

Students' Computational Thinking in Flat-Surfaced Solid Geometry: A Systematic Literature Review

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Abstract

The integration of computational thinking (CT) has become increasingly essential in mathematics education, particularly in topics that require spatial reasoning and structured problem solving, such as flat-surfaced solid geometry. This study aims to synthesize empirical evidence on students' computational thinking abilities within this specific mathematical context through a Systematic Literature Review (SLR). Using a descriptive qualitative approach, this review analyzed seven peer-reviewed articles published between 2020 and 2025 in nationally accredited journals indexed at SINTA levels 1–5. The literature search was conducted using Google Scholar and Publish or Perish, guided by predefined inclusion and exclusion criteria, and the study selection process followed PRISMA guidelines. The findings reveal that students' computational thinking abilities are generally at low to moderate levels and unevenly developed across indicators, with abstraction and decomposition more prominent than pattern recognition and algorithmic thinking. Instructional designs incorporating visualization, contextualization, and structured problem engagement effectively supported CT development, whereas unplugged and manipulative-based activities proved beneficial at the elementary level. However, most studies emphasize outcome-based assessments and provide limited insight into students' cognitive processes during problem solving. These findings highlight the need for theoretically grounded instructional designs and process-oriented assessment frameworks to support a more integrated and sustainable development of computational thinking in geometry learning.

INTRODUCTION

The rapid advancement of digital technology and the growing emphasis on twenty-first-century competencies have firmly positioned computational thinking (CT) as a core capability in contemporary mathematics education. Computational thinking is increasingly conceptualized not merely as programming proficiency but as a universal cognitive framework that enables learners to analyze problems systematically through decomposition, pattern recognition, abstraction, algorithmic reasoning, and evaluation of solutions (Duckworth & Fraillon, 2025). These components align closely with higher-order thinking skills, supporting learners in addressing complex and ill-structured problems across disciplines. Empirical studies have demonstrated strong associations between CT and key twenty-first-century skills, including critical thinking, creativity, and problem-solving, particularly among prospective mathematics and science teachers (Kaya et al., 2025). Moreover, CT has been identified as a mediating cognitive tool that bridges conceptual understanding and competency-based learning, reinforcing its relevance beyond technical or programming contexts (Youjun & Xiaomei, 2022; Wu et al., 2024). Large-scale reviews further

confirm that CT has become a central construct within mathematics education research, reflecting a global shift toward competence-oriented curricula that emphasize transferable thinking skills rather than procedural mastery alone (Lv et al., 2023; Zubainur et al., 2025). Consequently, CT is now widely regarded as a foundational mode of mathematical thinking essential for preparing students to meet the intellectual demands of the digital era.

Recent literature has increasingly emphasized the integration of computational thinking into mathematics instruction, particularly in geometry, where abstract reasoning and spatial visualization are central. Three-dimensional geometry, particularly flat-surfaced solid geometry such as cubes, cuboids, prisms, and pyramids, presents substantial cognitive challenges for students because they must mentally coordinate relationships among faces, edges, and vertices. Studies indicate that geometry learning provides a fertile context for activating CT processes, as students must decompose complex structures, recognize spatial patterns, and construct algorithmic strategies to solve problems (Fachrudin & Juniati, 2023). Empirical evidence further shows that instructional designs incorporating dynamic visual representations—such as GeoGebra, augmented reality, and tangible programming tools—significantly enhance students' spatial reasoning and CT performance in geometry topics (Abdul Hanid et al., 2022; Wardoyo et al., 2025). Additionally, students with stronger mathematical habits of mind demonstrate greater ability to mobilize multiple CT indicators when engaging with three-dimensional geometry tasks, suggesting that geometry learning is not only content-rich but also cognitively generative for CT development (Abidi et al., 2023). These findings collectively position flat-surfaced solid geometry as a meaningful and pedagogically powerful domain for fostering computational thinking in mathematics education.

Despite the growing body of research on computational thinking in mathematics, several critical gaps remain evident. Existing studies largely concentrate on instructional interventions, learning outcomes, or general conceptual understanding, while systematic investigations into how CT is assessed and operationalized within specific mathematical topics—particularly flat-surfaced solid geometry—are still limited. Multiple studies report that students' CT abilities remain predominantly at low to moderate levels, with persistent difficulties observed in abstraction, pattern generalization, and algorithmic formulation (Fauzi et al., 2024). Furthermore, assessment practices for CT exhibit substantial variation in indicators, rubrics, and measurement approaches. Many assessment instruments are adapted directly from computer science contexts, resulting in misalignment with the epistemological and cognitive characteristics of mathematical thinking (Lu et al., 2022; Wang et al., 2026). Scoping and systematic reviews consistently highlight the absence of a coherent, mathematics-sensitive framework for CT assessment, which complicates cross-study comparison and limits the cumulative advancement of knowledge (Acevedo-Borrega et al., 2022; Mitrayana & Nurlaelah, 2023; Mangiri & Prabawanto, 2024). This fragmentation underscores the need for a focused synthesis that maps how CT indicators and assessment strategies have been applied within geometry learning, particularly at the junior secondary level.

In response to these gaps, this study conducts a Systematic Literature Review (SLR) of research published between 2020 and 2025 that examines students' computational thinking abilities in flat-surfaced solid geometry. Unlike previous reviews that broadly explore CT across disciplines or instructional models, this study narrows its focus to a specific mathematical content area, enabling a more precise analysis of how CT is conceptualized, measured, and reported in geometry learning contexts. The novelty of this study lies in its systematic mapping of CT indicators, assessment instruments, and empirical findings derived from accredited national journal articles, thereby offering a contextually grounded synthesis of existing evidence. By adopting a descriptive

qualitative SLR approach, this study aims to provide a coherent and comprehensive portrayal of students' CT abilities in flat-surfaced solid geometry. The findings are expected to contribute to the development of more valid and context-sensitive CT assessment frameworks and to inform instructional designs that align geometry learning with the demands of digital-era mathematics education (Aulia et al., 2025; Juandi, 2024; Sumarno et al., 2025).

METHODS

Research Design

This study employed a Systematic Literature Review (SLR) to critically examine and synthesize empirical evidence on students' computational thinking (CT) abilities in flat-surfaced solid geometry. The SLR approach was selected because it provides a structured, transparent, and reproducible procedure for identifying, evaluating, and integrating findings from prior studies, enabling a comprehensive mapping of research trends, gaps, and methodological practices within a specific educational domain (Ye et al., 2023). Given the objective of synthesizing existing knowledge rather than aggregating effect sizes, this study adopted a descriptive qualitative design, which emphasizes interpretative and narrative synthesis without manipulating or intervening in the original data sources (Mohamed et al., 2022).

Research Question

The review was guided by the following research question: *How are students' computational thinking abilities characterized and reported in studies focusing on flat-surfaced solid geometry?* This question was formulated to capture both the conceptualization and empirical assessment of CT within a specific mathematics topic, allowing for a focused examination of how computational thinking is operationalized and evaluated in geometry learning contexts.

Search Strategy

The literature search was conducted using Google Scholar and Publish or Perish (PoP), as these platforms provide broad access to peer-reviewed journal articles in mathematics education. The search employed a combination of English and Indonesian keywords, including *computational thinking*, *computational thinking skills*, *berpikir komputasional*, and *bangun ruang sisi datar*, using Boolean operators (AND, OR) to refine results. To ensure the relevance and currency of the reviewed studies, the search was limited to articles published between 2020 and 2025.

Inclusion and Exclusion Criteria

Table 1. Inclusion and Exclusion Criteria

Aspect	Inclusion Criteria	Exclusion Criteria
Publication Year	Articles published between 2020 and 2025 to ensure the inclusion of recent and up-to-date research findings.	Articles published before 2020 or after 2025.
Source and Indexing	Articles published in nationally accredited journals indexed at SINTA levels 1–5, ensuring academic credibility and peer-reviewed quality.	Articles from non-accredited journals, conference proceedings, repositories, or non-peer-reviewed sources.

Language	Articles written in English or Indonesian, allowing for comprehensive coverage of both international and national research contexts.	Articles written in languages other than English or Indonesian.
Research Focus	Studies that explicitly examine computational thinking within the context of flat-surfaced solid geometry (e.g., cubes, cuboids, prisms, pyramids).	Studies that do not directly address computational thinking, focus on other mathematical topics, or examine CT in non-mathematical contexts.
Type of Publication	Empirical research articles, including quantitative, qualitative, and mixed-methods studies.	Editorials, opinion papers, literature reviews without systematic procedures, conceptual papers, and non-academic literature.
Data Relevance	Studies providing clear descriptions of CT indicators, assessment methods, or learning outcomes related to geometry.	Studies lacking sufficient methodological detail or unclear CT operationalization.
Duplication	Original articles reporting unique data or analyses.	Duplicate publications or multiple reports of the same study.

Study Selection and PRISMA Flow

The study selection process adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to enhance transparency and methodological rigor. At the identification stage, the initial search yielded 17 records. During the screening stage, titles and abstracts were reviewed to remove studies that were not relevant to computational thinking or geometry learning. In the eligibility stage, full-text articles were assessed using the predefined inclusion and exclusion criteria. As a result of this multi-stage screening process, 7 studies met all eligibility requirements and were included in the final synthesis. The systematic application of the PRISMA flow ensured a transparent and reproducible selection process (Hidayat et al., 2022).

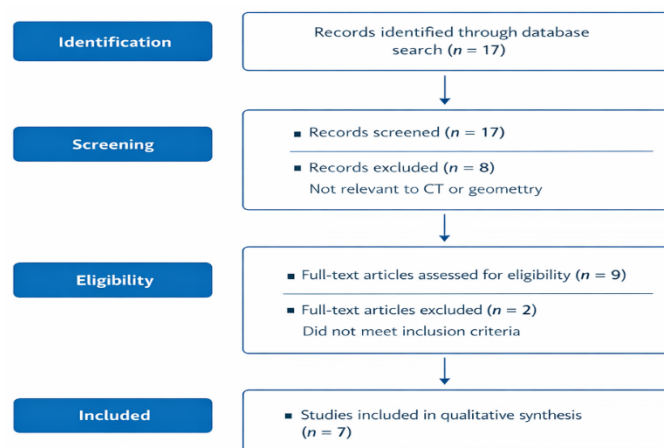


Figure 1. Study Selection and PRISMA Flow

Quality Appraisal

The methodological quality of the included studies was assessed to ensure the credibility of the synthesized findings. Each article was evaluated based on the clarity of research objectives, appropriateness of research design, alignment between research questions and methods, and transparency of data analysis procedures. Only studies that met minimum quality standards were retained, ensuring that the synthesis was grounded in methodologically sound research.

Data Analysis and Synthesis

Data analysis was conducted using a narrative synthesis approach. Relevant information from each study—including research focus, computational thinking indicators, assessment instruments, participant characteristics, and key findings—was systematically extracted and organized into analytical categories. The synthesis emphasized identifying recurring patterns, similarities, and differences across studies, particularly in how computational thinking was conceptualized and assessed within flat-surfaced solid geometry. This approach enabled the construction of a coherent, integrative overview of the existing evidence, providing a robust basis for interpreting students’ computational thinking abilities in geometry learning contexts (Saragih et al., 2025).

RESULT

This systematic literature review synthesized empirical findings from seven journal articles that examined students’ computational thinking (CT) abilities in the context of flat-surfaced solid geometry. The selected studies were published in nationally accredited journals indexed at SINTA levels 2–5, indicating that the topic has attracted moderate but growing scholarly attention within mathematics education research.

Table 1. Distribution of Selected Studies by Journal Accreditation

Journal Accreditation	Number of Articles
SINTA 2	1
SINTA 4	4
SINTA 5	2
Total	7

The dominance of SINTA 4 publications suggests that research on computational thinking in flat-surfaced solid geometry remains underdeveloped and has not yet become a central focus in high-impact national journals. This distribution further supports conducting an SLR to consolidate fragmented empirical evidence.

Empirical Findings on Students’ Computational Thinking Abilities

Across the reviewed studies, students’ computational thinking (CT) abilities in flat-surfaced solid geometry were predominantly reported to fall within the low-to-moderate range, with a consistent and measurable disparity across CT indicators. Quantitative evidence consistently indicated that abstraction and decomposition were more developed than pattern recognition and algorithmic thinking. Several studies have documented that the majority of students can restate problems, identify known variables, and isolate relevant geometric elements such as faces, edges, and vertices, indicating a basic capacity for abstraction and problem decomposition. However, when students were required to move beyond problem representation toward solution

construction, their performance declined markedly. For instance, empirical results showed that while more than 70% of students achieved acceptable scores on abstraction-related tasks, fewer than 60% consistently applied algorithmic procedures, such as formulating ordered solution steps or generalizing solution strategies across similar problems. This imbalance suggests that students' development of computational thinking remains partial and fragmented, with stronger conceptual recognition than procedural execution. The pattern also implies that instructional practices may implicitly support abstraction through explanation and visualization, yet provide insufficient scaffolding for algorithmic reasoning and pattern generalization, which require sustained exposure to structured problem-solving experiences.

At both the elementary and junior secondary levels, empirical findings indicate that students generally identify relevant geometric components and decompose complex problems into simpler subproblems, reflecting early-stage computational thinking competence. This ability is particularly evident in tasks involving concrete manipulation, visual representation, or contextual problem-solving, where students can rely on perceptual cues to guide their reasoning. Nevertheless, significant difficulties arise when tasks require recognizing underlying structural patterns or formulating step-by-step solution algorithms. Many students struggle to detect invariant relationships among geometric properties or to translate conceptual understanding into systematic procedures, such as determining a general formula for volume or applying consistent reasoning across variations of a problem. These difficulties suggest a cognitive gap between knowing *what* elements are involved in a problem and understanding *how* those elements interact within a logical sequence of operations. Consequently, students' conceptual understanding of geometry does not always translate into procedural fluency, a defining characteristic of mature computational thinking. This finding underscores the need for instructional designs that explicitly bridge conceptual reasoning and algorithmic construction, ensuring that students are guided not only to understand geometric concepts but also to operationalize them through structured and repeatable problem-solving processes.

Instructional Interventions and CT Indicator Development

The reviewed studies employed diverse instructional approaches, including visual media, contextual learning models, and activity-based instruction. Table 2 summarizes the empirical characteristics and main findings of each study.

Table 2. Summary of Empirical Findings on Computational Thinking in Flat-Surfaced Solid Geometry

No.	Study (Year)	Educational Level	Method	Instructional Strategy / Media	Main Empirical Findings
1	Amelia et al. (2025)	Junior high school	Descriptive quantitative	Conventional instruction	CT ability mostly moderate; abstraction highest, pattern recognition lowest Significant improvement in CT;
2	Ocktariya et al. (2023)	Elementary school	Experimental	Flash card media	strongest gains in decomposition and algorithms

3	Amelia et al. (2024)	Junior high school	Development research	Android-based CT assessment	Instrument valid and effective in mapping CT levels
4	Cahdriyana & Nurnugroho (2023)	Secondary school	Needs analysis	Augmented reality (AR)	AR identified as necessary to support spatial reasoning and CT
5	Perdana et al. (2023)	Junior high school	Classroom action research	Problem Based Learning	Progressive increase in CT mastery across all indicators
6	Widiyawati et al. (2022)	Elementary school	Descriptive quantitative	Unplugged CT activities	Strong performance in pattern recognition and abstraction
7	Widyanti et al. (2024)	Elementary school	Experimental	PMRI approach	Significant improvement in all CT indicators

Empirical evidence across the reviewed studies consistently demonstrates that instructional design is a decisive factor in shaping students' computational thinking (CT) development in flat-surfaced solid geometry. Instructional approaches that integrate visualization, contextualization, and structured problem engagement were found to yield measurable improvements across multiple CT indicators. Visual learning supports—such as flashcards, augmented reality (AR), and GeoGebra—enhanced students' ability to decompose geometric problems and construct accurate spatial representations by externalizing the abstract relationships among faces, edges, and vertices. These representations reduced cognitive load and allowed students to focus on identifying relevant information and organizing problem elements logically. In parallel, contextual and problem-based learning models, including Problem-Based Learning (PBL) and Indonesian Realistic Mathematics Education (PMRI), provided students with authentic problem situations that required systematic reasoning rather than rote application of formulas. Empirical results from experimental and classroom-based studies showed that students exposed to these approaches exhibited notable gains in algorithmic thinking, particularly in their ability to formulate step-by-step solution procedures and justify their reasoning. By situating geometric tasks within meaningful real-world contexts, such instructional designs facilitated the integration of conceptual understanding and procedural execution, which is essential for mature computational thinking. Collectively, these findings suggest that CT development in geometry is highly sensitive to pedagogical design and that learning environments emphasizing visualization, contextual relevance, and structured inquiry are more effective in fostering comprehensive and balanced CT competencies.

Synthesis of Empirical Patterns

The empirical synthesis identifies three dominant and interrelated patterns across the reviewed studies. First, students' computational thinking abilities in flat-surfaced solid geometry are unevenly developed across indicators, with algorithmic thinking consistently emerging as the most challenging component, while abstraction and decomposition are relatively more accessible. Second, visualization and contextualization play a crucial role in supporting CT development, particularly in spatially demanding geometry tasks where concrete representations and real-world contexts help reduce cognitive complexity and facilitate systematic reasoning. Third, the existing body of research primarily emphasizes learning outcomes and score improvements, with limited

attention to the underlying cognitive processes through which students construct, refine, and apply computational strategies during problem solving. Collectively, these findings confirm that flat-surfaced solid geometry provides a rich and meaningful context for cultivating computational thinking, while simultaneously underscoring the need for more theoretically grounded instructional designs and systematic assessment frameworks that capture both product and process dimensions of CT.

DISCUSSION

The findings of this systematic literature review indicate that students' computational thinking (CT) development in flat-surfaced solid geometry remains uneven across indicators. Abstraction and decomposition are generally more accessible, while pattern recognition and algorithmic thinking consistently emerge as the most challenging components. Students tend to identify geometric elements and understand problem structures, yet often fail to translate this understanding into coherent and generalizable solution procedures. This condition suggests that CT development in geometry is conceptually grounded but procedurally fragile. From a theoretical perspective, algorithmic thinking represents a higher level of cognitive coordination that requires sequencing, conditional reasoning, and procedural fluency, which are not automatically fostered through conceptual understanding alone (Lehmann, 2024). This pattern reinforces the view that CT should be understood as a hierarchical construct rather than a uniform skill set (Navarro & de Sousa, 2023).

The persistent difficulty in algorithmic thinking highlights a critical instructional issue in geometry learning. Many classroom practices emphasize formula application and correct numerical results, while providing limited attention to the reasoning processes underlying those solutions. Consequently, students may achieve procedural accuracy without developing transferable problem-solving strategies. This instructional tendency supports the argument that computational thinking should be framed as a process-oriented competency rather than merely as a learning outcome (Fitdyawati & In'am, 2025). Without explicit scaffolding that guides students in designing, testing, and refining solution procedures, CT development remains fragmented and context-bound. Similar concerns have been raised regarding the limited alignment between instructional objectives and assessment practices, which often fail to capture students' reasoning trajectories (Winarni et al., 2025).

The review further demonstrates that instructional design plays a decisive role in strengthening computational thinking. Learning environments that integrate visualization, contextualization, and interaction consistently support CT development, particularly in spatially demanding geometry tasks. Visual tools and dynamic representations help externalize abstract geometric relationships and reduce cognitive load, enabling students to coordinate multiple representations more effectively (Weng et al., 2024). Contextual and problem-based learning approaches encourage students to construct algorithms through meaningful problem situations rather than relying on memorized formulas (Moreno-Palma et al., 2024). These pedagogical mechanisms facilitate the transition from conceptual understanding to procedural execution, which is essential for developing robust algorithmic reasoning in geometry contexts (Dagli & Sancar Tokmak, 2022).

At the elementary level, evidence from unplugged and manipulative-based learning indicates that computational thinking does not inherently depend on digital technology. Instead, CT emerges through well-designed tasks that emphasize decomposition, pattern recognition, and logical sequencing aligned with students' cognitive development. Hands-on activities and tangible

representations allow younger learners to explore geometric structures concretely while gradually internalizing computational processes (Pellas, 2025). Studies on unplugged learning further confirm that such approaches effectively foster foundational CT skills when tasks are carefully sequenced and cognitively scaffolded (Tsortanidou et al., 2023). However, as students progress to higher grade levels, insufficient progression toward more complex and abstract problem-solving tasks may hinder the maturation of algorithmic and pattern-based reasoning.

Despite these pedagogical strengths, the reviewed literature reveals a significant methodological limitation. Most studies prioritize outcome-based measures, such as test scores or categorical CT levels, while offering limited insight into the cognitive processes students employ during problem solving. This outcome-oriented focus restricts understanding of how students construct, adapt, and refine computational strategies in geometry contexts. Emerging assessment research emphasizes the importance of capturing reasoning paths, decision points, and error patterns to represent CT as a dynamic cognitive process rather than a static outcome (Clarke-Midura et al., 2023). Process-oriented assessment frameworks are therefore essential to align instructional design with students' actual cognitive needs (Masiulionytė-Dagienė & Jevsikova, 2025).

Overall, this discussion confirms that flat-surfaced solid geometry constitutes a powerful and authentic context for cultivating computational thinking due to its inherent demands for spatial reasoning, structural analysis, and systematic problem-solving. However, maximizing this potential requires theoretically grounded instructional designs and coherent assessment instruments that explicitly align geometric reasoning with CT indicators. Addressing these needs will enable mathematics education to move beyond fragmented skill development toward a more integrated and sustainable cultivation of computational thinking, particularly across different cultural and instructional contexts (Prahmana et al., 2024; Ochogboju & Díez-Palomar, 2025; Çakiroğlu & Selçuk, 2025).

CONCLUSIONS

This systematic literature review synthesizes empirical evidence on students' computational thinking (CT) in flat-surfaced solid geometry and reveals consistent patterns in its development, instructional support, and assessment. The findings indicate that students' CT abilities remain uneven across indicators, with abstraction and decomposition more developed than pattern recognition and algorithmic thinking, suggesting that CT development is conceptually grounded but procedurally limited. Instructional designs that integrate visualization, contextualization, and structured problem engagement are shown to play a critical role in strengthening CT by bridging conceptual understanding and algorithmic reasoning, including through unplugged and manipulative-based activities at the elementary level. However, the literature remains predominantly outcome-oriented, offering limited insight into students' cognitive processes during problem solving. These results underscore the need for theoretically grounded instructional designs and process-sensitive assessment frameworks that explicitly align geometric reasoning with indicators of computational thinking, thereby supporting the more coherent and sustainable development of CT in mathematics education.

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