International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 11 , November - 2026

Metacognition in STEM Teaching and Learning: A Narrative Analysis

Latifa Rahman
Department of Administrative and Instructional Leadership, School of Education, St. John's University

Abstract - *Background*: Metacognition - the awareness and regulation of one's thinking - is relevant to STEM education because learners must plan investigations, monitor reasoning, evaluate evidence, and revise solutions.

***Purpose:* This narrative analysis examines the role of metacognition in STEM teaching and learning, focusing on conceptual foundations, instructional practices, implementation challenges, and educational implications.**

***Approach*: The article offers a narrative synthesis of the educational literature and illustrative classroom applications across science, technology, engineering, and mathematics. It does not present original participant data or conduct a systematic review.**

***Key insights:* Metacognitive knowledge and regulation support reflective engagement with STEM tasks. Planning, monitoring, and evaluation can be integrated through think-aloud modeling, reflective questioning, learning journals, collaborative inquiry, and problem-based learning. Teacher preparation, curricular time, assessment practices, and institutional support may constrain implementation.**

***Conclusion:* Explicitly embedding metacognitive reflection in STEM instruction may strengthen learners' strategic awareness, independence, and capacity to adapt problem-solving approaches. Further empirical research is needed to establish the magnitude and consistency of effects on learning outcomes.**

***Keywords:* Metacognition, STEM education, teaching and learning, self-regulated learning, critical thinking, problem-solving, reflective learning.**

I. INTRODUCTION

Metacognition provides a conceptual foundation for the reflective dimension of learning. Flavell (1979) characterized metacognition as knowledge of and monitoring of cognitive processes. Later scholarship distinguished learners' awareness of their knowledge and strategies from the regulation of cognition through planning, monitoring, and evaluation (Schraw & Dennison, 1994; Veenman, 2012). In instructional settings, these processes can become visible when students articulate what they know, justify their approach, identify uncertainty, and reconsider a solution in light of feedback.

The relevance of metacognition is particularly apparent in STEM classrooms because disciplinary reasoning frequently requires students to make decisions while working. A learner solving an unfamiliar equation may first select a representation, then check whether intermediate results remain plausible, and finally compare alternative solutions. A student conducting an investigation may question whether a variable has been controlled adequately or whether the evidence warrants a conclusion. These are illustrative applications of metacognitive regulation, not claims that reflection automatically produces higher achievement (Schneider & Artelt, 2010; Zohar & Barzilai, 2013).

Metacognitive instruction also has a pedagogical dimension. Teachers can model uncertainty, verbalize strategy choices, and use prompts that direct attention toward reasoning processes. Guided reflection and repeated

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 11 , November - 2026

opportunities to monitor understanding may help students become more strategic learners; however, outcomes are likely to depend on task design, instructional scaffolding, and opportunities to practice across contexts (Santangelo et al., 2021; Stanton et al., 2021). A distinction must therefore be maintained between students reporting awareness of a strategy and demonstrating effective use of that strategy during a demanding task.

Interest in metacognition also intersects with self-regulated learning, which encompasses cognitive, motivational, and behavioral processes used to pursue learning goals. Although the constructs overlap, metacognition refers more specifically to awareness and regulation of thinking. In STEM education, it can be examined through planning before an investigation, monitoring during problem solving, and evaluation after a design or experiment. Classroom activities should make these processes explicit without treating them as a rigid sequence; learners may move repeatedly among planning, monitoring, and evaluation as new evidence emerges (Flavell, 1979; Schraw & Dennison, 1994; Vosniadou et al., 2024).

Important questions remain about how to teach metacognitive practices consistently across STEM subjects and student populations. Curriculum pacing, teacher preparation, the difficulty of assessing internal reasoning, and differences in students' prior knowledge may affect implementation. Moreover, evidence from a particular STEM discipline or educational level should not be generalized uncritically to all learners. The present article therefore adopts a narrative-analysis approach to examine foundational concepts, instructional applications, implementation barriers, and implications for teaching. It synthesizes selected literature and classroom illustrations rather than reporting original data or estimating intervention effects through a systematic review.

Science, technology, engineering, and mathematics (STEM) education concerns not only the acquisition of disciplinary knowledge but also how learners apply that knowledge to investigate uncertain situations, interpret evidence, and revise explanations. Authentic STEM tasks often involve competing strategies, incomplete information, and iterative decision-making. Consequently, students need opportunities to examine the quality of their reasoning rather than merely reproducing a correct procedure (English, 2023; Zohar & Barzilai, 2013).

I.A. Metacognition in STEM Teaching and Learning

Metacognition is central to STEM education, as STEM learning inherently involves problem solving, inquiry, experimentation, mathematical reasoning, engineering design, interpretation of evidence, and revising ideas. (Veenman, 2012) The learning process is rarely linear; learners may experience uncertainty, encounter mistakes, test ineffective approaches, and revisit their assumptions to develop alternative strategies before arriving at a solution.

For example, when solving a mathematics problem, a student may identify available information, determine the specific question, and select an appropriate strategy. Throughout the problem-solving process, the student monitors the validity of calculations and reasoning. Upon reaching a solution, the student evaluates its sensibility and considers whether a more efficient method could have been employed. This exemplifies the metacognitive processes of planning, monitoring, and evaluating.

Similar processes occur across all STEM disciplines. In a science investigation, students make predictions, conduct procedures, observe results, encounter anomalies, and may need to reconsider their initial explanations. In engineering, students design solutions, construct models, test them, and, if outcomes are unsatisfactory, revise their designs. In technology, students select digital resources or tools, evaluate the information obtained, and adjust their approach if the chosen tool does not yield the desired result. Thus, metacognition is integral to the iterative and reflective nature of STEM learning. (Zohar & Barzilai, 2013).

I.B. Metacognition in the STEM Learning Cycle

The following conceptual sequence summarizes the integration of metacognitive regulation within iterative STEM learning:

This sequence illustrates how learners may revisit and re-examine earlier decisions when evidence, feedback, or errors indicate the need for a revised strategy. It represents an instructional synthesis rather than a validated linear model. (Amri et al., 2026).

As shown in Table 1, the instructional strategies connect teacher guidance with students' metacognitive processes and illustrative STEM applications.

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 11 , November - 2026

Table 1. Metacognitive Instructional Strategies and STEM Applications

Strategy	Teacher's Role	Student's Metacognitive Process	STEM Example
Think-aloud	Models reasoning	Awareness	Teacher verbalizes steps while solving an equation
Metacognitive prompts	Asks reflective questions	Monitoring	"How do you know your answer is reasonable?"
Planning questions	Guides preparation	Planning	Students predict variables before an experiment
Error analysis	Encourages examination of mistakes	Monitoring/evaluation	Students identify why a calculation failed
Reflection journal	Provides reflection structure	Evaluation	Students explain what worked after a lab
Self-questioning	Models strategic questions	Monitoring	"What information am I missing?"
Concept mapping	Helps organize relationships	Knowledge monitoring	Students map an ecosystem or physical system
Peer explanation	Facilitates discussion	Social metacognition	Students compare alternative solutions
Problem-based learning	Presents authentic problems	Planning–monitoring–evaluation	Engineering design challenge
Exit reflection	Prompts final evaluation	Evaluation	"What would I change next time?"

A useful analytical distinction is that metacognitive knowledge concerns what learners understand about their cognitive resources, whereas regulation concerns how they deploy that knowledge in real time. These dimensions interact: a student may know that diagrams are useful yet fail to select one when a problem becomes complex. For this reason, assessment should examine both students' explanations of strategies and evidence of their actual strategy use (Flavell, 1979; Schraw & Dennison, 1994).

II. UNDERSTANDING METACOGNITION IN EDUCATION

Metacognition is an individual's capacity to understand, monitor, and regulate personal cognitive processes. It helps learners understand how they acquire knowledge, process information, and approach learning activities (Thomas, 2012; Santangelo et al., 2021).
Metacognition is generally discussed through two major dimensions:

II.A. Metacognitive Knowledge

Metacognitive knowledge is individuals' understanding of their own thinking and learning processes. It includes knowledge of personal abilities, learning tasks, and strategies that support successful learning.
For example, a student may recognize that understanding mathematical equations requires regular practice, whereas learning scientific concepts may require diagrams, experiments, and hands-on demonstrations.
Metacognitive knowledge includes:

- Knowledge of oneself as a learner.
- Knowledge of different learning strategies.
- Knowledge of the requirements of particular learning tasks.

II.B. Metacognitive Regulation

Metacognitive regulation is the ability to control and manage cognitive processes during learning. It involves three key activities: planning, monitoring, and evaluation.

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 11 , November - 2026

Table 2. Metacognitive Regulation in STEM Education

Component	Definition	Student Actions	Example in STEM Learning	Educational Benefit
Planning	Preparing for learning by identifying objectives, understanding task requirements, and selecting appropriate strategies.	Sets goals, reviews prior knowledge, chooses strategies, organizes resources, and estimates time needed.	Before conducting a science experiment, a student identifies the purpose, gathers materials, and plans the procedure.	Promotes organization, goal setting, strategic thinking, and readiness for learning.
Monitoring	Examining understanding and progress while completing a learning task.	Checks comprehension, identifies errors or difficulties, tracks progress, and adjusts strategies when necessary.	While solving a mathematics problem, a student checks each step and changes the approach when the answer does not make sense.	Develops self-awareness, problem-solving skills, adaptability, and independent learning.
Evaluation	Reflecting on learning and performance after completing a task.	Reviews outcomes, assesses strategy effectiveness, identifies strengths and weaknesses, and considers improvements.	After completing an engineering design project, a student evaluates whether the design worked and considers how to improve it.	Encourages reflection, continuous improvement, responsibility, and transfer of learning to future tasks.

III. THE RELATIONSHIP BETWEEN METACOGNITION AND STEM EDUCATION

STEM education integrates Science, Technology, Engineering, and Mathematics to equip students with the skills necessary to understand and solve real-world problems. (IEEE Technology Navigator). Metacognition underpins this approach by enabling students to reflect on their own thinking as they participate in interdisciplinary learning activities. (Domokos & Huey, 2021). For example, when students are tasked with designing a bridge using engineering principles, they must identify the problem, plan their design, select appropriate materials, test the structure, and evaluate the outcome. Throughout this process, students employ metacognitive skills to monitor their decisions and assess the effectiveness of their approaches. (David et al., 2024) Metacognition is particularly relevant in the following domains of STEM education:

III.A. Science Education

Science education involves observation, experimentation, hypothesis formulation, and evidence interpretation. Metacognition enables students to reflect on how they develop scientific explanations and interpret experimental results. Students may consider questions such as:

- What do I already know about this scientific concept?
- Why did I pick that particular hypothesis?
- Does the evidence support my conclusion?
- What could I have done differently in another experiment?

These questions promote scientific reasoning and foster deeper conceptual understanding. (Amri et al., 2026)

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 11 , November - 2026

Discussions of metacognition in science education emphasize the importance of students becoming aware of and controlling their own thinking and learning. They also highlight the need for teachers to make scientific thinking explicit within classroom practice (Zohar & Barzilai, 2013). (Stanton et al., 2021).

III.B. Technology Education

Technology education focuses on students' understanding of how technological tools and systems work and how they can be applied to solve problems. Metacognition encourages students to reflect on their decisions when using digital tools, programming applications, and other technological resources. For example, during the development of a computer program, students may be prompted to consider why their code is not working, identify errors, and explore alternative solutions. This process cultivates computational thinking, logical reasoning, and independent problem-solving skills. (Zhang et al., 2024).

III.C. Engineering Education

Engineering involves identifying problems, designing solutions, constructing models, testing prototypes, and refining outcomes. Metacognition supports engineering education by prompting students to evaluate their design decisions and consider the effectiveness of their solutions.
Students can consider questions such as:

- What problem are we trying to solve?
- Is my design the right one for the problem we have identified?
- Why did our original design fail?
- How can I improve my solution?

This kind of reflection fosters creativity, innovation, and ongoing improvement. (Zohar & Barzilai, 2013).

III.D. Mathematics Education

Mathematics requires logical reasoning, pattern recognition, analytical skills, and problem-solving abilities. Metacognition enables students to recognize the strategies used to solve mathematical problems, identify errors, and assess the validity of their solutions.
For instance, after solving a mathematical problem, students can articulate the steps taken, compare different approaches, and evaluate which method was most effective.
This approach fosters genuine understanding of mathematics rather than mere mechanical memorization of formulas. (Schneider & Artelt, 2010).

IV. METACOGNITION AND EFFECTIVE TEACHING AND LEARNING

Metacognition enhances teaching and learning by encouraging students to take responsibility for their own educational progress. (He et al., 2024) Traditional teaching methods often focus on transmitting information from teacher to student. While direct instruction has value, students also require opportunities to question, investigate, reflect, and evaluate their own learning.
Metacognitive teaching approaches give students opportunities to engage actively in the learning process. (Santangelo et al., 2021).

IV.A. Promoting Independent Learning

Metacognition supports the development of independent learners by enabling students to identify their learning needs and select appropriate strategies.
Students who are aware of their strengths and weaknesses are better equipped to manage the demands of academic work.

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 11 , November - 2026

In STEM disciplines, independent learning is essential because students frequently encounter novel problems that require autonomous problem-solving. (Tang et al., 2024).

IV.B. Improving Problem-Solving Skills

Problem-solving is central to STEM education. Students must analyze problems, extract relevant information, generate possible solutions, and evaluate them. Metacognitive strategies enable students to approach these activities systematically. (Ozbey-Demir, 2025) Critical thinking involves evaluating information, assessing evidence, identifying assumptions, and forming independent judgments.

Metacognition enhances critical thinking by prompting students to reflect on their own thought processes. Students may be asked to explain why they selected a particular scientific method or mathematical approach and to consider whether alternative methods might have been more effective. Students may struggle with complex STEM concepts, which can negatively affect their confidence and motivation.

Metacognitive activities help students recognize that learning involves identifying errors, reflecting on experiences, and determining strategies for improvement. (Clark et al., 2024) When students recognize their own progress and understand how they have overcome obstacles, they are more likely to develop the confidence needed to master challenging subjects. (Han et al., 2021) Research on first-year university students working through biochemistry problems has shown how planning, monitoring, evaluation, and self-coaching can occur during a difficult problem-solving exercise (Halmo et al., 2024).

V. STRATEGIES FOR INTEGRATING METACOGNITION INTO STEM TEACHING

Teachers play a central role in developing students' metacognitive skills. Metacognition does not occur spontaneously; educators must explicitly teach and model it. (Santangelo et al., 2021)

V.A. Reflective Questioning

Teachers can pose questions to students before, during, and after the learning activity. Before the activity, students can reflect on their prior knowledge and identify what they wish to learn. Teachers can assess whether students understand the task and whether their strategies are working. After the activity, students can reflect on their learning outcomes (Clark et al., 2024) and consider areas for improvement.

V.B. Learning Journals (Amri et al., 2026).

Learning journals provide a means for students to record their learning experiences, challenges encountered, and successes achieved. In STEM education, students can use journals to document scientific observations, mathematical problem-solving processes, engineering design decisions, and reflections on practical work. This process helps them identify patterns in their learning and areas for improvement. (Clark et al., 2024).

V.C. Problem-Based Learning

Problem-based learning provides students with opportunities to examine real-world problems and develop potential solutions. (Youngerman, 2019) For example, students may be tasked with designing a water filtration system using available materials. Throughout the activity, students must plan their approach, monitor progress, evaluate results, and make necessary adjustments. This approach integrates STEM knowledge with metacognitive regulation. (Markandan et al., 2022). Problem-Based Learning and Collaborative learning involve students working together, sharing ideas, and explaining their reasoning. (Reznitskaya et al., 2009) Group discussions allow students to compare different problem-solving approaches and reflect on their own thinking processes. (Li et al., 2023). Teachers can also prompt students to explain their strategy choices and the reasoning behind their conclusions.

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 11 , November - 2026

V.E. Think-Aloud Strategies

Think-aloud activities involve students verbalizing their thought processes as they complete tasks. A student working through a maths problem might explain why they picked a particular formula, how they worked through it, and how they checked their answer.

Teachers can also model their own thinking to demonstrate how an experienced learner approaches complex tasks. This practice makes otherwise implicit cognitive processes more accessible to students. (Santangelo et al., 2021) Implementation should not be reduced to adding reflection worksheets. If students lack prerequisite content knowledge, prompts may increase task demands without improving understanding. Likewise, a journal may document reflection without showing that a learner can independently change strategy. Teachers need sustained professional learning and assessments that attend to both reasoning processes and disciplinary outcomes (Belland et al., 2017; Michalsky, 2024).

VI. CHALLENGES OF IMPLEMENTING METACOGNITION IN STEM EDUCATION

VI.A. Limited Teacher Preparation

Some teachers may have limited knowledge of metacognition and may be uncertain how to effectively integrate metacognitive activities into their teaching.

Effective implementation requires teachers to possess a thorough understanding of metacognitive processes and to develop appropriate strategies to support them. (Michalsky, 2024).

VI.B. Curriculum and Time Constraints

STEM curricula are typically content-heavy, and teachers are expected to cover all material within limited instructional time. As a result, teachers may focus on completing the syllabus rather than providing opportunities for student reflection or self-evaluation.

Incorporating brief reflective activities into regular lessons can help address this issue. (Zohar & Barzilai, 2013).

VI.C. Assessment Difficulties

Traditional examinations typically emphasize final answers rather than the processes used to reach them. However, metacognition involves understanding how students plan, monitor, and evaluate their own learning. Teachers may therefore need to use supplementary assessment methods, such as reflective journals, portfolios, classroom observations, and self-assessment activities (Clark et al., 2024).

VI.D. Differences in Students' Learning Abilities

Students have varying levels of prior knowledge, confidence, motivation, and learning experiences. Some students may struggle to reflect on their thinking or identify appropriate learning strategies. Teachers should provide guidance and gradually help students take greater responsibility for their own learning (Ma et al., 2025). Lack of Institutional Support. Successful implementation of metacognitive approaches requires institutional support. Schools and universities must provide adequate teaching resources, professional development opportunities, and learning environments that promote student reflection and independence (Phillips et al., 2016).

VII. Implications for STEM Teachers and Educational Institutions

Integrating metacognition into STEM will have significant implications for teachers, students, curriculum designers, and educational institutions (Clark et al., 2024). Teachers should explicitly teach metacognitive

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 11 , November - 2026

strategies rather than assuming students will develop them independently (Santangelo et al., 2021). Second, STEM lessons should give students opportunities to plan, monitor, and evaluate their own learning. Third, assessment should evaluate students' reasoning, decision-making, and problem-solving, as well as the final answer. Fourth, teacher education programs should incorporate metacognition as a key element of effective teaching practice.

Finally, educational institutions should encourage pedagogies that foster inquiry, collaboration, reflection, and independent learning. By adopting these recommendations, STEM education can move beyond rote memorization and develop students who understand how to think, learn, and apply their knowledge.

VIII. CONCLUSION

This review paper examines the educational value of incorporating metacognitive approaches into STEM teaching. Evidence indicates that metacognitive awareness and self-regulation enable students to identify learning difficulties, evaluate alternative solutions, detect misconceptions, and make informed judgments about their learning. (David et al., 2024) Rather than relying solely on memorization or procedural learning, students with metacognitive awareness are better equipped to reflect on their learning processes, assess the effectiveness of their approaches, and adjust strategies as needed. (Markandan et al., 2022). Metacognitive processes support these demands through three interrelated dimensions: planning, monitoring, and evaluation. (Clark et al., 2024) During planning, students establish learning objectives, draw upon prior knowledge, and select appropriate strategies. In the monitoring phase, they assess their understanding, identify errors, and determine whether their strategies are helping them make progress. In the evaluation phase, students consider outcomes, assess the effectiveness of their strategies, and identify areas for improvement. When these processes are explicitly integrated into STEM learning activities, students are afforded opportunities to become more strategic and reflective problem solvers. Metacognitive instruction can also foster critical thinking, academic confidence, persistence, and the transfer of learning strategies across contexts. (Schuster et al., 2020) The extent of these outcomes depends on instruction quality, students' developmental characteristics, the learning environment, and the specific nature of the metacognitive intervention. (Belland et al., 2017) Teachers play a critical role in transforming metacognition from an abstract cognitive concept into a tangible instructional practice. (Gamby & Bauer, 2022) Effective STEM instruction gives students opportunities to structure their thinking by explaining their reasoning, questioning assumptions, evaluating learning processes, and reflecting on the strategies they use to complete tasks. (Zohar & Barzilai, 2013).

Instructional approaches such as think-alouds, reflective questioning, learning journals, problem-based learning, collaborative inquiry, peer discussion, and formative self-assessment can be employed to make thinking processes more visible and accessible. (Clark et al., 2024) For example, in mathematics, teachers may ask students to explain their strategy choices, identify points where their reasoning faltered, and consider alternative approaches. In science investigations, similar practices can be applied to experimental design, interpreting anomalous results, and evaluating whether conclusions are supported by data.

These instructional practices position students at the center of knowledge construction and evaluation, rather than as passive recipients of information. Metacognitive development requires extensive teacher modeling, guided practice, constructive feedback, and a gradual increase in opportunities for independent reflection. (Michalsky, 2024) Consequently, metacognitive strategies should be integrated into daily STEM instruction rather than isolated as separate reflection activities. (Gamby & Bauer, 2022)

Curriculum frameworks should provide explicit opportunities to plan, monitor, and evaluate learning within STEM activities. (Vosniadou et al., 2024) Assessment practices can be enhanced by evaluating the quality of reasoning, the strategies employed, and the reflective processes underlying students' final answers, in addition to the correctness of the answers themselves(Amri et al., 2026)

At the institutional level, supportive educational policies, high-quality instructional resources, opportunities for collaborative professional learning, and adequate classroom flexibility all contribute to the sustained implementation of metacognitive teaching. (Biswas et al., 2022)

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 11 , November - 2026

The findings of this narrative review highlight the need for further research into the effectiveness and implementation of metacognitive strategies across STEM disciplines and diverse educational contexts. While existing literature supports the theoretical and empirical basis for metacognitive instruction, it remains premature to conclude which approaches are most effective for specific age groups, learning outcomes, and educational settings. (Ferreirós et al., 2024)

Future research should examine the long-term relationships between metacognitive development, academic achievement, problem-solving performance, learning motivation, and self-regulated learning. Longitudinal, rigorously designed intervention studies could provide robust evidence on the persistence of metacognitive learning outcomes and the conditions that facilitate the transfer of reflective strategies across STEM disciplines. Research should also examine how digital learning environments, educational technologies, and AI-assisted teaching tools can provide meaningful feedback and support metacognitive reflection. It should be possible to distinguish between what the students say they know about their own learning and what they actually do with that knowledge.

Educational equity should also be considered in relation to how students' language backgrounds, socio-economic circumstances, prior educational experiences, and access to instructional resources influence their opportunities for metacognitive development. (Maximino-Pinheiro et al., 2024) Understanding these contextual factors is essential for creating more inclusive and accessible STEM learning environments. (Jackson et al., 2021) In summary, metacognition should be regarded as an essential dimension of high-quality STEM education rather than as an ancillary activity. Its value lies in connecting cognitive awareness with intentional learning behaviors, enabling students to understand not only what they are learning but also how and why they are learning it.

Systematically embedding metacognitive planning, monitoring, evaluation, and reflection into STEM teaching can create a learning environment that fosters deeper conceptual understanding, enhanced strategic problem solving, increased intellectual curiosity, and greater learner autonomy. (Amri et al., 2026) This approach better equips students to address learning challenges, evaluate evidence, and adapt their thinking when confronted with novel problems. (Amri et al., 2026)

However, effective implementation of metacognitive instruction requires appropriate teacher preparation, curriculum alignment, meaningful assessment, institutional support, and ongoing empirical investigation. (Michalsky, 2024) This narrative review synthesizes a range of educational perspectives and research findings but does not establish causal links or provide quantitative estimates of instructional effectiveness.

The goal of metacognitive STEM education extends beyond producing students who can arrive at correct answers; it seeks to develop individuals capable of reflecting on their own thinking. The objective is to cultivate students who can evaluate their reasoning, recognize the limits of their knowledge, assess their decisions, and enhance their learning approaches. Metacognitive STEM education aims to produce learners who are reflective, adaptable, creative, self-directed, and equipped with the intellectual capabilities necessary for a lifelong learning society.

REFERENCES

[1] Amri, S. A., Dewi, N. R., & Arifin, V. S. (2026). The Data-Based Claim Evaluation, Socioscientific Reasoning, and Metacognition in STEM Education: Systematic Literature Review: 2021–2026. Jurnal Ilmu Pendidikan 12(2). https://doi.org/10.21831/jipi.v12i2.97874

[2] Belland, B. R., Walker, A. E., Kim, N. J., & Lefler, M. (2017). Synthesizing Results From Empirical Research on Computer-Based Scaffolding in STEM Education: A Meta-Analysis. Review of Educational Research, 87(2), pp. 309–344. https://doi.org/10.3102/0034654316670999

[3] Biswas, S., Benabentos, R., Brewe, E., Potvin, G., Edward, J., Kravec, M., & Kramer, L. (2022). Institutionalizing evidence-based STEM reform through faculty professional development and support structures. International Journal of STEM Education, 9. https://doi.org/10.1186/s40594-022-00353-z

[4] Clark, R. M., Guldiken, R., Kaw, A., & Uyanik, O. (2024). The case for metacognition support in a flipped STEM course. International Journal of Mechanical Engineering Education, 53(3). https://doi.org/10.1177/03064190241255113

[5] Clark, R. M., Kaw, A., & Guldiken, R. (2023). Metacognition instruction and repeated reflection in a fluid mechanics course: Reflective themes and student outcomes. International Journal of STEM Education, 51(4). https://doi.org/10.1177/03064190231164719

[6] David, L., Biwer, F., Baars, M., Wijnia, L. & Merriënboer, J. J. (2024). The Relation Between Perceived Mental Effort, Monitoring Judgments, and Learning Outcomes: A Meta-Analysis. Educational Psychology Review, 36. https://doi.org/10.1007/s10648-024-09903-z

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 11 , November - 2026

[7] Domokos, S. & Huey, M. (2021). Simple Metacognitive Prompts for Enhancing Student Learning: An Interdisciplinary Study. Journal of Education, 203(1), pp. 113–117. https://doi.org/10.1177/00220574211017290
[8] English, L. D. (2023). Ways of thinking in STEM-based problem solving. Research in Science Education, 55. https://doi.org/10.1007/s11858-023-01474-7
[9] Ferreirós, M. A., Gil, S. A., Enríquez, M. R., Rodríguez, Á. C., & Deaño, M. D. (2024). Improvement in simultaneous processing through metacognitive instruction. Frontiers in Education, 9. https://doi.org/10.3389/feduc.2024.1346739
[10] Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. American Psychologist, 34(10), 906–911.
[11] Gamby, S., & Bauer, C. F. (2022). Beyond "study skills": a curriculum-embedded framework for metacognitive development in a college chemistry course. International Journal of STEM Education, 9. https://doi.org/10.1186/s40594-022-00376-6
[12] Halmo, S. M., Yamini, K. A., & Stanton, J. D. (2024). Metacognition and self-efficacy in action: How first-year students monitor and use self-coaching to move past metacognitive discomfort during problem solving. CBE—Life Sciences Education, 23(2), ar13. https://doi.org/10.1187/cbe.23-08-0158
[13] Han, J., Kelley, T., & Knowles, J. G. (2021). Factors Influencing Student STEM Learning: Self-efficacy and Outcome Expectancy, 21st-century skills, and Career Awareness. Journal for STEM Education Research, 4. https://doi.org/10.1007/s41979-021-00053-3
[14] He, G., Chen, S., Lin, H. & Su, A. (2024). The association between initial metacognition and subsequent academic achievement: a meta-analysis of longitudinal studies. Learning and Instruction, 36. https://doi.org/10.1007/s10648-024-09922-w
[15] Jackson, C., Mohr-Schroeder, M. J., Bush, S. B., Maiorca, C., Roberts, T., Yost, C., & Fowler, A. (2021). Equity-oriented conceptual framework for K-12 STEM Literacy. Equity and Excellence in Education, 54(3), pp. 294–310. https://doi.org/10.1186/s40594-021-00294-z
[16] Li, W., Liu, C., & Tseng, J. C. (2023). Development of a metacognitive regulation-based collaborative programming system and its effects on students' learning achievements, computational thinking tendency, and group metacognition. BJET 55(1), pp. 318–339. https://doi.org/10.1111/bjet.13358
[17] Ma, B., Li, H., Li, G., Chen, L., Tang, C., Xie, Y., Gu, C., Shimada, A. & Konomi, S. (2025). Scaffolding Metacognition in Programming Education: Understanding Student-AI Interactions and Design Implications. arXiv preprint. https://doi.org/10.48550/arXiv.2511.04144
[18] Markandan, N., Osman, K., & Halim, L. (2022). Integrating Computational Thinking and Empowering Metacognitive Awareness in STEM Education. Frontiers in Psychology. https://doi.org/10.3389/fpsyg.2022.872593
[19] Maximino-Pinheiro, M., Menu, I., Boissin, E., Brunet, L., Barone, C., & Borst, G. (2024). Metacognition as a mediator of the relation between family SES and language and mathematical abilities in preschoolers. Scientific Reports, 14. https://doi.org/10.1038/s41598-024-60972-0
[20] Michalsky, T. (2024). Metacognitive scaffolding for preservice teachers' self-regulated design of higher-order thinking tasks. Heliyon 10(2). https://doi.org/10.1016/j.heliyon.2024.e24280
[21] n.d.). Metacognition. Teaching and Learning Resource Center. https://teaching.resources.osu.edu/glossary/term/metacognition
[22] (n.d.). STEM. IEEE Technology Navigator. https://technav.ieee.org/topic/stem/
[23] Ozbey-Demir, O. (2025). Regulating the Load: A Systematic Review of SRL and Metacognitive Strategies in STEM Problem Solving Tasks. International Journal of Education in Mathematics, 13(1), pp. 1–15. https://doi.org/10.46328/ijemst.5429
[24] Phillips, J. A., McElwain, M. C., & Clemmer, K. W. (2016). Metacognitive Training in Professional Development Can Improve and Sustain Student Achievement. arXiv preprint. https://doi.org/10.48550/arXiv.1607.07856
[25] Reznitskaya, A., Kuo, L. J., Clark, A. M., Miller, B., Jadallah, M., & Anderson, R. C. (2009). Collaborative reasoning: A dialogic approach to group discussions. Cambridge Journal of Education, 39(1), pp. 29–48. https://doi.org/10.1080/03057640802701952
[26] Santangelo, J., Cadieux, M., & Zapata, S. (2021). Developing student metacognitive skills using active learning with embedded metacognition instruction. Journal of STEM Education, 22(2), pp. 1–10. https://doi.org/10.1002/meet.2021.145058
[27] Schneider, W., & Artelt, C. (2010). Metacognition and Mathematics Education. ZDM: The International Journal on Mathematics Education, 42(2), pp. 149–161. https://doi.org/10.1007/s11858-010-0240-2
[28] Schraw, G., & Dennison, R. S. (1994). Assessing metacognitive awareness. Contemporary Educational Psychology, 19(4), 460–475.
[29] Schuster, C., Stebner, F., Leutner, D., & Wirth, J. (2020). Transfer of metacognitive skills in self-regulated learning: an experimental training study. Metacognition and Learning, 15(3). https://doi.org/10.1007/s11409-020-09237-5
[30] Stanton, J. D., Sebesta, A. J., & Dunlosky, J. (2021). Fostering Metacognition to Support Student Learning and Performance. CBE Life Sciences Education, 20(2). https://doi.org/10.1187/cbe.20-12-0289
[31] Tang, K., McLure, F., Williams, J., & Donnelly, C. (2024). Investigating the role of self-selected STEM projects in fostering student autonomy and self-directed learning. The Australian Educational Researcher, 51. https://doi.org/10.1007/s13384-024-00696-2
[32] Thomas, G. P. (2012). Metacognition in science education: Past, present and future considerations. In B. J. Fraser, K. Tobin, & C. J. McRobbie (Eds.), Second international handbook of science education. Springer.
[33] Veenman, M. V. J. (2012). Metacognition in science education: Definitions, constituents, and their intricate relation with cognition. In A. Zohar & Y. J. Dori (Eds.), Metacognition in science education: Trends in current research. Springer.
[34] Vosniadou, S., Bodner, E., Stephenson, H., Jeffries, D., Lawson, M. J., Darmawan, I. N., Kang, S., Graham, L., & Dignath, C. (2024). The promotion of self-regulated learning in the classroom: a theoretical framework and an observational study. Learning: Research and Practice, 19. https://doi.org/10.1007/s11409-024-09374-1
[35] Youngerman, E. (2019). Problem-Based Learning (PBL): Real-World Applications to Foster (Inter)Disciplinary Learning and Integration. New Directions for Higher Education, 2019(188), pp. 23–32. https://doi.org/10.1002/he.20342
[36] Zhang, J., Zhou, Y., Jing, B., Pi, Z., & Ma, H. (2024). Metacognition and Mathematical Modeling Skills: The Mediating Roles of Computational Thinking in High School Students. J. Intell. 12(6). https://doi.org/10.3390/jintelligence12060055
[37] Zohar, A., & Barzilai, S. (2013). A review of research on metacognition in science education: Current and future directions. Studies in Science Education, 49(2), 121–169.

(This work is licensed under a Creative Commons Attribution 4.0 International License.)