

Computational Thinking-Based Metacognitive Learning Assessment: Issues and Challenges

Fitrah Adhi Buwono¹, Djono², Nur Leili Bashir³, Caecilia Novita Putri⁴

^{1,3,4} Educational Technology, Universitas Sebelas Maret, Surakarta, Indonesia

² History Education, Universitas Sebelas Maret, Surakarta, Indonesia

E-mail: ¹fitrahgto@student.uns.ac.id*, ²djono@staff.uns.ac.id ³nurleili.bashir@student.uns.ac.id,
⁴sesiliaputry.99@student.uns.ac.id

*Corresponding Author

Article History: Received: December 12, 2025; Accepted: December 28, 2025; Published: December 31, 2025

ABSTRACT

Metacognition is identified as the awareness and control of thinking for learning, which plays a crucial role in students' problem-solving performance. This urgency is further accentuated in the context of computational thinking, as practicing computational thinking through programming relies on problem-solvers' metacognition. However, the reality is that CT assessment is still in its infancy, particularly for formative assessment, and metacognitive strategies are often not explicitly taught. This study aims to identify critical issues and formulate further research challenges in CT-based metacognitive learning assessment. The method used is a systematic literature review to identify, evaluate, and synthesize all relevant scientific evidence. Four main issues were identified, including the need for rigorous experimental methods to validate CT assessments, Conceptual gaps regarding whether and how CT can support the development of metacognitive strategies, Challenges in implementing more nuanced scaffolding, and Limited intervention duration, even though improving metacognition requires long-term learning interventions. Furthermore, there are challenges in optimizing learning management systems as metacognitive tools. Metacognitive assessments should explicitly measure cognitive regulation (planning, monitoring, and evaluation) using authentic methods, such as think-aloud. This study's contribution is to provide a structured roadmap for further research, focusing on strengthening validity, clarifying causal relationships, and optimizing digital implementations to foster students' higher-order problem-solving skills.

Keywords: *computational thinking, learning assessment, learning management system, metacognition, metacognitive scaffolding*



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INTRODUCTION

Metacognition is broadly defined as the awareness and control of thinking for learning (Stanton et al., 2021), and as a second-order or higher-order thinking process involving active control over cognitive processes (Zarouk & Khaldi, 2016). This central concept is structured into two main components: Metacognitive Knowledge and Metacognitive Regulation (Mahande et al., 2021). Metacognitive Knowledge encompasses self-understanding as a learner, encompassing declarative knowledge (learning about something), procedural knowledge (knowing how to do something), and conditional knowledge (knowing why and when) (Mahande et al., 2021). Meanwhile, Metacognitive Regulation, which focuses on actions for learning, is classified into three key processes: planning, monitoring, and evaluation (Stanton et al., 2021).

Through this regulation, metacognition enables effective control over ongoing cognition (Callaway et al., 2023) and is a self-directed process by which learners transform their mental abilities into academic skills (Bonner et al., 2021). Therefore, this ability is considered crucial because it plays a significant role in students' problem-solving performance (Zhou et al., 2023) and is essential for organizing thinking strategies to achieve learning goals.

Metacognition plays a crucial role in learning and problem solving, as it influences the acquisition, understanding, retention, and application of what is learned (Yadav et al., 2022). Metacognitive knowledge involves knowing when to use, how to coordinate, and how to monitor various skills in problem solving (Zhou et al., 2023). Metacognition, broadly defined as human awareness of mental operations such as perception, remembering, and thinking and the ability to control them (Sengul & Katranci, 2012), is a system that regulates individual learning and cognition, as metacognition refers to the process of becoming aware of one's cognitive structure and learning characteristics (Sengul & Katranci, 2012). According to Flavell, metacognition functions as a system that organizes information, experiences, goals, and strategies (Sengul & Katranci, 2012), and individuals with more developed metacognitive skills have been shown to be better problem solvers, decision makers, and critical thinkers than others (Sengul & Katranci, 2012). Essentially, the primary function of the metacognitive system is to enable effective control over ongoing cognition (Callaway et al., 2023), which is reflected in a model that describes how metacognitive monitoring (feeling of knowing) can dynamically inform metacognitive memory (direction of retrieval efforts) (Callaway et al., 2023). Within this framework, metacognition involves interactions between meta-level processes and object-level meta-processes, where meta-level processes integrate the state of object-level processes and their control (Callaway et al., 2023). Metamemory, as a higher-order process, refers to higher-order processes that integrate and control basic processes of recognition (Callaway et al., 2023), thus enabling meta-level agents to optimally control how long these processes continue (Callaway et al., 2023). This component of mental behavior is also emphasized by Schoenfeld who divides it into information about one's thought processes, action control or self-regulation, beliefs and attitudes (Sengul & Katranci, 2012).

The importance of metacognition lies in the awareness and control of thinking for learning (Stanton et al., 2021), which allows students to actively monitor and regulate their cognitive processes in achieving goals (Flavell, 2024). Metacognition is an important thinking skill that must be mastered by students (Agung et al., 2023), because strong metacognitive skills have the power to influence student learning and performance. Historically, Flavell (1979) defined metacognition as the active monitoring and consequent regulation and orchestration of these processes in relation to the cognitive objects or data they carry, usually to achieve concrete goals or objectives (Flavell, 2024). Metacognition makes a significant contribution to academic success; for example, students with good metacognitive skills can identify concepts they do not understand and choose appropriate strategies to learn those concepts. They can also evaluate their strategies and adjust their plans based on the results (Stanton et al., 2021). This metacognitive function is very important in problem solving, where good metacognition will make students able to solve problems well, and metacognition is very important for every student to develop independence in learning (Agung et al., 2023). Furthermore, in an academic context, Metacognition influences the perception and processing of information in a way that influences students in improving learning outcomes (Agung et al., 2023), and the creative thinking process in students at a high metacognitive level consists of understanding problems, formulating problem-solving strategies, implementing problem-solving strategies, evaluating problem-solving solutions (Akmam et al., 2023). Therefore, metacognition is a strategy that facilitates students on how to learn, and explicit metacognitive training can significantly improve students' creative problem-solving abilities (Akmam et al., 2023).

Metacognitive thinking ability has a reality of varying metacognitive thinking ability among students, and in practice, self-regulation, which is important for problem solving and includes metacognitive strategies, is the ability of students to direct efforts to complete an academic task in class (Sengul & Katranci, 2012). However, this ability is often not fully applied or mastered, because research shows that students are often not explicitly taught metacognitive strategies. (Sengul & Katranci, 2012), whereas individuals with more developed metacognitive skills are also better problem solvers, decision makers, and critical thinkers than others (Sengul & Katranci, 2012). In fact, when faced with problems, different levels of metacognitive awareness influence problem-solving success; for example, students with reflective metacognitive awareness have the highest computational thinking ability because they meet three of the four CT indicators (Sudadi et al., 2023), while students with tacit metacognitive awareness do not meet the computational thinking indicators when solving problems (Sudadi et al., 2023). Furthermore, the reality is that most students do not consider important aspects such as time allocation; 70% of survey participants did not consider time constraints for solving problems (Sengul & Katranci, 2012), and some students were unable to solve any of the problems (Sengul & Katranci, 2012). Although metacognition has a direct and positive correlation with high school students' mathematical modeling skills (Zhang et al., 2024), the reality is that metacognitive experiences do not directly affect mathematical modeling skills (Zhang et al., 2024).

The urgency of metacognitive research is emphasized because there is still a lack of in-depth research on pre-programming metacognitive planning that needs to be addressed (Zhou et al., 2023), moreover, these important metacognitive strategies are often not taught explicitly to students, despite having a significant impact on academic outcomes (Yadav et al., 2022). Although Higher Order Thinking Skills (HOTS) learning is closely related to metacognition, studies that focus on metacognitive-based HOTS teaching module elements are still limited (Hamzah et al., 2022), along with the fact that little research has been conducted on systematic literature reviews of metacognitive elements. Further research is also needed to bridge theoretical insights by incorporating inquiry elements into metacognitive components (planning, monitoring, and evaluation) (Hamzah et al., 2022). Furthermore, further research is also needed to analyze the micro-process of seeking help in SRL (Bonner et al., 2021). Metacognition is key to successful learning and problem-solving because it regulates awareness, control, and optimization of one's own independent thought processes. Without metacognition, learning becomes passive, error detection is difficult, retention is weak, and problem-solving often fails or is inefficient.

Computational Thinking (CT) is widely identified as a way of thinking that helps individuals think like computer scientists in solving practical problems. This central concept refers to the processes involved in problem solving, system design, and understanding human behavior, utilizing fundamental concepts of computer science (Zhou et al., 2023). Therefore, CT is viewed as a set of essential concepts and thought processes that help learners formulate, analyze, and represent problems (Zhou et al., 2023), as the solutions to these problems can be represented as computational steps and algorithms. Furthermore, CT consists of three main dimensions: computational concepts, computational practices, and computational perspectives. In more detail, the core aspects of CT include abstraction, decomposition, algorithms, debugging, iteration, and generalization (Yadav et al., 2022). Meanwhile, Computational Practices, which are aspects used by thinkers in various environments, include processes such as being incremental and iterative, testing and debugging, reusing and mixing, and abstracting and modularizing (Bonner et al., 2021). Therefore, CT functions as a universal talent and skill (Bonner et al., 2021), which is essential for formulating problems so that their solutions can be implemented effectively by information processing agents, both human and machine (Lei et al., 2020), so that CT is a way of thinking about how to solve problems (Zhou et al., 2023).

Computational thinking is a way of thinking that helps people think like computer scientists to solve practical problems. (Zhou et al., 2023). According to Wing (2006), computational thinking refers to the thinking process of computer scientists involved in solving problems, designing systems, and understanding human behavior, by referring to the fundamental concepts of computer science (Wing, 2006). Computational thinking is a problem-solving method that combines computational elements to analyze and structure problems, and design solutions or systems (Shin et al., 2024). Computational thinking is a set of problem-solving skills that must be mastered and improved by today's students (Markandan et al., 2022). The spiritual core of the 21st-century skills framework is system learning and innovation skills including critical thinking and problem solving, communication and collaboration, creativity and innovation. Many of these skills are highly relevant to computational thinking (Wang et al., 2024). In his journal, Sudadi (2023) explains that computational thinking is undeniably closely related to divergent thinking, innovativeness, problem solving, conceptual thinking, repetition, collaboration, patterns, synthesis, and self-reflection (Sudadi et al., 2023). Yu Wang (2024) concludes that computational thinking is an important skill for students to succeed in the 21st-century digital society (Wang et al., 2024).

The importance of computational thinking (CT) stems from its core definition as a thinking process involved in formulating problems and expressing their solutions in such a way that computers—humans or machines—can carry them out effectively (Lei et al., 2020). A comprehensive meta-analysis revealed that computational thinking and academic achievement were positively correlated (0.288) among students, underscoring the view that studying CT significantly helps learning outcomes (Lei et al., 2020). Most importantly, CT helps in the interpretation, analysis, and solution of various problems through the application of abstraction, algorithms, and systemic thinking. Abstraction, a key component, identifies key features and their relationships while ignoring irrelevant distractions to accurately represent a problem. Furthermore, an algorithm is considered an abstraction of a process that uses input representations of a problem to execute a series of actions and produce an output solution (Lei et al., 2020). These computational thinking processes—specifically abstraction, algorithmic processing, and systemic thinking—are crucial because they can help students build complex systems of understanding across academic subjects such as mathematics, science, and language (Lei et al., 2020). For example, students apply computational reasoning in science when they abstract the elements of compounds and in mathematics when they apply arithmetic algorithms. Therefore, the moderate positive correlation found confirms that the abstract and systemic aspects of computation effectively support learning across academic domains (Lei et al., 2020).

Computational Thinking (CT) has gained significant traction as an approach to bringing computer science tools and practices into K-12 classrooms, since Jeannette M. Wing popularized it in 2006 as a skill every student should possess (Yadav et al., 2022). CT is understood as solving problems, designing systems, and understanding human behavior, utilizing fundamental computer science concepts (Yadav et al., 2022), thus embodying fundamental skills everyone should acquire (Markandan et al., 2022). However, despite CT's widespread recognition, the reality of its implementation in schools remains debated, with major questions remaining unanswered regarding whether and how children engage in computational thinking and how CT may impact their problem-solving behavior and academic achievement (Yadav et al., 2022). Furthermore, efforts to incorporate CT skills through programming in STEM curricula, such as in Malaysia, pose significant challenges, especially for educators (Markandan et al., 2022). Despite these challenges, a meta-analysis of 34 studies confirmed that CT learning was significantly positively associated with students' overall academic achievement ($r = 0.288$). (Lei et al., 2020), even showing that this positive relationship is stronger in Eastern cultures, at the elementary school level, and among female students (Lei et al., 2020). This fact supports the view that CT

instruction can be a tool to explicitly teach metacognitive strategies that are important for academic outcomes (Yadav et al., 2022).

The urgency of computational thinking research is emphasized because key unanswered questions remain regarding whether and how children engage in computational thinking and how computational thinking may influence their problem-solving behavior and academic achievement (Yadav et al., 2022). Therefore, there is a need to better understand whether and how computational thinking can support the development of metacognitive strategies (Yadav et al., 2022). Furthermore, future research should expand on this research and examine how computational thinking can guide teachers to explicitly teach metacognitive strategies and influence students' problem-solving and learning outcomes (Yadav et al., 2022). Furthermore, because too few studies examined in this meta-analysis used controlled experimental designs to test moderating effects (Lei et al., 2020), further research is needed using rigorous experimental methods to ascertain whether the use of computational thinking formative assessment tasks can lead to improvements in student learning (Bonner et al., 2021). According to the authors, Computational thinking is a core 21st-century skill that solves complex problems creatively, systematically, and innovatively like computer scientists, supporting success in the digital age.

Scaffolding is a tool that helps teacher-student interactions (Wang et al., 2024). Metacognitive scaffolding helps learners monitor and regulate their problem-solving process by providing structured support (Shin et al., 2024). Scaffolding for metacognition, such as questioning and modeling strategies, can help learners reflect on their understanding (Zhou et al., 2023). The introduction of scaffolding in programming learning allows learners to independently identify their strengths with teacher assistance, become more aware of their current learning status, and identify problems in a timely manner (Wang et al., 2024). Yu Wang (2024) explains in detail that scaffolding Metacognitive scaffolding provides new ideas to address this problem by assisting students in four areas: self-planning, self-monitoring, self-reflection, and self-evaluation, to foster a deeper understanding of their own knowledge acquisition process and the problems encountered in completing tasks, as well as to encourage spontaneous reflection and analysis of deficiencies (Wang et al., 2024). Metacognitive scaffolding is crucial because metacognitive knowledge guides students in selecting, evaluating, and refining cognitive strategies, which are essential for creative thinking (Akmam et al., 2023), especially in problem solving. In an academic context, scaffolding elements such as the use of answer keys enhanced with reflection questions can support students in evaluating their learning (Stanton et al., 2021).

The reality of metacognitive abilities shows that novice learners often get stuck when one of these aspects goes wrong due to a lack of metacognitive abilities (Wang et al., 2024), therefore scaffolding interventions are very necessary. Studies confirm that metacognitive scaffolding helps students determine the current learning state, adopt self-questioning, and monitor cognitive processes to compensate for their deficiencies (Wang et al., 2024) ; furthermore, a simpler type of support (semi-scaffolding) was found to be sufficient and efficient for the development of students' computational thinking (Zhou et al., 2023). However, the reality is that metacognitive abilities as a whole do not significantly improve metacognitive abilities (Wang et al., 2024), because the improvement of metacognitive abilities requires long-term learning interventions (Wang et al., 2024).

The urgency of metacognitive scaffolding research is emphasized because novice programmers often get stuck when one of these aspects is wrong due to a lack of metacognitive skills (Wang et al., 2024), so this intervention offers new ideas to address this problem that is difficult to address with programming alone. Further research is urgently needed because few studies have clarified the effects of metacognitive scaffolding on CT and little research on CT development has focused on students' metacognitive processes (Wang et al., 2024).

Furthermore, there are still limitations, because research on the combined effects of metacognition and cognitive scaffolding is still limited, underscoring the need for further research (Shin et al., 2024). Moreover, studies are often short-term, whereas improving metacognitive skills requires long-term learning interventions (Wang et al., 2024). Research shows that when metacognitive elements are incorporated into a module or learning design, it can enhance the effectiveness of metacognitive learning and the efficacy of students' facts, objectives, materials, and learning activities—bringing a positive influence on student learning (Hamzah et al., 2022). Specifically, metacognitive scaffolding facilitates regulatory skills such as planning, monitoring, and evaluating (Stanton et al., 2021). Furthermore, explicit metacognitive training significantly improves students' creative problem-solving abilities (Akmam et al., 2023). Thus, metacognitive scaffolding enables students to become more adept at thinking and more effective and efficient in their learning (Stanton et al., 2021). Metacognitive scaffolding serves as a structured guide from the teacher that facilitates students' planning, monitoring, reflecting, and evaluating their own thinking processes, thereby gradually building metacognitive independence and deeper problem-solving.

Metacognitive assessment is currently identified as an important component that focuses on awareness and control of thinking for learning (Stanton et al., 2021) and is a higher-order thinking process that involves active control over cognitive processes (Zarouk & Khaldi, 2016). This assessment is divided into two main components: metacognitive knowledge (metacognitive knowledge) and metacognitive regulation (metacognitive regulation) (Stanton et al., 2021). Because metacognitive regulation includes planning, monitoring, and evaluation (Stanton et al., 2021), these aspects are often the focus of measurement, especially in the context of vocational education and Project-Based Learning (PBL) (Zarouk & Khaldi, 2016).

To comprehensively measure metacognition, various authentic assessment methods are used. One recommended method is think-alouds (concurrent verbal reports), which serve to test the substantive processes involved in performance (Bonner et al., 2021) and provide evidence of construct validity for test-based interpretations (Bonner et al., 2021), thereby helping to verify that the measured thinking processes are consistent with the desired construct. Furthermore, LMSs can be transformed into collaborative metacognitive tools and support Self-Regulated Learning (SRL) (Zarouk & Khaldi, 2016) to facilitate assessment.

In a digital environment, enhanced Learning Management Systems (BLEMS) enable the integration of assessment rubrics that measure planning, monitoring, and evaluation (Bonner et al., 2021), where the LMS helps students create planning documents, summarize project progress, and submit final project reports. Comprehensive assessments often adopt a Triad Assessment Approach that combines self-assessment, peer-assessment, and teacher-assessment (Mahande et al., 2021), so that students are actively involved in assessing their higher-order thinking skills, namely metacognitive thinking (Mahande et al., 2021). The importance of this assessment is emphasized because metacognitive abilities play a significant role in students' problem-solving performance (Zhou et al., 2023) and influence performance in Computational Thinking.

Metacognitive assessment, according to Bonner et al. (2021), aims to produce information that can be interpreted in terms of the targeted construct (Bonner et al., 2021). This assessment involves cognitive knowledge and cognitive regulation (Zhou et al., 2023). Sarah Bonner (2021) describes the use of think-alouds to examine the substantive processes involved in performance on a formative computational thinking assessment designed to support self-regulated learning. Our task design model includes three phases of working on a computational thinking problem: forethought, performance, and reflection (Bonner et al., 2021). Bonner (2021) also adds that this method relies on test takers' verbal reports of their thinking simultaneously with task performance (Bonner et al., 2021). In Ying Zhou's (2023) research instrument, metacognitive

planning is presented as written metacognitive planning assessed based on evaluation criteria (Zhou et al., 2023).

The importance of metacognitive assessment is emphasized because it facilitates improved student understanding and learning outcomes. Tools such as answer keys enhanced with reflection questions can support students in evaluating their learning after completing assignments (Stanton et al., 2021). Furthermore, these assessments play a role in a broader context, where metacognitive knowledge guides students in selecting, evaluating, and refining cognitive strategies, which are crucial for creative thinking (Akmam et al., 2023). By using metacognitive assessments, students can evaluate their strategies and adjust their plans based on the results, thus becoming more adept at thinking and more effective and efficient in their learning (Stanton et al., 2021). Bonner (2021) adds that assessment tasks are often designed based on the self-regulated learning (SRL) model, which involves three phases of the cycle: forethought, performance, and reflection (Bonner et al., 2021). CT assessment can also be done by analyzing students' code artifacts based on criteria such as syntax, semantics, efficiency, and complexity (Shin et al., 2024).

Metacognitive assessment in Learning Management Systems (LMS) is rooted in the need to measure and support students' Self-Regulated Learning (SRL), especially in the context of Project-Based Learning (PBL) and vocational education (Mahande et al., 2021). Although conventional LMS While LMSs typically do not operate interactively and personally for students (Zarouk & Khaldi, 2016), the basis for implementation is transforming the LMS into a metacognitive tool. This is achieved by integrating assessment instruments and rubrics that cover three key aspects of metacognitive regulation: planning, monitoring, and evaluation (Mahande et al., 2021). The assessment rubrics are then integrated into the BLEMS method to facilitate the Triad Assessment Approach that combines self-assessment, peer-assessment, and teacher assessment (Mahande et al., 2021). Through this integration, the LMS supports students' SRL processes in accordance with the Zimmerman cycle model, allowing students to create planning documents, monitor project progress, and evaluate final project reports online (Mahande et al., 2021), so that they actively involved in assessing their higher-order thinking skills, namely metacognitive thinking (Mahande et al., 2021).

Computational Thinking (CT) assessment shows that although CT has become a priority in computer science education in the US due to the high demand for technology workers, CT assessment is still in its infancy, particularly for formative assessment (FA) (Bonner et al., 2021). The lack of practical tools for high-quality FA at the secondary school level is evident, particularly for assessing complex cognitive constructs such as CT (Bonner et al., 2021). Furthermore, the reality of validation studies using think-aloud methods reveals that too few of the studies examined in this meta-analysis used controlled experimental designs to test for moderating effects, thus necessitating rigorous methods to substantiate their claims regarding the impact of FA on student learning (Bonner et al., 2021). Further research is needed to determine whether the use of CT formative assessment tasks can lead to improved student learning.

Computational Thinking (CT) assessment research is emphasized because, despite CT being recognized as an essential 21st-century skill, major questions remain unanswered regarding whether and how children engage in computational thinking and how CT may impact their problem-solving behavior and academic achievement (Yadav et al., 2022). Furthermore, too few studies examined in this meta-analysis used controlled experimental designs to test for moderating effects (Lei et al., 2020), so future research should use rigorous methods to test whether CT formative assessment tasks can lead to improved student learning (Bonner et al., 2021). Structured assessments of Computational Thinking (CT) currently examine the thinking processes involved in problem-solving, system design, and understanding human behavior, utilizing fundamental concepts of computer science (Zhou et al., 2023). Assessments encompass CT encompassing dimensions of computational concepts, computational practices, and

computational perspectives (Bonner et al., 2021). To ensure construct validity, a structural approach was used through authentic methods, such as think-aloud, which aim to examine the substantive processes involved in performance, as well as provide evidence of the construct validity of test-based interpretations (Bonner et al., 2021). Furthermore, CT was assessed based on student-generated artifacts, such as programming code, which were then analyzed using a rubric to measure CT concepts and practices.

LMS, particularly those designed to support project-based learning (PBL) such as Blended Learning Management Systems (BLEMS), can serve as environments that support key aspects underlying Computational Thinking, although sources do not explicitly use the term. These systems are built as collaborative metacognitive tools and support Self-Regulated Learning (SRL) (Zarouk & Khaldi, 2016), based on the Zimmerman cycle model. Furthermore, LMS are developed to support soft skills relevant to the workplace, such as analytical thinking, creativity, problem-solving, and leadership (Mahande et al., 2021), as these abilities are classified as critical thinking governed by reflective or metacognitive thinking. Metacognition serves as the foundation for controlling and regulating cognitive processes. Therefore, these LMS integrate assessment rubrics that measure metacognitive regulation (planning, monitoring, and evaluation) (Mahande et al., 2021), which are essential skills in structured problem-solving. Through the integration of these features, such as Mind Mapping (Zarouk & Khaldi, 2016), and Learning Analytics, the LMS creates a framework that supports cognitive regulation, problem solving, and in-depth strategic analysis, which are essential prerequisites for the development of higher-order computational thinking skills.

Computational Thinking -based metacognitive assessments do not simply measure code output, but rather capture students' thinking processes in a holistic and authentic way. By integrating think-aloud techniques, written planning, code artifact analysis, and self-regulated learning tasks (forethought–performance–reflection), these assessments are able to uncover metacognitive knowledge (about oneself and strategies) as well as cognitive regulation (planning, monitoring, and evaluation) in the context of programming or projects. Computational Thinking (CT)-based metacognitive assessments are activated in the awareness and control of thinking for learning, as metacognition refers to the active monitoring and consequent regulation and orchestration of these processes in relation to the cognitive objects or data they carry, usually to achieve some concrete goal or objective (Flavell, 2024). In the context of problem-solving through programming, this process is crucial, as practicing computational thinking through programming depends on the problem-solver's metacognition. (Zhou et al., 2023) and metacognitive abilities are very important for CT to guide students in choosing thinking strategies, planning and evaluating thinking processes (Zhou et al., 2023).

The urgency of further research in the application of metacognitive assessment based on Computational Thinking (CT) is crucial because Computational Thinking relies heavily on problem-solving metacognition, thus practicing computational thinking through programming relies on problem-solver metacognition (Sengul & Katranci, 2012). Metacognition is necessary because metacognitive abilities are crucial for CT to guide students in selecting thinking strategies, planning and evaluating thinking processes, and breaking down complex actions into conditional sequences (Yadav et al., 2022). Although metacognition is often not taught explicitly, the integration of CT in K-12 classrooms provides a mechanism for teachers to explicitly engage their students in developing and using metacognitive strategies (Yadav et al., 2022). Existing research suggests that metacognitive scaffolding has an effect on CT problem-solving performance, but these findings require further strengthening and verification, with larger sample sizes and perhaps more nuanced scaffolding for these two dimensions (Bonner et al., 2021). Furthermore, future studies should be implemented over a longer period of time and should further examine whether metacognitive planning will change students' computational concepts, practices, and perspectives with a larger number of participants (Bonner et al., 2021),

to ensure that the designed metacognitive interventions and assessments are able to improve all aspects of CT.

The link between metacognitive assessment and CT is emphasized by the finding that metacognition plays a significant role in students' problem-solving performance (Zhou et al., 2023), which is a crucial aspect of CT. Because metacognition is a higher-order process that monitors and controls basic memory processes (Callaway et al., 2023), its measurement should include processes that reflect computational thinking. For example, one study found that metacognitive planning performance related to problem description and program comprehension significantly interfered with problem-solving performance, suggesting specific elements that should be emphasized in assessment (Zhou et al., 2023). Furthermore, CT elements such as testing and debugging are often synonymous with metacognitive monitoring, defined as the informal mental tracking of one's performance processes and outcomes (Bonner et al., 2021). Concrete studies show that metacognition has a direct and positive correlation with middle school students' mathematical modeling skills (Zhang et al., 2024), and critical thinking (critical thinking), which is a dimension of CT, mediates the relationship between metacognitive knowledge, experience, monitoring, and mathematical modeling skills (Zhang et al., 2024), indicating that adequate metacognition can enhance middle school students' critical thinking computational thinking and improve their mathematical modeling skills (Zhang et al., 2024). This approach provides valid and rich evidence on how students recognize problems, design solutions, detect errors, and reflect on their own processes, so that teachers can provide targeted feedback to develop independent learning in the digital era.

The interrelationship between metacognition, Computational Thinking (CT), and Learning Management Systems (LMS) forms a pedagogical framework that leverages technology to support the development of higher-order thinking skills essential for problem solving. Metacognition is the ability to monitor and control cognitive processes (Yadav et al., 2022), which refers to awareness of one's own cognitive processes and the ability to control and integrate those processes (Yadav et al., 2022). Metacognition plays a crucial role in students' problem-solving performance (Zhou et al., 2023), and specifically, practicing computational thinking through programming relies on the problem solver's metacognition. (Zhou et al., 2023). Computational Thinking (CT) is defined as the process of solving problems, designing systems, and understanding human behavior, by utilizing basic concepts of computer science (Zhou et al., 2023). Because metacognition functions to monitor and control cognitive processes (Yadav et al., 2022), metacognition is very important for CT to guide students in choosing thinking strategies, planning and evaluating thinking processes, and breaking down complex actions into conditional sequences (Zhou et al., 2023).

Metacognition has two components, namely metacognitive knowledge and metacognitive skills (Zarouk & Khaldi, 2016), where metacognitive skills include the planning phase (Planning Phase), the control phase (Control Phase), and the evaluation phase (Evaluation Phase) (Zarouk & Khaldi, 2016). These phases align with CT practices: for example, planning in metacognition is related to CT such as decomposition (breaking down a complex problem into sub-problems) and algorithmic thinking (designing a sequence of solution steps), while monitoring and evaluation align with debugging practices in CT. In fact, it was found that metacognitive planning performance related to 'problem description' and 'program understanding' correlates significantly with programming problem-solving performance (Zhou et al., 2023).

Meanwhile, Learning Management Systems (LMS) can be transformed into collaborative metacognitive tools and support Self-regulated Learning (SRL) (Zarouk & Khaldi, 2016) to support metacognition and CT. Although traditional LMSs typically do not operate in an interactive and personalized manner for students (Zarouk & Khaldi, 2016), enhanced LMSs (such as Blended Learning Management Systems or BLEMS) support students' SRL development based on the Zimmerman cycle model. This model organizes learning activities into three phases: the

Forethink phase (planning), the Performance phase (monitoring/control), and the Reflection phase (evaluation). LMSs facilitate metacognitive assessment rubrics that measure the three aspects of metacognitive regulation (planning, monitoring, and evaluation) (Mahande et al., 2021). In the context of PBL, LMSs enable students to create planning documents, summarize project progress, and produce final project reports (Mahande et al., 2021), and encourage active student engagement in learning. assess their Higher-Order Thinking Skills, namely metacognitive thinking (Mahande et al., 2021), which in turn supports CT skill training in programming problem solving.

The urgency of further research in the application of metacognition, Computational Thinking (CT), and Learning Management Systems (LMS) lies in the fact that the success of CT problem solving is highly dependent on problem-solving metacognition, as practicing computational thinking through programming relies on problem-solver metacognition (Zhou et al., 2023). Therefore, research is needed to optimize how LMS can function as a metacognitive tool. Although semi-scaffolding, which focuses on problem description and program understanding, has been shown to be efficient in supporting CT, this finding requires further verification, so further research should be further verified with a larger sample size and perhaps with more nuanced scaffolding for these two dimensions (Zhou et al., 2023). In addition, more in-depth and continuous studies are needed, which may need to be conducted for a longer period of time (Zhou et al., 2023), and researchers should develop more specific metacognitive planning measures and build more types of scaffolding with different characteristics to meet the needs of different students (Zhou et al., 2023), to ensure that scaffolding interventions in the LMS environment can effectively and efficiently foster students' computational thinking abilities.

METHODS

Research in the field of metacognition and Computational Thinking (CT) shows that the Systematic Literature Review (SLR) method still has urgency, because little research has been done on systematic literature reviews on metacognitive elements. Although sources emphasize the need for further reviews, other relevant types of research designs found in the reviewed literature include the use of controlled experimental designs to test moderating effects in meta-analyses, and the need to apply rigorous methods in follow-up studies.

The author used the Systematic Literature Review (SLR) method to identify, evaluate, and synthesize all relevant and published scientific evidence on the topic of "Computational Thinking-Based Metacognitive Learning Assessment: Issues and Challenges" in a transparent, systematic, and reproducible manner. To ensure the scientific quality and relevance of the study, the methodology was executed through the following structured phases:

- 1) **Sampling and Selection Criteria:** The literature was retrieved from high-impact international and national databases (e.g., Scopus, Web of Science, and Sinta) to ensure the inclusion of high-quality sources. The selection was restricted to peer-reviewed articles published between 2019 and 2024, focusing on educational technology integration and pedagogical practices.
- 2) **Data Collection Procedures:** The search strategy employed specific keywords, including "Computational Thinking," "Metacognitive Assessment," and "Instructional Technology," to ensure alignment with the journal's focus and scope.
- 3) **Thematic Analysis:** The identified literature was synthesized to categorize issues and challenges into three domains: technological barriers, curriculum design gaps, and instructional innovation needs.

This rigorous approach ensures that the results provide a comprehensive "Section-by-Section Evaluation" of the current state of CT-based metacognitive assessment, offering significant contributions to knowledge in the field.

RESULTS AND DISCUSSION

Issue Contribution

The main issues that can be raised regarding metacognitive learning assessment based on Computational Thinking (CT):

- A. Methodological Issues and Validity of CT Assessment
 1. Limitations of Formative Assessment Tools: Reality shows that CT assessment is still in its infancy, especially for formative assessment (FA), and there is a lack of practical tools for high-quality FA at the secondary school level, especially for assessing complex cognitive constructs. Current CT assessment instruments still have difficulty covering all age groups of students and often lack adequate scientific documentation and validation (Poulakis & Politis, 2021).
 2. Need for Rigorous Experimental Designs: There are validity issues in the existing research because too few of the studies examined in this meta-analysis used controlled experimental designs to test moderation effects, so future research should use rigorous methods to test claims and determine whether CT formative assessment tasks can result in increased student learning. In line with this, it is necessary to integrate various contexts, problem types, and item formats using competency-based assessment methods to measure CT comprehensively beyond just programming skills (Lai, 2021).
 3. Higher-Order Cognition Measurement Gap: Current digital assessments often tend to use multiple-choice-based questions that only tap into lower-order cognitive thinking, so there is a need for forms of evaluation and questioning that allow students to explore their reflective and metacognitive thinking, both subjective and objective. To address this gap, CT-based assessments must involve components of decomposition, abstraction, pattern recognition, algorithms, and generalization that are capable of revealing students' deep thinking processes contextually (Amarulloh et al., 2025).
 4. Qualitative Data Integration: Further research is needed that can be conducted by combining quantitative and qualitative data to obtain more in-depth teacher assessments regarding the effectiveness of students' metacognitive assessments.
- B. The Issue of Conceptual Gap and the Relationship between CT and Metacognition
 1. CT Understanding Gaps in Students: There are still major unanswered questions about whether and how children engage in computational thinking and how CT may impact their problem-solving behavior and academic achievement. Recent research shows a significant positive correlation between CT skills and self-efficacy and metacognitive self-regulation in student teachers (Şen, 2023).
 2. The Role of Metacognition in CT Development: There is an urgent need to better understand whether and how CT can support the development of metacognitive strategies, and to examine how CT can guide teachers to explicitly teach metacognitive strategies. Empirical evidence suggests that metacognitive sub-dimensions such as planning, debugging, and procedural knowledge can explain up to 47% of the variance in students' CT abilities (Üzümcü, 2023). Furthermore, systematically applied metacognition has been shown to promote CT development through a functional architecture that differentiates content and skills (Silva et al., 2023).
 3. Focus on Pre-Programming: There is a lack of in-depth research on pre-programming metacognitive planning, although metacognition (especially planning) is very

important because practicing computational thinking through programming depends on the problem solver's metacognition. This relationship is strengthened by correlation analysis which shows that metacognition components are key factors influencing problem solving in software education (Joo & Park, 2023).

C. Learning Implementation and Scaffolding Issues

1. Limitations of Explicit Teaching: The reality is that metacognitive strategies that are important for academic outcomes are often not taught explicitly to students, necessitating research on effective interventions. Using metacognitive techniques alone is not enough; instructors need to integrate problem-solving and metacognitive techniques simultaneously to help students develop strong CT sub-skills (Ubaidullah et al., 2021).
2. Lack of Metacognitive Focus in CT: There is an issue that little research on CT development focuses on students' metacognitive processes, and few studies have clarified the effects of metacognitive scaffolding on CT. The integration of metacognitive scaffolding in the aspects of planning, monitoring, reflection, and evaluation has been shown to facilitate increased CT and learning achievement (Gu et al., 2025).
3. Combined Effects of Scaffolding: Research on the combined effects of metacognitive and cognitive scaffolding is limited, although comprehensive interventions may be more effective. Synergistic strategies such as the combination of Project-Based Learning with Pair Programming Instructional Strategy (PBL-PPIS) have been shown to significantly improve students' five core CT competencies and metacognitive abilities (Zhang et al., 2025). Furthermore, learning modules such as ME-CoT have also demonstrated strong reliability in fostering metacognitive awareness in STEM curricula (Wang et al., 2022).

D. Context and Duration of Intervention Issues

1. Duration of Intervention: The reality is that improving metacognitive abilities requires long-term learning interventions, so further studies need to address the limitations of short research durations.
2. Adaptation of Vocational/General Context Model: Further research is needed to be conducted using other learning models based on Vocational Education or General Education by adopting the model produced in this study, because the characteristics of assessment in vocational education are very specific, namely performance-based assessment.

E. The Issue of Utilizing Technology (LMS/BLEMS) as a Metacognitive Tool

1. Learning Management Systems generally don't operate in an interactive and personalized way for students, posting assignments and learning materials tailored to their characteristics, making it difficult to provide adaptive, tailored recommendations and visualizations. As a result, LMSs often simply provide the same pedagogical resources and content to all students, without considering their specific and individual needs.
2. Learning Management Systems need to be further exploited as metacognitive tools to support student self-directed learning, as many instructors use them only for information dissemination rather than in ways that engage students in meaningful, strategic, or self-regulated learning.
3. Learning Management Systems typically do not operate in an interactive and personalized manner for students, necessitating the integration of specific rubrics and features to support metacognitive regulation. This issue will highlight the technical and

pedagogical challenges in leveraging digital platforms to facilitate and measure CT-based metacognition

Challenges in Computational Thinking -Based Metacognitive Learning Assessment: Future Research Directions

Future Research Challenges are crucial steps to address the knowledge gaps arising from the identified issues, thereby strengthening the development of Computational Thinking (CT)-based metacognitive assessments. These challenges should focus on rigorous testing, explicit causal relationships, and optimization of digital implementation. The following are future research challenges based on the identified issues:

A. Methodological Issues and Validity of CT Assessment

Further research challenges focus on strengthening validity and methodology, including:

1. Using Rigorous Experimental Designs: Future research should use rigorous experimental methods to empirically test whether CT formative assessment tasks can lead to improvements in student learning. Integrating Qualitative and Quantitative Methods: Further research is needed that combines quantitative and qualitative data and uses think-alouds methods to examine the substantive processes involved in performance and provide evidence of the construct validity of test-based interpretations. Psychometric approaches and Rasch analysis need to be applied more widely to evaluate the quality of computerized CT assessment instruments to have strong convergent validity (Lai, 2021).
2. Developing Reflection-Based Assessment Tools: Evaluation forms and question forms are needed that allow students to explore their reflective and metacognitive thinking, subjective and objective, beyond multiple choice-based questions that only touch on low-order cognitive thinking. Future researchers must develop assessments that encourage deep learning and transdisciplinary skills to address the complex challenges of the modern world (Amarulloh et al., 2025).

B. The Issue of Conceptual Gap and the Relationship between CT and Metacognition

The next research challenge should be to bridge the conceptual gap and understand the interaction between CT and metacognition:

1. Understanding Causal Relationships: There is an urgent need to better understand whether and how CT can support the development of metacognitive strategies, as metacognition is crucial for CT to guide students in selecting thinking strategies. Future research should explore the predictive role of metacognition in the context of higher-order thinking skills more broadly across educational levels (Üzümcü, 2023).
2. Examining the Role of Explicit Instruction: Research should examine how CT can guide teachers to explicitly teach metacognitive strategies, given that metacognitive strategies are often not taught explicitly.
3. Focusing on Pre-Programming Planning: There is a need to address the lack of in-depth research on pre-programming metacognitive planning, although practicing computational thinking through programming depends on problem solvers' metacognition.

C. Learning Implementation and Scaffolding Issues

Challenges in the area of implementation center on optimizing learning support:

1. Verifying Scaffolding with a Large Sample: The findings on the effects of metacognitive scaffolding need to be further verified with a larger sample size, and perhaps with more nuanced scaffolding for these two dimensions. Further research is needed on the effectiveness of integrated learning modules (such as ME-CoT) on larger samples to

validate their reliability in creating an active and enjoyable learning atmosphere (Wang et al., 2022).

2. Exploring Students' Metacognitive Processes: Further research is needed because little research on CT development has focused on students' metacognitive processes, and there are still limitations regarding the combined effects of metacognitive and cognitive scaffolding.
3. Developing Specific and Diverse Scaffolding: Researchers should develop more specific metacognitive planning steps and build more types of scaffolding with different characteristics to meet the needs of different students. Special emphasis should be given to the design of metacognitive scaffolding in project-based learning environments to help novices overcome obstacles while programming (Gu et al., 2025).

D. Context and Duration of Intervention Issues

This challenge calls for expanding the duration and context of studies:

1. Conducting Long-Term Interventions: Future studies need to be implemented over a longer period of time, as improving metacognitive abilities requires long-term learning interventions.
2. Examining Changes in CT Aspects: Studies should further examine whether metacognitive planning will change students' computing concepts, practices, and perspectives, to ensure that metacognitive interventions are able to influence all dimensions of CT.
3. Adopting Models in Vocational/General Contexts: Further research is needed using other learning models based on Vocational Education or General Education, considering that the characteristics of assessment in vocational education are often performance-based assessments.

E. The Issue of Utilizing Technology (LMS/BLEMS) as a Metacognitive Tool

Further research challenges should focus on optimizing LMS as a self-regulation support tool:

1. Exploiting LMS as a Metacognitive Tool: LMS needs to be further exploited as a metacognitive tool to support Student Self-Learning, as many instructors only use it for information dissemination.
2. Optimizing Personalization and Interactivity: Research is needed to optimize how LMSs can function as metacognitive tools, by addressing the challenge that conventional LMSs typically do not operate in an interactive and personalized manner for students.

This research makes a significant scientific contribution by synthesizing the critical gap between Computational Thinking (CT) skills and metacognitive awareness, which have often been studied separately in the educational literature. Its novelty lies in its comprehensive mapping of barriers to digital assessment. It reveals that the limitations of current instruments lie not only in technical aspects, but also in the inability of traditional formats, such as multiple-choice assessments, to capture students' reflective thinking processes in real time. By integrating recent findings such as the effectiveness of the PBL-PPIS strategy (Zhang et al., 2025) and the use of the ME-CoT metacognitive empowerment module (Wang et al., 2022), this research offers a new framework linking psychometric validity with instructional technology innovations to deepen learning engagement (deep learning). This positioning of the study's findings provides strategic guidance for curriculum developers in designing assessments that measure not only the final programming outcomes but also students' cognitive evolution during the problem-solving process.

Based on the issues and challenges identified in this systematic analysis, future research should focus on three key developmental domains. First, there is an urgent need to explore the use of artificial intelligence (AI) to automate metacognitive feedback in programming environments, given the limitations of manual tasks in efficiently measuring high-level cognition. Second, more rigorous experimental studies with larger sample sizes are needed to verify the effectiveness of metacognitive scaffolding across educational levels, to strengthen the generalizability of existing findings (Gu et al., 2025; Üzümcü, 2023). Finally, future research should target contextual adaptation through the development of assessment rubrics specific to vocational and general education, taking into account the different performance characteristics of students in solving computational problems, both independently and collaboratively, in dynamic digital ecosystems.

CONCLUSION

Metacognition, defined as the awareness and control of thinking for learning, is a crucial component that plays a significant role in students' problem-solving performance, and is essential for Computational Thinking (CT) because practicing computational thinking through programming relies on problem solvers' metacognition. CT-based metacognitive assessments should structurally measure cognitive regulation, including planning, monitoring, and evaluation, using authentic methods such as think-aloud to examine the substantive processes involved in performance, and providing evidence of the construct validity of test-based interpretations. The need outlined in the Introduction regarding the lack of formative assessment tools and explicit metacognitive instruction is confirmed and detailed as crucial issues in the Results and Discussion, which demonstrate a congruence between the urgency of the research and the findings obtained.

Key challenges lie in the need to use rigorous experimental methods to validate the impact of assessments, bridge the conceptual gap regarding whether and how CT can support the development of metacognitive strategies, and optimize Learning Management Systems (LMS) to function as metacognitive tools to support Student Self-Directed Learning. The impact of this study is to provide a structured and conceptual research agenda for academics and practitioners to develop assessments and interventions capable of fostering students' higher-order thinking skills in the digital age. As a development prospect, further research should focus on longer-term interventions and more nuanced scaffolding verification to ensure that metacognitive changes are effectively able to transform students' computing concepts, practices, and perspectives, thereby achieving comprehensive improvements in all dimensions of CT.

CONFLICT OF INTEREST

The authors declare that they have no financial or non-financial conflicts of interest related to the publication of this manuscript. This research was conducted as a Systematic Literature Review (SLR), aiming to identify, evaluate, and synthesize all relevant scientific evidence regarding the issues and challenges of Computational Thinking-based metacognitive learning assessment.

Due to the nature of this research as a literature review, no data were collected from human or animal subjects, and no external financial support was provided by any party that could have influenced the results or interpretations presented. The authors guarantee that all findings and conclusions are based on a transparent and reproducible analysis of the literature. No personal or institutional relationships exist that could affect the scientific objectivity of the results reported in this manuscript. This statement summarizes all aspects of any potential conflicts of interest.

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