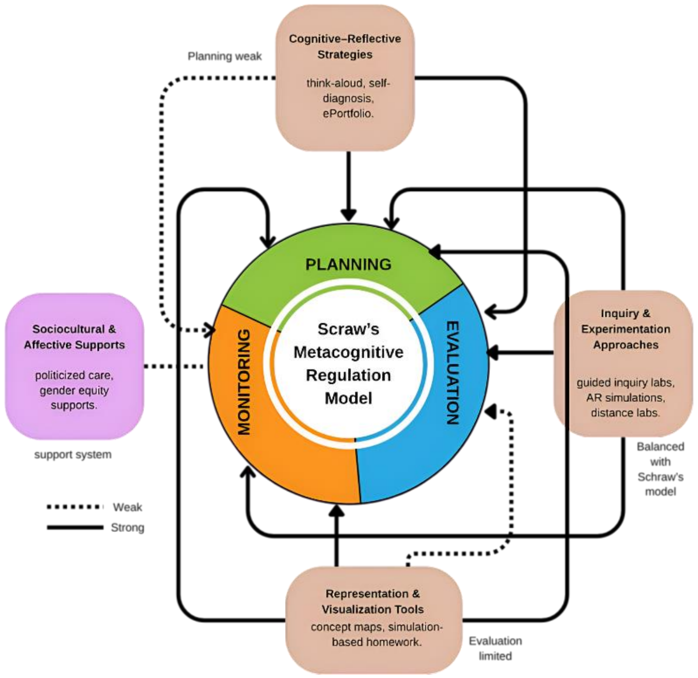

Figure 4. Typology of metacognitive interventions in scraw's model

Figure 4 illustrates that the four groups of interventions align with Schraw's (1995) model in various ways. Cognitive-reflective strategies and inquiry-based approaches significantly involve monitoring and evaluation, whereas visualization tools and sociocultural supports create conducive conditions but offer less direct scaffolding for planning. The imbalance highlights that, although physics education research increasingly advocates for reflective practices and inquiry cycles, the explicit focus on planning remains underdeveloped. This underscores an essential trajectory for forthcoming instructional design: the integration of structured anticipatory activities (goal-setting, experimental design, anticipatory inquiries) to equilibrate the metacognitive cycle and optimize educational outcomes.

Patterns and Gaps Across Studies

A clear pattern emerges across the corpus: most interventions improve monitoring and evaluation, but planning is always left out. This imbalance suggests that physics teachers tend to focus on thinking about things after they happen rather than before. Additionally, although inquiry-based and reflective strategies exhibit significant potential, their efficacy is contingent upon explicit scaffolding that incorporates all three metacognitive phases. Strategies that utilize technology offer new approaches, but they only work when paired with structured reflection. Finally, sociocultural supports demonstrate that metacognition is not just a cognitive process; it is also integral to identity and equity contexts.

Implications

The synthesis indicates that metacognitive strategies in secondary education Physics effectively enhance problem-solving skills, conceptual comprehension, and self-efficacy. However, their overall effect is weaker because they lack clear planning assistance. To fully use Schraw's model in physics classrooms, it is important to include activities that require forethought (like setting goals, defining criteria, and designing experiments) along with monitoring and evaluation. Additionally, incorporating equity-driven pedagogies guarantees that these strategies are both cognitively effective and socially inclusive. The creation of a typology for metacognitive interventions—cognitive-reflective, inquiry-based, visualization tools, and sociocultural supports—provides a descriptive synthesis and a prescriptive framework for future instructional design in physics education.

RQ2 - The Assessment of Metacognitive Skills in Physics Teaching

Evaluating the 22 relevant studies reveals that the assessment of metacognitive skills in teaching secondary school physics is almost exclusively based on self-report surveys, with very little use of task-embedded rubrics, technology-enhanced assessments, and qualitative approaches. This situation is problematic. Self-report questionnaires are useful, but they capture only students' self-reflected awareness and often do not account for the on-the-spot self-regulation, especially during the planning mode in Schraw's model. The collected data illustrate not only the assessment instruments but also the contexts of their psychometric properties and their varying fit to planning, monitoring, and evaluation.

Table 6. Overview of metacognition assessment methods in secondary physics education

Category	Representative Studies	Primary Instruments / Approaches	Schraw's Phase Most Captured
Self-report inventories	Ulu & Yerdelen-Damar (2024); Stanton et al. (2021)	MAI (52 items), PPEQ, Physics Identity Survey	Monitoring, Evaluation (weak in Planning)
Task-embedded rubrics/protocols	Dulger & Ogan-Bekiroglu (2025); Safadi & Saadi (2021)	Think-aloud protocols, 20-point rubric, self-diagnosis rubrics	Balanced (Planning–Monitoring–Evaluation)
Technology-enhanced tools	Cai et al. (2021). Rugh et al. (2023); Mešić et al. (2022)	Augmented Reality tasks, Interactive concept maps, Simulation tasks	Planning & Monitoring (Evaluation partial)

Category	Representative Studies	Primary Instruments / Approaches	Schraw's Phase Most Captured
Qualitative/alternative methods	Carroll et al. (2023). Mathis et al. (2025); Dragnic-Cindric et al. (2024)	ePortfolios, reflective journals, discourse & SSRL analysis	Monitoring & Social Regulation; weak in Planning

Standardized Lists

Self-report questionnaires, especially the Metacognitive Awareness Inventory (MAI) (Schraw & Dennison, 1994), still lead the way. Ulu and Yerdelen-Damar (2024) and Stanton et al. (2021) utilized very large samples ($n > 1000$) and very reliable ($\alpha > 0.9$) surveys. Such instruments may be distributed on a large scale, and the surveys focus mostly on the monitoring and evaluation parts of the cycle; the planning phase, however, is mostly overlooked. This is problematic as self-perception questionnaires are known to raise doubts about ecological validity in real classroom settings.

Rubrics and Protocols that are Part of the Task

Dulger and Ogan-Bekiroglu (2025) employed think-aloud protocols and rubric scoring across the four dimensions of knowledge, planning, monitoring, and evaluation, while Safadi and Saadi (2021) discussed self-diagnosis rubrics in the area of optics. These tools implemented Schraw's three-phase cycle, providing valuable insight into the workings of students' minds. This approach, however, requires extensive teacher knowledge and dependable coding, which limits its scalability.

Technology-enhanced Instruments

Cai et al. (2021) utilized augmented reality to engage learners in wave-particle duality tasks, whereas Rugh et al. (2023) focused on the validation of interactive concept maps (DIME maps). Similarly, Mešić et al. (2022) employed simulation-based homework assignments to encourage student reflection on the material they had learned. All these tools vividly capture the planning and monitoring components; however, unstable technology and a lack of student familiarity remain barriers to effective usage.

Qualitative and Alternative Methodologies

Research by Carroll et al. (2023) regarding ePortfolios, Mathis et al. (2025) regarding politicized care, and Dragnic-Cindric et al. (2024) on socially shared regulation sheds light on the socio-cognitive complexities of metacognition. They highlight the impact of regulation, which includes identity, the climate of the classroom, and discourse, elements frequently overlooked by standardized assessments. However, case specificity makes them difficult to transfer to other contexts.

Figure 5 illustrates that self-report inventories constitute the majority of the identified instruments. While self-report tools offer high psychometric quality and facilitate comparisons across contexts, they tend to overemphasize monitoring and evaluation. Although task-embedded rubrics and protocols are less frequent, they show the best alignment with Schraw's comprehensive cycle, especially with the planning stage, which is often neglected. Technology-enhanced approaches are appealing for real-time process capture; however, infrastructure and training gaps limit their widespread

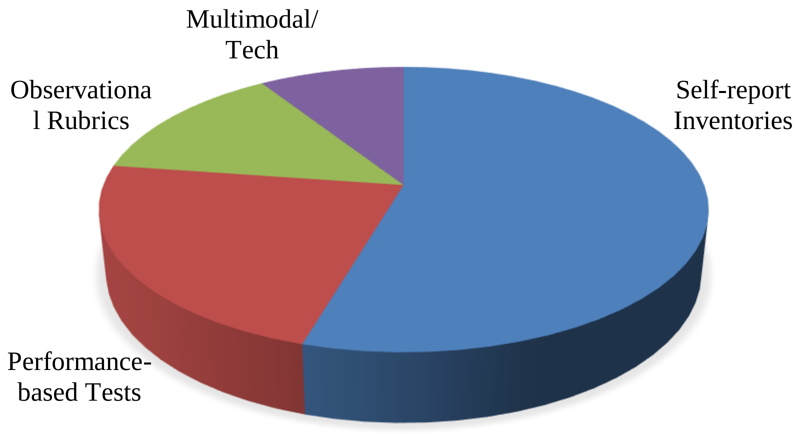

Figure 5. Distribution of assessment instruments in secondary physics education (2021–2025)

adoption. Finally, qualitative approaches contribute to understanding socio-affective regulation; however, they are not scalable.

This imbalance highlights a more extensive issue within the literature itself: planning, which is arguably the most critical component of learning physics and problem-solving, remains the least examined facet of metacognition. Addressing this issue requires hybrid models that integrate inventories, embedded tasks, and qualitative analysis. Such models need to encompass both breadth and depth.

RQ3 - Research Designs, Educational Contexts, and Implementation Challenges

The studies included in the review varied significantly in terms of research design, educational context, and implementation challenges. This lack of uniformity directly affects the degree to which metacognition is integrated into the teaching of physics and which part of Schraw's regulation cycle is the focus, while the other parts are disregarded. Among the 22 eligible studies, designs varied from large-scale surveys and psychometric surveys to quasi-experiments and qualitative case studies. These designs influenced the types of evidence and the extent to which evidence on the planning, monitoring, and evaluation components was discussed.

Table 7. Overview of research designs, contexts, and challenges in secondary physics education (2021–2025)

Design Type	Representative Studies	Typical Contexts (Country/Setting)	Challenges Reported
Large-scale surveys	Ulu & Yerdelen-Damar (2024); Stanton et al. (2021)	Turkey, multi-school urban settings	Risk of survey fatigue; indirect capture of planning
Psychometric validation	Sukarelawan et al. (2021). Jahanifar (2022)	Indonesia, Iran (instrument adaptation studies)	Item bias (gender/culture), limited generalizability

Quasi-experimental interventions	Cai et al. (2021); Mešić et al. (2022); Yerdelen-Damar & Eryılmaz (2021)	China, Bosnia, Turkey (lab tasks, AR, homework)	Technical instability, reliability of measures, and scalability
Case-based qualitative	Carroll et al. (2023); Mathis et al. (2025); Dragnic-Cindric et al. (2024)	USA, socially under-resourced classrooms	Limited transferability, small-N design, bias risk
Mixed/multimodal	Rugh et al. (2023). Sobocinski et al. (2022)	USA, Finland (interactive maps, multimodal SSRL)	Complexity of coding, technology integration, and training needs

Large-scale Surveys

Across Turkey and beyond, surveys are the most used research design. As noted by Ulu and Yerdelen-Damar (2024), surveys provide statistically solid results across large student populations. While useful in identifying broad trends in monitoring and evaluation, these designs have consistently underestimated the planning aspect. The use of Likert-type inventories is indicative of potential superficiality in research, as the explanatory scope of classroom interventions is limited.

Psychometric Validation Studies

The groundwork accomplished by validation studies, such as Sukarelawan et al. (2021) in Indonesia, should be acknowledged. They contribute to the adaptation of instruments to specific local contexts. These studies, however, do not test interventions. The greatest difficulty lies in ensuring that the items accurately represent authentic planning and evaluation. A vast majority of instruments tend focus mostly on monitoring.

Quasi-experimental Interventions

The integration of AR in Cai et al. (2021), simulation-based homework in Mešić et al. (2022), and epistemic interventions by Yerdelen-Damar & Eryılmaz (2021) constitute the basis of such interventions. These designs have the potential to establish causal links and demonstrate how proposed interventions incorporate all three of Schraw's cycles. Issues of scalability, regardless of the proposed interventions, have, however, been a common concern. Time-constrained reflective prompts and technological breakdowns tend to suggest a lack of feasibility within standard classroom settings.

Qualitative Case-based Studies

Focused on ePortfolios, Carroll et al. (2023) and Mathis et al. (2025) exemplify the politicized care, illustrating the complex ways in which metacognitive activity functions within the sociocultural and affective domains. The description of floating inequities and issues of identity within survey-based literature suggests the value of these studies. The unique contribution of such literature is socially shared, regulated learning, as defined. A common limitation is the absence of generalizability.

Multimodal and Mixed Methods Research

Recent research, such as Sobocinski et al. (2022), on socially shared regulation using video and heart rate data, highlights new opportunities for integrating behavioral and physiological approaches. These studies provide real-time, nuanced evidence regarding the regulation and monitoring of adjustments. However, galvanic studies remain methodologically intensive and resource-demanding, requiring sophisticated coding and technology that is typically unavailable in schools.

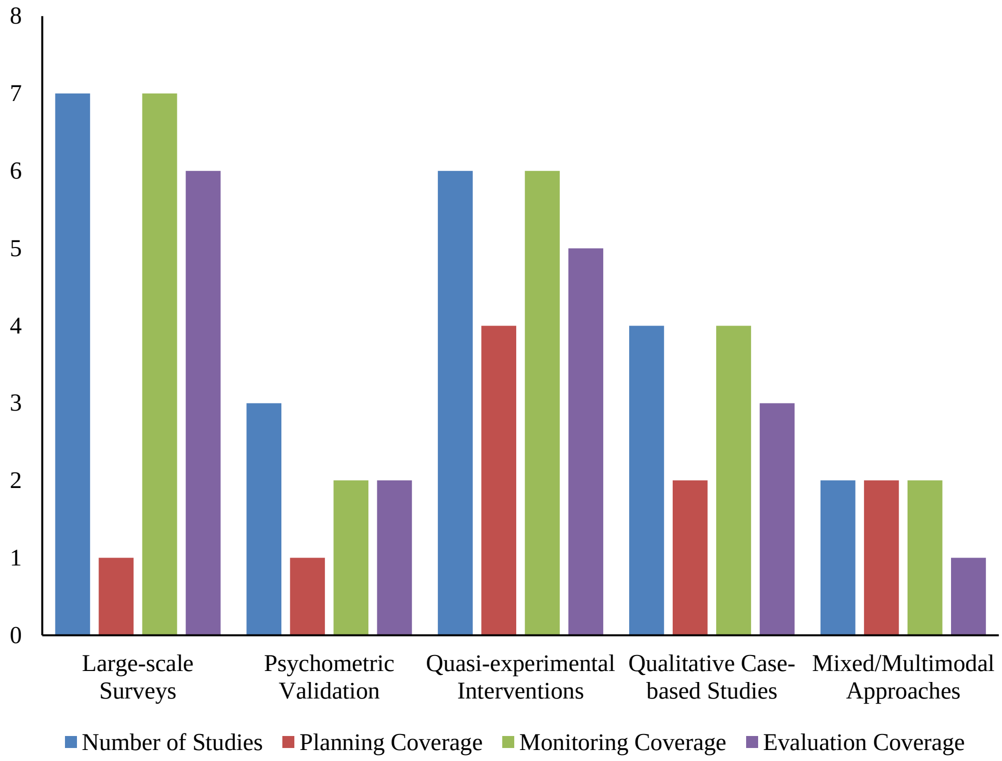

Figure 6. Distribution of research designs and their alignment with schraw's model

In Figure 6, a bibliometric analysis of the distribution of research designs is presented, highlighting their alignment with Schraw's work and his planning monitoring evaluation model. The field is characterized by a predominance of survey designs, which demonstrates a methodological drift towards shallow and scalable forms of evidence. In contrast, quasi-experimental and multimodal research, although fewer in number, had the most comprehensive alignment. Schraw's model and qualitative socio-cultural case studies offer depth and nuanced insights into equity. However, the lack of transferability highlights the need for blended designs to provide a wider scope with contextual richness.

In the case of innovative research designs within the broader scope of physics education, there is a notable absence of planned, systematic, and scalable neglect within this context. To bridge this disconnect, there is a need to place scalable investigation designs with focus and alignment on forethought planning activities, as well as integrated survey frameworks within task analytical rubrics and socio-cultural frameworks.

This review goes beyond reporting standalone findings to contribute theoretically by formulating a Typology of Metacognitive Interventions in Secondary Physics Education. Synthesizing the 22 studies that met the eligibility criteria, four distinct clusters were identified: cognitive and reflective strategies, inquiry and experimentation, representation and visualization, and sociocultural and affective foundations. Each of these clusters relates differently to Schraw's (1995) regulation model. Cognitive, reflective, and inquiry strategies more directly engage the processes of monitoring and evaluation, whereas visualization and sociocultural frameworks provide enabling contexts. This typology approximates how systematic classification of interventions may be achieved, based on the metacognitive processes of planning, monitoring, and evaluation. By this means, the review highlights the disproportionate focus of the literature on monitoring and evaluation strategies to the detriment of planning. By situating the evidence within this framework, the review integrates current practices, offering a theoretical guide for future interventions that more fully target the metacognitive cycle.

▪ CONCLUSION

This review encompassed 22 studies (2021–2025) on metacognitive practices in secondary physics education. Interventions were organized into four types: (1) cognitive / reflective trategies, (2) inquiry/experimentation, (3) representational/visualization aids, and (4) sociocultural/affective supports. These approaches showed positive impacts on students' understanding, problem-solving, and self-efficacy, although an imbalance in Schraw's model was evident: planning was weak, while monitoring and evaluation were robust. Assessments were primarily self-reported, with limited embedded multi-modal or task-based assessment components.

Limitations stemmed from focusing exclusively on Scopus-indexed articles. With only 22 studies to draw from, contextual variations and the quality of reporting were uneven, notably in the planning and evaluation phases, which appear to be under-documented.

This review presents an original typology of interventions, grounded in Schraw's model of self-regulation, with a particular emphasis on planning. For physics educators, this practical guidance entails integrating more structured forethought (goal setting, anticipation tasks, experimental design) and authentic assessments (e.g., think-alouds, portfolios). At the curriculum level, integrating culturally responsive pedagogies in physics can promote equity while fostering the development of metacognitive practices.

Future research should design more structured forethought activities to enhance the planning phase of physics learning. These activities could include goal-setting rubrics, anticipatory problem-framing, and pre-lab design tasks. Most studies of secondary physics classrooms use self-report tools; however, to my knowledge, no research has integrated real-time measures, such as process tracing or digital logs. The incorporation of sociocultural contexts has also been insufficient; to my knowledge, the metacognitive scaffolding frameworks have not been tested in interventions in culturally diverse or underserved contexts. Also, in physics education, augmented reality simulations, interactive concept maps, and digital portfolios, which have potential for scalable and dependable assessments of metacognition, have not been adequately explored.

The concentration of research on monitoring and evaluation, while not focusing on the planning phase, has insufficiently developed the approaches. Integrative frameworks that foreground all components of metacognitive regulation, in conjunction with authentic assessments and culturally sustaining pedagogy, will promote equity and produce the most self-regulated, reflective learners in physics.

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