



Implementing Computational Thinking-Based Summative Assessment in STEM: Opportunities and Barriers in an Indonesian Islamic Senior High School

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Abstract: Rapid technological advancement and the increasing complexity of real-world problems require students to develop ways of thinking that enable them to analyze, structure, and solve problems systematically. Computational thinking (CT) has therefore emerged as a crucial competence, particularly within STEM education. Despite growing interest in CT integration through project-based learning, limited attention has been given to how CT is incorporated into end-of-schooling summative assessment at the senior high school level. This study examines teachers' and students' understanding of computational thinking, their perceptions of CT-based summative assessment through STEM projects, classroom implementation practices, and the challenges faced during implementation. Using a qualitative case study approach, data were collected through interviews, classroom observations, and document analysis at a private Islamic senior high school in Indonesia. The participants included seven teachers from different subject areas and eleven twelfth-grade students who were directly involved in a CT-based summative STEM project. Data were analyzed thematically through an iterative process of data condensation, display, and verification. The findings indicate that both teachers and students generally conceptualize CT as systematic, step-by-step problem-solving. While teachers demonstrate a broader conceptual understanding of CT, its core dimensions, such as decomposition, abstraction, and algorithmic thinking, are not yet explicitly operationalized in summative assessment criteria. Students can apply CT to practical project tasks, although their understanding remains basic. Both teachers and students perceive CT-based summative assessment positively, as it emphasizes thinking processes, hands-on learning, collaboration, and real-world problem contexts. However, implementation is constrained by limited assessment literacy, challenges in interdisciplinary alignment, time constraints, unequal student participation, and resource limitations. Overall, the study suggests that CT-based summative assessment through STEM projects has strong potential to support meaningful learning at the senior high school level. Nevertheless, clearer assessment frameworks, targeted teacher professional development, and stronger institutional support are required to bridge the gap between conceptual intentions and assessment practices.

Keywords: computational thinking, project-based learning, summative assessment, STEM, 21st-century competencies.

▪ INTRODUCTION

The rapid advancement of digital technologies has brought profound changes to multiple aspects of human life, including learning, work, and social interaction. In response, educational systems are increasingly expected to equip students with competencies to navigate complex, fast-changing, and technology-rich environments (Tariq et al., 2025). One such essential competence is computational thinking (CT), which has been widely recognized as an essential skill for addressing complex, multidisciplinary problems in the digital era (Lai & Ellefson, 2022; Lamprou & Repenning, 2018; Weintrop et al., 2021). Beyond its relevance to computer science, CT is increasingly

viewed as a core competence that supports twenty-first-century skills, including critical thinking, problem-solving, and adaptability (Kaya et al., 2025; Nouri et al., 2020).

CT is a multifaceted construct with diverse definitions and interpretations across educational contexts (Ezeamuzie & Leung, 2022; Li & Oon, 2024; Pallop et al., 2025). Wing (2006) conceptualizes CT as “solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science” (p. 33). Similarly, Li and Oon (2024) define CT as “a problem-solving/thought process that involves selecting and applying appropriate tools and practices for solving problems effectively and efficiently (p. 3). These perspectives position CT as a multidimensional cognitive competence encompassing both general computational reasoning and domain-specific problem-solving abilities, extending beyond programming tasks into non-programming contexts (Lai & Ellefson, 2022).

In the education context, the integration of CT not only supports students’ understanding of academic content but also fosters logical, critical, and structured ways of thinking that are transferable to everyday problem situations (Bocconi et al., 2018). Consequently, CT serves as a foundational basis for the development of higher-order thinking skills (HOTS), such as problem-solving (Montuori et al., 2024; Vourletsis & Politis, 2020), as well as more advanced capacities such as decision-making and innovation, which rely on analytical reasoning, evaluation of alternatives, and creative solution design (Bocconi et al., 2018; Shute et al., 2017).

Recent empirical evidence has increasingly positioned computational thinking as a foundational component of Science, Technology, Engineering, and Mathematics (STEM) education. Rather than being confined to computer science, CT serves as a universal mode of thinking that supports core STEM practices such as modeling, data analysis, simulation, and design-based problem-solving (Li et al., 2020). Systematic reviews and meta-analyses provide empirical evidence that integrating CT into STEM instruction yields positive effects, both cognitive and noncognitive, reinforcing the view that CT and STEM are mutually reinforcing domains (Li & Oon, 2024). Recent syntheses further emphasize that CT has become essential for engaging students in complex, interdisciplinary, and technology-rich STEM problem contexts (Tariq et al., 2025).

Project-Based Learning (PBL) is widely recognized as an effective approach for CT into STEM education due to its close alignment with the cognitive and procedural nature of CT (Chen & Hui, 2024; Feng & Yang, 2022; Wang et al., 2021). CT involves processes such as problem decomposition, pattern recognition, abstraction, and algorithmic thinking, which are most effectively developed through engagement with complex, authentic problems rather than routine tasks (Shute et al., 2017; Wing, 2006). Empirical studies demonstrate that project-based STEM learning enables students to apply CT meaningfully while integrating knowledge across disciplines (Chondrogiannis et al., 2021; Hsieh et al., 2022). A recent meta-analysis of 31 empirical studies provides strong evidence that PBL significantly enhances students’ computational thinking skills, including collaboration, critical thinking, algorithmic reasoning, innovation, and problem-solving (Zhang et al., 2024). The findings confirm PBL as an effective approach for developing computational thinking across K–12 education, though its impact varies by educational level.

Assessment is increasingly seen as important for developing twenty-first-century skills because it influences not only what students learn but also how they learn. Studies

in STEM and inquiry-based learning show that well-designed assessments can help reveal and develop complex skills, such as collaboration, critical thinking, and problem-solving, especially when assessments are integrated into authentic, project-based tasks (Buitrago-Flórez et al., 2021; Herro et al., 2017). However, these benefits depend heavily on teachers' assessment literacy and the alignment between learning objectives, instructional practices, and assessment criteria; without such alignment, assessment risks becoming procedural rather than pedagogically meaningful (Bonner et al., 2021; Manfra et al., 2022).

CT poses specific challenges for assessment because it involves complex and process-oriented ways of thinking. Skills such as abstraction, decomposition, and algorithmic reasoning are difficult to measure using traditional assessment methods. Researchers emphasize that clear definitions of CT are essential for designing valid assessments, as unclear or inconsistent understandings can weaken curriculum and evaluation practices (Lai & Ellefson, 2022). Despite increased attention to CT, studies show that teachers still face difficulties translating it into observable, assessable indicators, especially when CT is integrated into authentic classroom tasks (Bubica & Boljat, 2022; Li et al., 2020; Ukkonen et al., 2025).

Research on assessment in STEM learning has addressed both formative and summative purposes (Bonner et al., 2021; Hadad et al., 2020; Hubber et al., 2022). Although some scholars argue that balancing these two purposes is challenging, others suggest that formative and summative goals can be addressed simultaneously through carefully designed assessment (Black & Wiliam, 2018; Dixson & Worrell, 2016; Imlig & Ender, 2018). This perspective is particularly relevant to CT, which involves complex and often invisible cognitive processes such as abstraction, decomposition, and algorithmic reasoning that develop over time.

In the Indonesian context, students' relatively low performance in international and national assessments, such as Programme for International Student Assessment (PISA) and the Minimum Competency Assessment (Asesmen Kompetensi Minimum/AKM), indicates persistent challenges in literacy, numeracy, and problem-based reasoning that require higher-order thinking skills. CT-based summative assessment embedded in STEM projects offers a promising and authentic approach to both measuring and developing these competencies by engaging students in real-world tasks that require problem formulation, data-driven solution design, iterative reasoning, and evaluation. Such processes align closely with the competencies assessed in PISA and AKM and support deeper learning than traditional assessment practices focused on rote memorization and isolated subject mastery (Cheng & Huang, 2025).

Despite the growing body of research on integrating CT into STEM through project-based learning, limited attention has been given to how CT is incorporated into school-level summative assessment systems, particularly from the perspectives of teachers and students. In addition, empirical studies at the K–12 level indicate a decline in the number of studies on integrating CT into STEM learning through projects as the educational level increases (Chen & Hui, 2024; Wang et al., 2021). This decline is presumed to be associated with increasing assessment pressures, including high-stakes examinations at the end of schooling (Chen & Hui, 2024), which reduce the emphasis on STEM project-based learning due to its substantial instructional time demands.

Furthermore, neither systematic literature reviews do not explicitly specifies whether the assessments examined were conducted for formative or summative purposes.

The novelty of this study lies in its focus on the senior high school level in Indonesia and its empirical examination of CT-based summative assessment through STEM projects from both teacher and student perspectives. While the STEM projects examined in this study were implemented as summative assessments, they also allowed for formative uses, as teachers continuously observed students' problem-solving processes, provided guidance, and monitored collaboration throughout project implementation. By capturing both assessment intentions and classroom practices, this study offers context-sensitive insights into how CT-based assessment through STEM projects can support more reflective, adaptive, and twenty-first-century-aligned learning systems.

▪ **METHOD**

Participant

This study was conducted from March to May 2023 at Al Fityan School, Tangerang, a senior high school located in Tangerang Regency, Banten Province, Indonesia. This school was selected as the research site because of its strong commitment to preparing students to face the challenges of the twenty-first century, as reflected in its vision, namely, "to become a leading Islamic senior high school in developing a faithful generation with strong mastery of knowledge and the ability to respond to the challenges of the times," as well as one of its mission statements, which emphasizes "equipping students with essential life skills to prepare them for the demands of the Industrial Revolution 4.0."

As part of its institutional policy to strengthen twenty-first-century learning, the school has, since 2021, introduced CT to its teachers through a collaboration with a private university in Indonesia. This collaboration was implemented through webinars, workshops, and ongoing teacher mentoring in classroom instruction through microteaching activities. Nearly all teachers at the school have participated in CT workshops and microteaching sessions as part of the Pengajar Era Digital Indonesia (PANDAI) initiative and have obtained certification from Bebras Indonesia.

Seven teachers and 11 students were purposively selected to participate in this study. The specific criteria for selecting the research samples were based on their direct involvement and experience in implementing CT-based summative assessment through STEM projects. Teachers were chosen if they met the following criteria: (1) actively involved in designing, implementing, or evaluating the STEM projects, (2) having at least two years of teaching experience in their respective subjects, and (3) demonstrating familiarity with performance-based assessment practices. Student informants were selected based on the following considerations: (1) they had participated in and completed the CT-based summative assessment through the STEM project; (2) they represented a range of achievement levels (high, middle, and low); and (3) they were willing to provide reflective and honest responses regarding their learning experiences.

The teachers who participated in this study were responsible for subjects integrated into the STEM project, such as Mathematics, Physics, Biology, Chemistry, Indonesian Language, Entrepreneurship, and Craft. Meanwhile, the students were 12th-graders who had completed the CT-based summative assessment through the STEM project. To ensure the confidentiality of the informants' identities and protect their personal data, a coding system was employed to maintain anonymity. This approach allowed informants

to feel safer and more open in sharing their views and experiences honestly. The informant codes used for teachers in this study are presented as follows.

Table 1. Teacher informant codes

Informant Code	Subject Taught
Teacher 1	Mathematics
Teacher 2	Mathematics
Teacher 3	Physics
Teacher 4	Biology
Teacher 5	Chemistry
Teacher 6	Indonesian Language
Teacher 7	Handicrafts and Entrepreneurship

Students were also involved as informants to provide a more comprehensive perspective on the implementation of CT-based summative assessment through STEM projects. To ensure confidentiality and protect the informants' original identities, each student was assigned an anonymous code, ranging from Student 1 to Student 11.

Research Design and Procedure

The study employed a qualitative case study approach (Hatch, 2002) to explore in depth the perceptions of teachers and students regarding CT-based summative assessment in the form of STEM projects at Al Fityan School, Tangerang. The case study approach was deemed appropriate because it allows for in-depth exploration within a specific school context, recognizing that each educational institution has unique characteristics. Therefore, the findings of this study are expected to provide a rich contextual description of how computational thinking-based summative assessment is implemented in practice.

After identifying and coding the informants, the next stage was data collection. Data were gathered using various techniques aligned with the qualitative case study approach, namely interviews, observations, and document analysis. All teacher interviews were conducted in the teachers' room, lasting approximately 15 to 20 minutes, and scheduled during school days when the teachers were free from teaching duties. Meanwhile, interviews with 12th-grade students were conducted after they had completed their classes, specifically after the School Final Examination, so that their participation in the research would not interfere with ongoing instruction. These interviews lasted approximately 10 to 15 minutes. With the informants' consent, the researcher used a voice recorder to document the conversations also took notes key points during the interviews.

The observation method used in this study was non-participant observation (Cohen et al., 2018), in which the researcher was present in the classroom without intervening in the learning process. The observation took place in a 12th-grade class of 35 students to directly observe the implementation of the CT-based summative assessment through a STEM project. The selection of 12th grade as the observation site was based on the consideration that students at this level have more mature learning experiences and have engaged in interdisciplinary learning throughout their three years of senior high school. Additionally, they had already completed the projects, which were expected to enable them to provide more comprehensive and in-depth reflections on the implementation and impact of the computational thinking approach within the project. Therefore, the data from the 12th-grade class were considered more representative for evaluating the

effectiveness of implementing a computational thinking-based summative assessment at the senior high school level. Document analysis in this study was conducted by examining assessment instruments, such as rubrics, students' project proposals, and final reports. These artifacts provided additional evidence for understanding how computational thinking principles were operationalized and assessed.

Instruments

The interviews used in this study were semi-structured (Creswell & Poth, 2018). For data collection, the researcher used an interview guide comprising predetermined, structured questions. The interviews were conducted face-to-face to allow the researcher to observe the informants' facial expressions and body language, and to provide opportunities to ask follow-up questions as needed to deepen understanding.

Data Analysis

The data in this study were analyzed using the framework proposed by Miles et al. (2014), comprising three key phases: data condensation, data display, and conclusion drawing. In the data condensation stage, the researcher selected and organized the data to identify central themes, recurring patterns, and significant. For example, several teachers described computational thinking as a structured and sequential way of thinking, as seen in statements such as "We think step by step, like a computer that follows a program" (Teacher 1) and "Computational thinking means thinking in a programmed and ordered way" (Teacher 3). At the same time, students expressed similar but simpler interpretations, referring to it as "thinking like a computer" (Student 7) or "thinking in an orderly way" (Student 8). These excerpts were condensed into the computational thinking category as systematic, step-by-step thinking, which was then compared with other condensed categories, including teachers' references to algorithmic reasoning and problem decomposition. Through this process of constant comparison, the condensed categories were integrated into the broader theme Teachers' and Students' Understanding of Computational Thinking, leading to the conclusion that teachers demonstrated a more articulated and multidimensional understanding of computational thinking. In contrast, students' understandings remained basic and practice-oriented. This conclusion was continuously checked against the original interview data to ensure that the interpretation accurately represented participants' perspectives. The next stage, data display, was carried out in tabular format to facilitate the visualization of patterns and relationships, enabling a more structured and systematic analysis. Finally, conclusions were drawn by evaluating the identified patterns and verifying their accuracy through triangulation to ensure high levels of validity and credibility (Creswell & Poth, 2017).

To ensure the credibility of this study, data triangulation was employed by involving teachers from different subject areas and twelfth-grade students with diverse academic abilities. In addition, methodological triangulation was achieved through multiple data collection methods, including document analysis, classroom observations, and interviews.

▪ RESULT AND DISSCUSSION

Description of the Projects

Document analysis, classroom observations, and interviews with teachers and students revealed that the practical examination, implemented as a CT-based summative

assessment through STEM projects, was conducted in groups of four to six students over three weeks. Each group received project funding of IDR 200,000, and any additional costs required for project completion were covered by the group members themselves. The project was implemented through a series of sequential stages: 1) socialization of the project to students, during which teachers explained the objectives, procedures, and assessment criteria of the practical examination; 2) development of a project proposal with teacher guidance; 3) presentation of the proposal in a seminar before a panel of teachers; 4) a teachers' meeting to determine which proposals were approved and which needed to be revised or redirected to different themes based on various considerations; 5) announcement of the proposal seminar results; 6) revision of approved proposals; 7) distribution of project funding; 8) purchase of tools and materials required for product development; 9) product development under continuous teacher supervision and monitoring; 10) presentation of the finished product and group assessment attended by all students, parents, and guest lecturers from a private university in Jakarta who served as members of the assessment panel; 11) individual assessments for each related subject to evaluate students' individual understanding; 12) exhibition of student projects attended by teachers from other schools and parents, during which each group prepared an exhibition booth, explained their products to visitors, and responded to questions; and 13) awarding of prizes to the best-performing groups. The STEM projects implemented in the classroom are presented in the appendix.

The STEM projects integrated multiple subject areas, including Mathematics (measurement, calculation, and data analysis), Physics (energy, heat, force, or motion), Biology (life systems and environmental contexts), and Chemistry (properties and changes of matter), which are part of STEM, as well as Indonesian language (scientific report writing and presentations) and Craft and Entrepreneurship for product or prototype design and construction, which are not classified as STEM subjects. PBL is also well-suited for summative assessment because it provides students with opportunities to demonstrate their ability to apply knowledge in an interdisciplinary manner as part of a practical examination at the end of the senior high school level. In addition, PBL allows students to be assessed through multiple forms (Hubber et al., 2022), including evaluations of planning, ongoing processes during task implementation, final products, presentations, and individual oral examinations.

Figure 1 illustrates the stages a student group followed in a STEM project to develop a water-level monitoring device. The stages refer to the conceptualization of the components of CT proposed by Anderson (2016) that consist of decomposition, pattern recognition, abstraction, algorithmic design, and evaluation. Based on classroom observations, interviews, and analysis of students' project reports, the project process began when students identified the problem to be addressed: the need for a water-level monitoring tool to support flood mitigation. At this initial stage, students engaged in problem decomposition by breaking the system into several key components: hardware (sensors, microcontrollers, LEDs, and buzzers), software (monitoring algorithms), and testing procedures.

The students then moved to the pattern recognition stage, during which they observed the relationship between changes in water level and sensor responses. Through these observations, students began to identify data patterns corresponding to low, medium, and high water conditions. At the abstraction stage, students simplified the

physical phenomenon of water level into numerical data representations (distance measured in centimeters) and logical categories such as safe, alert, and danger. This representation enabled students to design solutions without focusing on unnecessary technical complexity.

The next stage involved solution design and algorithmic thinking, in which students developed logical steps in the form of if–then–else algorithms to determine the device’s responses, such as automatically activating LEDs or buzzers based on the detected water level. These algorithms were then implemented by assembling and programming the device. In the final stage, students conducted testing, evaluation, and reflection. They tested the device under various water-level conditions, identified errors and mismatches in the results, and made improvements to both the circuitry and the algorithm. Through group discussions, students reflected on the effectiveness of their solution and considered possible refinements to enhance the device’s accuracy and reliability.

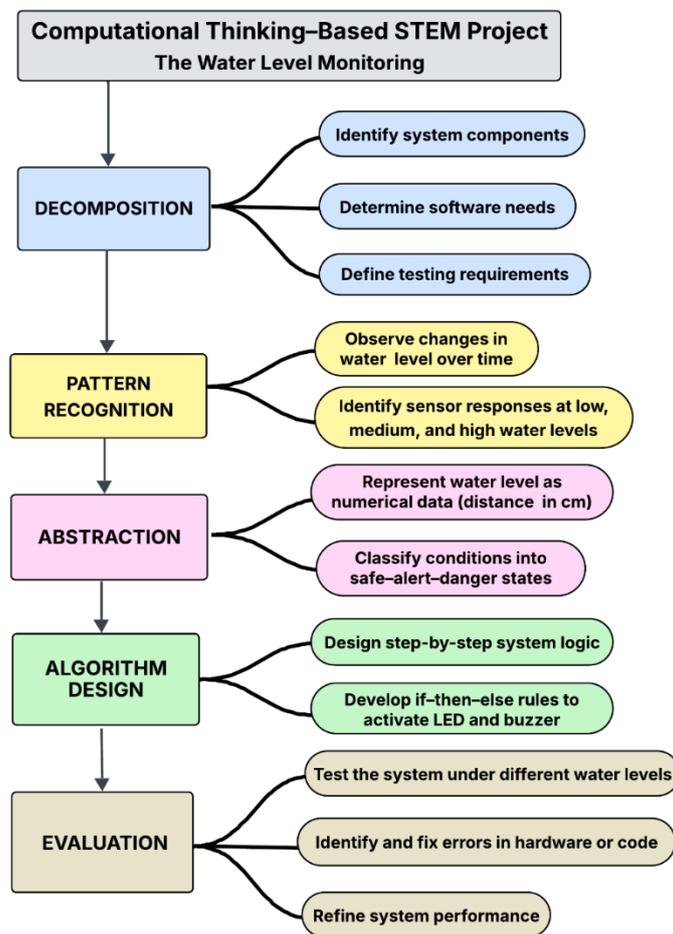


Figure 1. The stages in developing the water level monitoring device

The results of document analysis and interviews with teachers indicate that the integration of CT into STEM projects was intended to develop students’ thinking skills for addressing complex problems through an interdisciplinary approach, applying CT

principles. To some extent, these aims also reflect the three objectives of CT integration in project-based STEM learning identified by Chen & Hui (2024) in their systematic literature review. These objectives include, first, developing students' computational thinking skills; second, enhancing their understanding of the subject areas involved in the project; and third, fostering positive attitudes and self-efficacy toward STEM.

However, the CT elements were not explicitly assessed by teachers. One reason for this was that CT had only recently been introduced to both teachers and students. In addition, CT-based summative assessment through STEM projects was being implemented for the first time. During ongoing teacher supervision and monitoring, teachers conducted observations to examine students' participation and collaboration throughout the project implementation as part of the assessment process. Assessment of products, presentations, and individual oral examinations focused primarily on students' understanding of the basic competencies specified for each subject and on how they carried out the project to produce a final product using an interdisciplinary approach. Nevertheless, STEM project activities inherently involve core CT elements, such as problem decomposition, pattern recognition, abstraction, and algorithmic sequencing, as also emphasized in the CT literature (Shute et al., 2017; Wing, 2006). As a result, at these STEM projects, CT functions as a supporting cognitive process for learning rather than as the primary indicator in summative assessment.

Teachers' and Students' Understanding of the CT-Based Summative Assessment through STEM Projects

The findings with regards to teachers' and students' understanding of the CT-based summative assessment through STEM projects are presented in four main themes (1) teachers' and students' understanding of computational thinking, (2) teachers' and students' perceptions of computational thinking-based summative assessment in the form of STEM projects, (3) the implementation, and (4) the barriers and challenges in the implementation. The themes and sub-themes are presented in the following table.

Table 2. Themes and sub-themes of computational thinking-based

Theme	Subthemes
Teachers' and Students' Understanding of Computational Thinking	<ul style="list-style-type: none"> • Systematic and step-by-step thinking • Core dimensions of CT • CT for problem-solving • CT as a 21st-century skill
Teachers' and Students' Perceptions of CT-Based Summative Assessment through STEM Projects	<ul style="list-style-type: none"> • Making students' thinking processes visible • Learning through hands-on and real-world STEM projects • Perceived fairness and opportunities for all students • Students' mixed responses to the assessment challenges
Implementation of CT-Based Summative Assessment through STEM Projects	<ul style="list-style-type: none"> • CT-oriented STEM project design • Teachers' roles as facilitators • Assessment of process and product • Individual contribution and understanding within group projects

Barriers and Challenges in CT-Based Summative Assessment through STEM Projects	<ul style="list-style-type: none"> • Structural and resource constraints • Challenges in aligning subject-specific assessment with interdisciplinary projects • Challenges in assessment literacy for CT-based summative assessment • Difficulties in capturing individual understanding within group-based assessment • Time constraints in CT-based summative assessment • Potential threats to assessment validity
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Teachers’ and Students’ Understanding of Computational Thinking

The findings indicate that both teachers and students predominantly understood computational thinking as systematic, step-by-step thinking. Teachers frequently described CT as a structured cognitive process that follows clear sequences and predetermined steps, often referring to planned procedures and ordered stages, for example, as articulated by Teacher 1, “We think step by step, like a computer that follows a program.” Teacher 3 reinforced this view by describing CT as involving sequential and programmed thinking. This understanding is related to early conceptualizations of computational thinking that closely associated CT with programming and computing concepts, particularly sequencing as one of its core elements (Brennan & Resnick, 2012).

Students articulated this understanding using simpler expressions such as “thinking like a computer” (Student 7) or “thinking in an orderly way” (Student 8). Although these expressions were not dominant across all interviews, they reveal how some participants conceptualized CT through analogies with computational systems, emphasizing logic, rule-based processes, and efficiency rather than the literal use of computers. The expression “thinking like a computer” confirms findings from previous studies that have identified persistent misconceptions about CT, particularly the tendency to equate CT with machine-like or mechanical thinking (Lamprou & Repenning, 2018). As Wing (2006) emphasizes, CT does not mean that humans should think like computers; rather, it involves leveraging computational tools with human intelligence to solve problems that were previously difficult or nearly impossible to address.

Beyond these procedural and metaphorical interpretations, teachers demonstrated an understanding of CT as a set of interrelated cognitive components for approaching problems. For example, Teacher 2 explained that CT involves “breaking down a complex problem into simpler parts, identifying patterns, and then determining how to solve the problem step by step” (Teacher 2). Another described CT as a thinking process that includes “stages of decomposition, patterns, and algorithms, or how someone must think step by step to solve a problem and obtain a solution” (Teacher 6). Although conceptualizations of CT continue to vary in the literature, teachers’ understandings of its components largely reflect several of the most frequently cited core CT components, namely pattern recognition, decomposition, abstraction, and algorithms (Ezeamuzie & Leung, 2022).

CT was further understood by teachers and students as a framework for solving complex, real-world problems. Teachers highlighted that CT helped students systematically analyze complex problems and design solutions that integrated knowledge from multiple disciplines, as reflected in one comment: “Students learn to break down

complex problems and find solutions, not just memorize content” (Teacher 5). This perspective resonates with contemporary views of CT as a transferable problem-solving approach applicable beyond computer science (Bocconi et al., 2018; Wing, 2008). Previous studies have also shown that teachers perceive CT as a way of thinking for addressing complex problems across diverse contexts (Feng & Yang, 2022; Kite & Park, 2023). Furthermore, some teachers and students associated computational thinking with 21st-century skills, particularly critical and creative thinking. For example, Teacher 2 stated:

“It is a way, or what can be described as a method, for solving and addressing problems. This method trains our minds to think creatively and critically when dealing with problems by applying computational thinking concepts.”

Students echoed this perception, describing CT as “thinking creatively and critically” (Student 1; Student 5) and “thinking broadly, not from only one point of view” (Student 6). While computational thinking is often associated with critical and creative thinking because it draws on a range of higher-order thinking skills to address complex problems, it is more appropriately understood as the coordinated use of multiple higher-order thinking skills, including critical and creative thinking, to solve complex problems effectively and efficiently (Barr et al., 2011). Empirical studies further indicate that integrating computational thinking into learning can enhance the four 21st-century competencies, including critical and creative thinking skills (Buitrago-Flórez, 2021).

Teachers’ and Students’ Perception of Computational Thinking-Based Summative Assessment in STEM Projects

Teachers perceived CT-based summative assessment through STEM projects as an approach that made students’ thinking processes more visible. Rather than focusing solely on final products or presentations, teachers emphasized the importance of examining how students reasoned, planned, and solved problems throughout the project. One teacher explained, “I do not only assess the presentation. I also look at the process and ask students one by one, so I can see who really understands how the solution was made” (Teacher 1). Another teacher similarly noted that individual questioning was necessary to ensure that the assessment reflected genuine understanding rather than surface performance. Students shared this perception, reporting that the assessment required them to deeply understand their own work. A student commented, “We had to really understand what we did, because the teacher could ask us about any step, not just the final result” (Student 7). This perception aligns with assessment principles that emphasize making learning and thinking visible as a basis for meaningful evaluation (Wang et al., 2024). Another student added that process-oriented assessment reduced fear of making mistakes:

“In my opinion, process-oriented assessment makes me feel more confident. I used to be afraid of making mistakes if the final result was not perfect, but now I realize that the way I think and solve problems matters, too. So, I focus more on the process, not just the outcome.” (Student 2)

The student’s reflection indicates a clear shift in assessment orientation from emphasizing outcomes to valuing students’ thinking processes, with important implications for learning motivation. This process-oriented emphasis supports students’

sense of competence and autonomy, while collaborative project work promotes deeper engagement and learning motivation (Heng & Yeh, 2024). In the long term, such assessment practices may also influence students' achievement goal orientations and learning mindsets, as emphasizing effort, strategy use, and iterative improvement aligns with mastery-oriented goals and the development of a growth mindset (Yeager & Dweck, 2012). By emphasizing the process, students become more actively engaged, willing to take intellectual risks, and more creative in seeking solutions (Stuppan et al., 2025). They learn that mistakes are not failures, but rather part of the learning journey that leads to deeper understanding (Zhao et al., 2018). Over time, this experience shapes adaptive and resilient mindsets, enabling students to face new challenges with confidence, employ effective learning strategies, and develop critical and creative thinking skills essential for 21st-century competencies (Nouri et al., 2019; Stuppan et al., 2025).

Teachers and students also perceived CT-based summative assessment through STEM projects as closely connected to hands-on learning and real-world problem contexts. Teachers described projects as opportunities for students to apply classroom learning to everyday situations. As one teacher explained, "I try to connect the project to real-life problems, so students can see how what they learn is actually used" (Teacher 5). This perception suggests that assessment was not viewed as an abstract academic exercise, but as part of a practical learning experience. Students echoed this view, describing project work as more engaging and meaningful than traditional tests. One student stated, "It is not just theory. We have to build something, test it, and fix it if it does not work" (Student 8). Through these hands-on activities, students perceived clearer connections between science, mathematics, and technology, as well as the role of computational thinking in organizing and refining solutions. These perceptions are consistent with research on project-based learning, which highlights the value of contextualized and interdisciplinary tasks in fostering deeper understanding (Lee et al., 2024; Shin et al., 2021; Yeni et al., 2024).

Another prominent perception concerned fairness and opportunities for all students. Teachers viewed CT-based summative assessment as fairer than traditional assessments because it allowed them to recognize students' contributions beyond verbal fluency or presentation skills. One teacher remarked, "Sometimes students who are good at speaking look smarter, but they are not always the ones who actually work on the project" (Teacher 2). By examining both individual explanations and group processes, teachers believed that they could more fairly evaluate students' understanding. Students also perceived this assessment approach as offering more balanced opportunities to demonstrate their abilities. A student noted, "Even if you are not good at talking in front of the class, the teacher can still see your work and your ideas" (Student 4). These perceptions resonate with assessment literature emphasizing the importance of providing multiple ways for students to demonstrate learning, thereby supporting fairness and broader recognition of diverse strengths (Kafai & Proctor, 2022; Lai & Ellefson, 2022; Lu et al., 2022).

Despite generally positive perceptions, students expressed mixed responses to the workload associated with CT-based summative assessment through STEM projects. Several students described the projects as demanding, particularly at the beginning. One student explained, "At first it was confusing, because there were many steps and we had to think carefully about everything" (Student 8). Managing group coordination, time constraints, and iterative problem-solving was perceived as challenging. However, these

challenges were often accompanied by positive responses. As students became more familiar with the process, many described the work as enjoyable and satisfying. A student reflected, “It was tiring, but when we finally finished and understood the solution, it felt excellent” (Student 6). This perception aligns with previous research suggesting that demanding assessment tasks can promote deeper engagement and learning when students recognize their value (McMillan & Turner, 2014; Stuppan et al., 2025). Thus, students’ mixed responses indicate that while CT-based summative assessment through STEM projects requires considerable effort, it is perceived as meaningful because it supports deeper understanding and problem-solving.

Implementation of Computational Thinking-Based Summative Assessment through STEM Projects

Teachers emphasized that the implementation of CT-based summative assessment began with the intentional design of STEM projects that required students to engage in systematic, logical problem-solving. Project planning typically involves reviewing basic competencies (Kompetensi Dasar/KD), identifying connections between subject matter and real-life contexts, and ensuring that project tasks encourage step-by-step reasoning. As one teacher explained, “I first review the basic competencies, then connect the material to real-life problems, and design a project that requires students to analyze and solve problems step by step” (Teacher 5). This approach reflects the understanding that CT-based summative assessment is more effectively conducted through project-based tasks that require students to decompose problems, sequence solution steps, and justify their reasoning, rather than relying solely on written assessments (Saad & Zainudin, 2024; Shute et al., 2017; Zhang et al., 2024). By embedding CT elements into project design, teachers attempted to ensure that the assessment captured both disciplinary understanding and thinking processes.

During project implementation, teachers consistently described their role as facilitators rather than direct instructors, guiding students through problem formulation, experimentation, and solution refinement. Teachers reported providing contextual problems and monitoring students’ progress while intervening primarily when students encountered difficulties in determining the next steps. One teacher noted, “I divide students into groups and give them problems related to everyday life. They look for solutions themselves, but I stay close when they are confused about what to do next” (Teacher 3). This facilitative role aligns with research suggesting that CT development is most effective when teachers scaffold students’ reasoning processes rather than provide prescriptive solutions (Kong et al., 2020).

Students’ accounts further confirm this implementation pattern. Several students described learning as initially challenging but increasingly engaging as they collaborated and refined their ideas. As one student stated, “At first it was confusing, but over time it became fun because we discussed everything with our friends and had to think carefully about each step” (Student 8). This suggests that implementing CT-based assessment through STEM projects encouraged active cognitive engagement and collaborative problem-solving, which are central to CT-oriented learning (Galanti & Baker, 2023; Grover & Pea, 2013).

A key feature of implementation was that assessment was conducted by evaluating both the final product and students’ individual understanding of the process, even though

projects were completed collaboratively. Teachers commonly reported using observation and individual questioning to differentiate students' contributions and levels of understanding. One teacher explained, "There are students who are good at speaking but not involved in making the project, and others who are good at building but cannot explain. That is why I assess not only the presentation, but also the process and ask students one by one" (Teacher 1). Another teacher similarly stated, "I call the students individually so I can see who really understands the process and who does not" (Teacher 2). This assessment strategy aims to address a well-documented challenge in project-based learning: the difficulty of capturing individual learning within a group (Bubica & Boljat, 2022; Psycharis, 2015). By combining product evaluation with oral questioning, teachers sought to make students' computational thinking visible at the individual level. Such practices are consistent with research suggesting that CT-based assessment should focus on students' reasoning, explanation, and reflection rather than solely on artifact quality (Bocconi et al., 2018; El-Hamamsy et al., 2022).

Both teachers and students viewed collaboration as an integral part of implementing CT-based summative assessment. Projects were typically completed in groups, requiring students to negotiate roles, share ideas, and solve problems together. Students reported that collaboration supported their thinking processes, as reflected in one student's comment: "We worked in groups and discussed how to solve the problem step by step, so we could find the best solution together" (Student 1). This finding aligns with prior studies indicating that collaborative STEM projects provide fertile ground for the development of CT skills, as students externalize and refine their thinking through dialogue and shared problem-solving (Adler et al., 2023; Herro et al., 2017). At the same time, teachers acknowledged that collaboration required careful monitoring to ensure that all students were cognitively engaged. This reinforces the view that effective implementation of CT-based assessment depends not only on project design but also on teachers' ability to manage interaction and assess individual understanding within collaborative contexts (Lin et al., 2025; Ukkonen et al., 2025).

The Barriers and Challenges in the Implementation

Despite the generally positive perceptions of CT-based summative assessment through STEM projects, the findings reveal a range of barriers and challenges that constrained its implementation. These challenges were not limited to technical issues, but reflected broader structural, pedagogical, and assessment-related concerns that shaped how CT-based assessment was enacted in classroom practice.

One major barrier identified by teachers was related to structural and infrastructural limitations. Teachers reported that implementing CT-based summative STEM projects often required access to laboratories, digital tools, simulations, and a stable internet connection, which were not always available. As one teacher explained, "If the project requires simulations or applications, such as for chemistry experiments or physics trials, students often struggle. The school laboratory does not have adequate facilities, and not all students have access to laptops or the internet at home" (Teacher 3).

These limitations affected students' ability to fully engage in project activities and restricted the scope of tasks that teachers could design. Consistent with previous studies, limited infrastructure and unequal access to technology remain significant barriers to the effective implementation of CT-oriented learning and assessment (Aulia et al., 2025; Kite

& Park, 2023). In this context, CT-based assessment was often adapted to fit available resources rather than being implemented as originally planned.

Teachers also struggled to align interdisciplinary STEM projects with subject-specific assessment requirements. Several teachers expressed concern that not all subjects were equally represented across projects, making it challenging to conduct fair and meaningful assessments for each discipline. One teacher stated, “For interdisciplinary projects, assessment per subject becomes less specific. Some subjects may not appear strongly in a project, so it is difficult for teachers of those subjects to assess students properly” (Teacher 1). Another teacher added, “It becomes difficult when the project does not involve chemistry, because I cannot observe the process directly” (Teacher 2). This challenge reflects a common tension in interdisciplinary STEM assessment, where integrating multiple subjects can blur disciplinary boundaries and complicate subject-based evaluation (Psycharis, 2015). Although interdisciplinary projects are pedagogically valuable, the findings suggest that clearer coordination among subject teachers is needed to ensure that assessment remains aligned with curricular expectations.

Teachers also highlighted challenges related to assessment literacy, particularly when translating students’ explanations and project work into numerical scores. Several teachers expressed uncertainty in designing assessment criteria and determining appropriate scoring levels. One teacher stated, “The difficulty is determining the rubric—deciding which points should be asked and what kind of explanation deserves a score of 90” (Teacher 3). Another teacher emphasized that rubric development required careful consideration, explaining that “there are many things to think about when deciding the indicators and the scoring range” (Teacher 3). These accounts indicate that teachers struggled not only with rubric construction but also, more broadly, with operationalizing assessment principles in CT-supported project contexts. This finding is consistent with prior research showing that assessing complex, process-oriented learning requires strong assessment literacy, particularly when cognitive processes are not directly observable (Black & Wiliam, 2018; Bocconi et al., 2018; El-Hamamsy et al., 2022). In this study, the challenge was not assessing CT as a separate construct, but ensuring that subject learning outcomes and reasoning processes—supported by CT—were evaluated in transparent and defensible ways.

Another major assessment challenge involved capturing individual students’ understanding within collaborative project work. Teachers observed that while some students were actively involved in designing and building projects, others contributed minimally or lacked understanding of the final product. One teacher explained, “In every group, there are always one or two students who do not really participate and do not understand how the product works” (Teacher 7). Students themselves confirmed this issue, with one student stating, “I did not get active team members, so I ended up working on the project by myself” (Student 2). To address this issue, teachers frequently relied on individual questioning. As one teacher described, “I call students one by one so that the differences become clear—who really understands and who does not” (Teacher 2). This strategy was intended to ensure that individual understanding was assessed fairly, even within group-based tasks. Such findings align with project-based learning research, which emphasizes the importance of individual assessment strategies to prevent group work from obscuring individual learning evidence (Bubica & Boljat, 2022; Herro et al., 2017).

As found in previous studies (Chen & Hui, 2024; Lin et al., 2025), time constraints were also identified as another barrier, particularly when teachers attempted to assess students individually within group-based projects. Several teachers explained that limited assessment schedules restricted their ability to explore students' understanding in depth. One teacher explicitly stated, "The main challenge is time, because the assessment schedule is very limited, so we cannot explore students' understanding deeply" (Teacher 5). Although individual questioning was seen as an effective strategy to address unequal participation, it significantly increased teachers' workload and intensified time pressure.

Taken together, the structural constraints, difficulties in rubric design, unequal participation, and time limitations point to potential threats to assessment validity. When assessment criteria are unclear, time for individual evaluation is limited, and group work masks individual understanding, there is a risk that assessment outcomes may not accurately reflect students' actual computational thinking competencies. To mitigate this risk, several teachers reported assessing students individually even within collaborative projects. One teacher explained, "Even though the project is done in groups, I still assess students individually by asking them questions, so I can see who really understands the process" (Teacher 7). However, while such strategies helped reduce validity threats, they also reinforced other challenges, particularly time constraints and assessment workload. Moreover, the findings suggest that some assessment practices were implemented procedurally, without a strong conceptual understanding of assessment principles. Previous research emphasizes that strengthening teachers' assessment literacy is essential to ensure that innovative assessment approaches function not only as administrative tools but also as valid and meaningful measures of student learning (Black & Wiliam, 2018; El-Hamamsy et al., 2022).

▪ CONCLUSION

This study shows that CT-based summative assessment through STEM projects can serve as an alternative to end-of-schooling summative assessment at the senior high school level. By integrating STEM subjects with Indonesian Language, Craft, and Entrepreneurship, this assessment provides students with opportunities to apply their knowledge to solve real-world problems through systematic and logical thinking. Through project-based activities, students are also encouraged to develop important skills such as critical thinking, collaboration, creativity, and communication.

The findings indicate that most teachers and students understand CT mainly as an approach to solving complex problems. In classroom practice, CT is used as a general framework that helps students think through challenging tasks step by step. This shared understanding supports students' active engagement in project work and is viewed positively by both teachers and students.

The study further shows that the implementation of CT-based summative assessment is influenced by several pedagogical and institutional factors. Limited assessment literacy, difficulties in coordinating assessment across subjects, time constraints, and limited resources affect how consistently and fairly students' learning processes can be evaluated. Without clear assessment guidelines and sufficient support, the potential of CT-based summative assessment may not be fully achieved.

Overall, these findings suggest that summative assessment at the senior high school level can move beyond a focus on final products toward a more process-oriented approach

that values students' thinking and problem-solving processes. To support this shift, computational thinking needs to be clearly conceptualized as an assessable competence and aligned with learning objectives, assessment criteria, and classroom practices. At the school level, better coordination, clearer assessment frameworks, and adequate resources are essential to support the effective implementation of CT-based summative assessment.

Based on these implications, several practical actions are recommended. Teachers should be supported through targeted professional development to translate core CT components into simple, transparent, and feasible assessment indicators. Schools are encouraged to develop shared CT-oriented rubrics across subjects and to allocate specific time for individual assessment within group-based projects, such as through short questioning or reflection activities. Gradual implementation of CT-based summative assessment, beginning with manageable project designs and supported by regular coordination among subject teachers, can help reduce assessment complexity and workload.

Despite its contributions, this study has several limitations. The research was conducted in a single school with a limited number of teachers and students, which may restrict the transferability of the findings to other educational contexts. In addition, the study focused on assessment practices and participants' perceptions, without examining the long-term impact of CT-based summative assessment on students' computational thinking development or academic achievement. Future research involving more diverse contexts and longitudinal designs is therefore needed.

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▪ APPENDIX

Examples of Students' STEM Projects

No	Project Title/ Theme	Specific Learning Objectives	Main Student Tasks	Computational Thinking (CT) Components
1	Purifying Dirty Water Using Natural Materials	- Explain simple water filtration processes.- Design a water purification device using natural materials (sand, stones, charcoal).- Analyze experimental results.	- Identify sources of dirty water.- Build a simple water filter.- Test and compare filtration results.	Decomposition: Breaking down filtration stages (sedimentation–filtration–testing). Pattern Recognition: Comparing water clarity from different filter arrangements. Abstraction: Focusing on the function of filter materials while ignoring irrelevant physical details. Algorithmic design: Organizing the steps for constructing and testing the filtration tool. Evaluation/Debugging: Refining the design based on test results.
2	Balloon-Powered Car	- Explain thrust and motion concepts.- Design a simple air-powered vehicle.- Measure distance and speed.	- Assemble a car using recycled materials.- Conduct motion tests.- Compare results among groups.	Decomposition: Breaking the car system into components (balloon, wheels, axle, body). Pattern Recognition: Identifying relationships between balloon size, mass, and travel distance. Abstraction: Simplifying thrust and air energy into a basic motion model. Algorithmic design: Organizing assembly and testing procedures systematically. Evaluation/Debugging: Improving design (balloon or wheel placement) for optimal performance.
3	Growing Vegetables Using a Hydroponic System	- Explain plant growth without soil.- Design a simple hydroponic system.- Record and analyze plant growth data.	- Grow vegetables using recycled bottles.- Observe daily plant growth.- Present data in tables or graphs.	Decomposition: Breaking cultivation into stages (seeding–maintenance–observation). Pattern Recognition: Identifying growth patterns from daily data. Abstraction: Selecting key variables (water, nutrients, light). Algorithmic design: Organizing care and data-recording procedures sequentially. Evaluation/Debugging: Adjusting nutrients or

				watering based on growth results.
4	Water Level Monitoring System	- Design a water level monitoring system using sensors and microcontrollers.- Apply physics principles and programming logic for flood mitigation.- Analyze system performance through testing.	- Design circuit schematics and system workflow.- Develop water level monitoring algorithms.- Assemble and program the device.- Conduct trials and analyze results.	Decomposition: Dividing the system into hardware, software (algorithm), and testing components. Pattern Recognition: Identifying water level change patterns over time and sensor responses. Abstraction: Representing water levels as numerical data (distance in cm) and logical states (safe–alert–danger). Algorithmic design: Creating <i>if–then–else</i> logic to activate LEDs and buzzers automatically. Evaluation/Debugging: Testing and refining system accuracy under various conditions.
5	DERALIN (Eco-Friendly Detergent)	- Develop eco-friendly detergents as alternatives to polluting commercial products.- Analyze relationships between material composition, cleaning power, and environmental impact.- Evaluate product feasibility as a sustainable solution.	- Identify environmentally safe raw materials.- Design and follow systematic mixing procedures.- Test cleaning effectiveness and foam levels.- Compare with commercial detergents.	Decomposition: Breaking down detergent pollution problems into material selection, production, and testing stages. Pattern Recognition: Identifying relationships between composition and cleaning/foam results. Abstraction: Ignoring brand identity and focusing on essential chemical components (surfactants, phosphates). Algorithmic design: Organizing controlled and sequential mixing steps. Evaluation/Debugging: Testing effectiveness and refining formulas based on results.
6	Grass Paper (Using Nut Grass as Raw Material for Paper Production)	- Explore nut grass as an alternative paper raw material.- Analyze the impact of chemical processes on paper quality.- Evaluate the feasibility of the produced paper.	- Collect and prepare nut grass materials.- Produce pulp and print paper following procedures.- Conduct writing and printing quality tests.- Analyze results to determine product function.	Decomposition: Breaking deforestation problems into alternative raw materials and paper-making processes. Pattern Recognition: Identifying relationships between processing methods and paper texture/strength. Abstraction: Focusing on cellulose content as a wood fiber substitute. Algorithmic design: Following sequential production steps (boiling →

				blending → molding → drying). Evaluation/Debugging: Testing and improving processes to determine functional or artistic paper use.
7	Plant-Based Meat	- Develop plant-based meat alternatives to mitigate climate change.- Analyze nutritional profiles and sensory characteristics.- Evaluate feasibility as sustainable food products.	- Identify and combine plant-based ingredients (e.g., black beans, paprika, spices).- Follow systematic preparation steps (grinding, shaping patties, grilling).- Analyze strengths and limitations of the product.	Decomposition: Breaking livestock emission problems into alternative protein sources and production stages. Pattern Recognition: Identifying relationships between ingredient composition and texture/flavor acceptance. Abstraction: Focusing on nutritional and textural profiles while ignoring animal biological structures. Algorithmic design: Organizing preparation steps sequentially and in a controlled manner. Evaluation/Debugging: Evaluating weaknesses (taste or texture) and proposing formula improvements.
8	Earthquake Alarm	- Design a simple earthquake alarm as an early warning system.- Apply vibration and electrical circuit concepts for disaster mitigation.- Evaluate the functionality and limitations of the device.	- Design and assemble vibration-sensitive electrical circuits (copper wire, nut, buzzer).- Follow step-by-step assembly procedures.- Test sensitivity to vibrations.	Decomposition: Breaking earthquake safety issues into alarm solutions and component systems. Pattern Recognition: Identifying relationships between vibration intensity and alarm response. Abstraction: Representing complex seismic waves as simple vibration-triggered electrical contacts. Algorithmic design: Organizing assembly steps logically and sequentially. Evaluation/Debugging: Evaluating strengths (sensitivity) and weaknesses (physical durability and safety) and proposing improvements.
