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Enhancing Deep Learning Through Computational Thinking-Based Assessment

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Abstract

The transformation of 21st century education demands assessments that not only measure basic cognitive learning outcomes but also encourage deep engagement of higher-order thinking. Computational Thinking (CT), as a systematic and logical thinking approach to problem solving, offers great potential to be integrated in learning assessment design. Thus, this study aims to explore the development of CT-based assessments in promoting deep learning through analyzing relevant scientific literature. The method used is a descriptive qualitative literature review, by analyzing articles from various scientific sources that discuss CT theory, components, and implementation in the context of education and assessment. Data were collected from articles indexed in Google Scholar, ScienceDirect, and other academic sources, then analyzed thematically and comparatively. The results of the discussion show that CT-based assessments, which involve the components of decomposition, abstraction, pattern recognition, algorithms, and generalization, are able to reveal students' thinking processes in depth. This assessment not only measures knowledge, but also encourages reflective, creative, and transdisciplinary skills. In the context of project-based learning, such as the design of an AI-based automatic air purifier system, CT assessments can serve as a tool that encourages students to contextually understand, design, and evaluate solutions. In conclusion, CT-based assessments contribute significantly to deep learning and need to be systematically developed in educational practice. This is in line with the need to form a generation of adaptive, critical, and solutive learners in facing the challenges of a complex and technology-based modern world.

***Keywords**: Assessment, Computational Thinking, Deep Learning, 21st Education*

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INTRODUCTION

The transformation of 21st century education demands a paradigm shift from merely transmitting information to strengthening complex and contextual higher-order thinking skills (Gar Chi et al., 2021; Inayati, 2022). n this context, deep learning has become one of the important indicators of education quality (Grover et al., 2015; Min et al., 2015). Deep learning emphasizes the process of internalizing concepts, the ability to connect and transfer knowledge across situations, and build reflective and sustainable understanding (Kaur et al., 2020; Mustaghfirin & Zaman, 2025). However, various studies show that the implementation of deep learning in the classroom is far from ideal. Mansur et al. (2024) analyzed the minimum achievement of students based on the results of the national assessment from the National AKM data in 2022 which showed that 52% of students had not reached the minimum competency for reading literacy, while the percentage of students who had not reached the minimum competency for numeracy literacy reached 61% (Mansur et al., 2024). This shows that most students have not achieved the deep thinking skills expected in the current curriculum.

One of the factors contributing to the low quality of deep learning is the dominance of conventional assessment approaches that are summative, focus on final results, and do not explore students' thinking processes (B. Gane et al., 2020; Hoffer et al., 2019; W.-Y. Hsu et al., 2023). In classroom practice, assessments often act only as a measurement tool, not as a tool that stimulates students' deep cognitive engagement. In a systematic review of 96 CT assessment studies, Tang et al. (2020) found that more than 65% of CT assessments are still conventional, such as multiple-choice or fill-in-the-blank tests, and only a small proportion use authentic approaches such as portfolios or project-based assessments (Tang et al., 2020). In addition, most of these studies focused on evaluating programming skills, rather than computational thinking skills as a cognitive process that can be widely applied in various disciplines.

On the other hand, the Computational Thinking (CT) approach introduced by Wing (2006) offers a logical, systematic, and problem-solving-based framework, with key components such as decomposition, abstraction, pattern recognition, and algorithm design (Library of Congress Cataloging-in-Publication Data, 2022; Wing, 2006). A study conducted by Zohar and Barzilai (2023) that brought an innovative approach by combining CT principles and assessment for learning theory within a design-based research (DBR) framework showed a 35% improvement in analytical skills after the implementation of CT-based formative feedback. This implementation was carried out through three phases: (1) development of CT-based assessment prototypes for student difficulty topics based on AKM data (e.g., fractions in math, organ systems in science), (2) controlled trials in 15 schools with a variety of abilities (low-medium-high) referring to PISA criteria, and (3) refinement of rubrics that measure deep learning dimensions such as knowledge transfer (e.g., students' ability to apply the concept of decomposition to solve ecological problems). (Zohar & Barzilai, 2013). Tsarava, et al. (2022) also reported that CT has significant correlations with numerical, verbal reasoning, and non-verbal spatial abilities in primary school students (Tsarava et al., 2022), and can facilitate cross-disciplinary learning that promotes deeper conceptual understanding (Falloon, 2024). CT is also a foundational skill that can fulfill any aspect of current 21st century skills as it evolves into an integral part of students' daily interactions with technology (Alonso-García et al., 2024; Riley & Hunt, n.d.; Schlauch et al., 2025).

However, the application of CT in education has been mostly used as an approach in learning or teaching, not much explored in depth in the context of assessment design. In fact, assessment based on the principles of Computational Thinking has the potential not only as a teaching method for students, but also as an intervention tool that is able to encourage deep learning in a more structured and meaningful manner. Unfortunately, studies on the integration of CT into learning assessment strategies to encourage deep learning are still very limited and rarely developed in the context of primary and secondary education in Indonesia. Therefore, the implementation of computational thinking in education is important in equipping students' abilities. Therefore, this research aims to explore the development of Computational Thinking-based assessment in promoting deep learning, by examining its conceptual and implementative linkages, and offering an assessment framework that is able to bridge the need for formative assessments that not only measure, but also foster reflective and meaningful thinking in students.

METHODS

This research uses a descriptive qualitative approach that aims to analyze and develop conceptual ideas regarding Computational Thinking (CT)-based learning assessments in promoting deep learning. This research does not conduct experiments or field data collection, but focuses on searching and analyzing the literature as a basis for compiling theoretical arguments and synthesis. The data used in this research is secondary data, collected through a literature review of relevant scientific articles, research reports, and academic publications, both from national and international journals. These sources were obtained through online platforms such as Google Scholar, ScienceDirect, and other reliable sources. In addition, to strengthen the context, a search was also conducted for information from online media and educational institution reports that could support the framework in this paper. The data analysis process was conducted through two approaches, namely descriptive analysis and comparative analysis. Descriptive analysis was used to organize and interpret findings from the literature so as to describe the actual conditions and trends related to deep learning and CT-based assessment. Comparative analysis was conducted by comparing various approaches, findings, and assessment frameworks from the reviewed literature, in order to formulate a conceptual framework of assessment that is able to integrate CT principles in an effort to encourage reflective and meaningful cognitive engagement in students.

RESULT AND DISCUSSION

Computational Thinking

The term Computational Thinking (CT) was first popularized by Jeannette Wing (2006), who defined CT as a thought process to formulate problems and their solutions so that they can be effectively executed by information processing agents (Wing, 2006)This definition was later developed and refined into a systematic and algorithmic thinking approach to solving problems, designing systems, and understanding human behavior based on core computer science concepts (Cansu & Cansu, 2019). Furthermore, Selby and Woollard (2010) added that CT includes a set of cognitive processes such as abstraction, decomposition, algorithm design, evaluation, and generalization needed to design solutions logically and efficiently (Selby & Woollard, 2010).

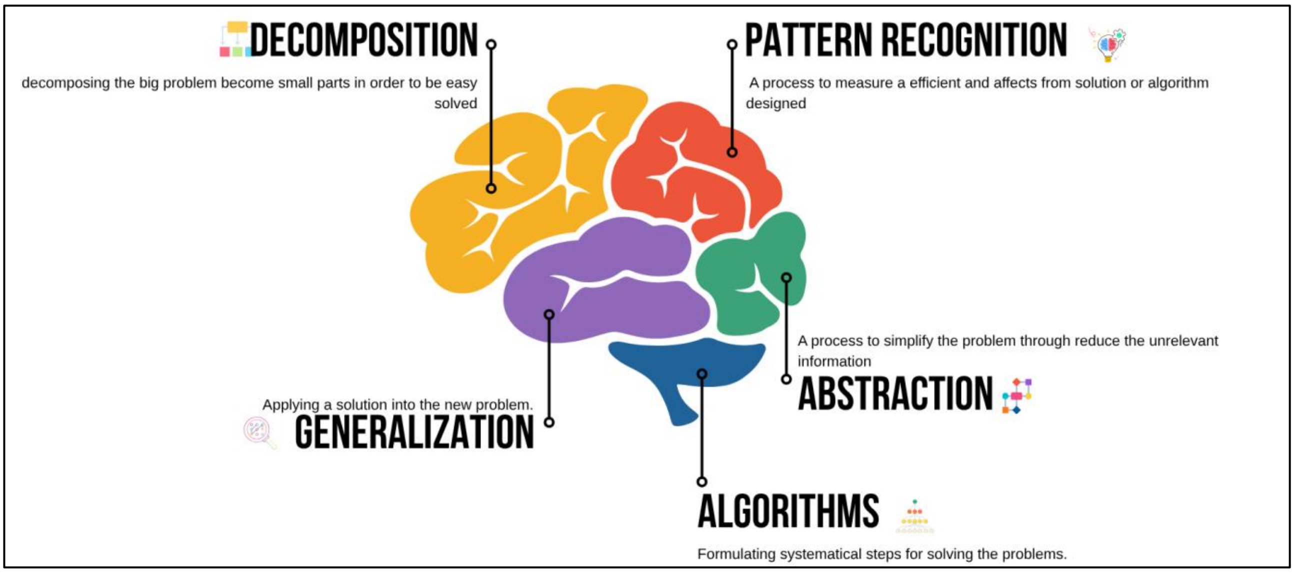

Figure 1. Computational Thinking Component Terminology

Based on **Figure 1**, the components of CT can be reviewed, namely 1) Abstraction, a process of simplifying the problem by removing irrelevant information so as to focus on the important aspects needed to find a solution. 2) Decomposition, the ability to break down large problems into smaller parts that are easier to handle. 3) Algorithm Design, formulating systematic steps to solve a problem. 4) Generalization, the ability to apply the solution that has been made to new similar problems. 5) Evaluation, the process of assessing the effectiveness and efficiency of the designed solution or algorithm (Selby & Woollard, 2010). Grover dan Pea (2013) added that CT also includes recursive thinking, conditional logic, and systematic debugging and error detection. They also highlighted the important role of programming as a medium to foster CT, although CT is not synonymous with teaching programming (Grover & Pea, 2013).

Computational Thinking in Education Perspective

In the context of education, CT is positioned as an important 21st century competency that complements science and math literacy. Luo, et al (2022) emphasized that CT is not only relevant for computer science, but also for various other disciplines such as science, arts, and humanities. Some national curricula have even begun to integrate CT into K-12 programs because of its potential in improving students' higher-order thinking and problem solving skills (Luo et al., 2022). This is also confirmed by a review of three articles (Basu et al., 2014, 2018; Cansu & Cansu, 2019) showing that there are variations in approaches to the definition, components, and application of CT. However, there is a common thread that unites them, which is the understanding that CT is not just a technical ability related to programming, but a set of higher-order thinking skills that can be applied across disciplines. All three sources consistently position CT as a cognitive thinking process that involves formulating problems and systematically searching for executable solutions.

Computational Thinking as a Framework for Learning Assessment

In making CT an integral part of 21st century learning, its internalization needs to be done not only through teaching strategies, but also through assessments used in the classroom. Assessment is an important tool to measure the extent to which students develop critical thinking skills through the Computational Thinking approach. Through the integration of CT components into assessments-such as the ability to abstract, decompose, recognize patterns, design algorithms, and logically evaluate solutions-teachers can evaluate more than just conceptual understanding (Basu et al., 2014). Such assessments encourage students to think more deeply, construct data-based arguments and come up with effective solutions to real problems.

The design of CT as a learning assessment can be detailed as follows. In the decomposition component, teachers can assess through questions or tasks that challenge students to decompose complex problems into smaller work steps. While on the abstraction component, the assessment can be in the form of case analysis questions that ask students to take the core of the problem from a complex situation. Students must be able to recognize what is most important to solve, without being trapped by additional information that is less relevant. In the pattern recognition component, assessments can involve data or graphs that students must analyze to find patterns. In the algorithm component, students can be asked to construct a flowchart, pseudocode, or sequence of procedures that describe the solution to the problem. Finally, on the generalization component, assessments can include problems that require students to apply the solutions or principles they have used in different contexts. This tests students' ability to organize solutions in an orderly and efficient manner (Hsu et al., 2018; Relkin et al., 2021).

Table 1. Computational Thinking-Based Learning Assessment Design

CT Component	**Indicator**	**Example of Task**	**Assessment Criteria**
Decomposition	Students are able to break down complex problems into small, structured steps.	Given a case study about traffic congestion in a city. Students are asked to identify causal factors and break it down into sub-problems.	* Main problem identified * Sub-logic and relevant problem * Clear step
Abstraction	Students are able to filter information and focus on relevant elements.	Given a narrative text about climate change. Students are asked to summarize the core issues and relevant information only.	* Core information is precise * Ignoring irrelevant data * Concise and focused summary
Pattern Recognition	Students are able to find patterns in data or events.	Given data on household electricity consumption for 12 months. Students are asked to find usage patterns and explain possible causes.	* Logical pattern recognized * Explanation of relationships between data * In-depth reasoning
Algorithm	Students are able to organize logical steps to solve problems.	Students are asked to create a flowchart or pseudocode about the online re-enrollment process at school.	* Systematic and coherent steps * No steps skipped * Efficient solution
Generalization	Students are able to apply solutions from one context to another.	After solving a logistics distribution problem in a disaster area, students are asked to apply the same approach to the context of online store delivery of goods.	* Solution adaptability * Logical concept transfer argumentation * Appropriateness of application in new context

Table 1 presents the design of the Computational Thinking (CT)-based learning assessment developed with reference to the five main components of CT: decomposition, abstraction, pattern recognition, algorithms and generalization. These five components not only represent the dimensions of computational thinking, but also reflect higher-order cognitive processes that contribute to deep learning. Each component is described in terms of observable indicators, with examples of authentic tasks and specific assessment criteria.

Technically, CT-based assessment can be realized in various forms, including project-based assessment, case studies, performance tasks, and open-ended questions that demand systematic thinking processes (Hou et al., 2023; Morales et al., 2013). For example, in science subjects, students can be given a contextual problem such as "How to design an automatic air purifier system integrated with Artificial Intelligence (AI)?"-which requires students to approach the problem by decomposing it into logical steps, building a simple algorithm, and evaluating the effectiveness of the design. Assessment should not only focus on the end result, but also on the students' thought process in developing the solution. The assessment rubric also needs to be adjusted to accommodate CT indicators such as: clarity of logical thinking, problem solving strategies, algorithm efficiency, and the ability to reflect on the solution. In this way, the assessment not only serves as a tool to measure learning outcomes, but also as a means of forming critical thinking skills through direct practice of CT.

Thus, the integration of CT in learning assessment not only helps students develop critical thinking skills systematically, but also prepares students to face the challenges of the digital era dominated by smart technology. The CT framework is aligned with the way artificial intelligence (AI) works, which relies on logical processes, pattern recognition, and algorithm-based decision-making. Therefore, the application of CT in education is a strategic step in preparing a generation that is not only technologically literate, but also able to think critically and solve problems in the midst of the growing complexity of the modern world.

As an implementative illustration, here is one example of a concrete CT-based assessment question designed for high school students in the context of applied science learning.

Task

Solution Design: Artificial Intelligence-Based Automatic Air Purifier System

Question Context

In the era of urbanization and increasing air pollution, there is a need for an intelligent air purifier system that can work automatically based on air quality data. You are tasked with designing an innovative solution in the form of an automated air purifier system integrated with artificial intelligence (AI). The system should be able to detect air conditions, decide on cleaning actions, and provide notifications to the user.

Task Instruction

1. Identify and describe the problem components that need to be solved in the system. (Decomposition)
2. Determine what information is most relevant in developing a solution (e.g. pollution levels, air sensors, AI system responses), and eliminate unimportant data. (Abstraction)
3. Observe air quality data or simulations (daily/weekly graphs) and identify patterns of pollution change. (Pattern Recognition)
4. Create a flowchart or pseudocode that explains the workflow of the air purifier system from measurement to system activation. (Algorithm)
5. Explain how this system logic can be applied to other contexts, such as flood monitoring systems or automatic fire detection. (Generalization)

Based on the assessment example, the teacher can develop an assessment rubric using a linkert scale (Permana & Hardyanto, 2023).

Table 2. Rubric for Assessment of Computiational Thinking-Based Learning Assessment

CT Component	Assessment Aspect	Score 1 *(Very low)*	Score 2 *(Low)*	Score 3 *(Good)*	Score 4 *(Very good)*
Decomposition	Elucidate the elements of the problem	Problem not recognized	Only a small part is identified	Majority of sub-problems well recognized	All problem components (sensors, AI logic, notifications, actuators) are fully identified
Abstraction	Disaggregate relevant information	Does not distinguish important information	Most information is incorrect	Key information identified	Important information is focused precisely and systematically
Pattern Recognition	Analyze patterns from air quality data	No pattern recognized	Pattern partially recognized, weak explanation	Patterns moderately well recognized	Patterns are analyzed in depth and linked to AI solutions
Algorithms	Construct an air purifier system workflow	Not logical or coherent	Sequence is present but ineffective	Flow moderately coherent and functional	Flow is very logical, efficient, and reflects the work of AI-based systems
Generalization	Transfer solutions to other contexts	Cannot transfer solution	Transfer is limited and inappropriate	Transfer moderately relevant	Transfer is very applicable and logical to other contexts (flood/fire)

Through the design of CT-based assessments in real contexts such as artificial intelligence-based air purifier systems, students are not only trained to think algorithmically and systematically, but also directed to understand how technology is used to solve environmental problems in a smart and sustainable manner. This assessment brings together analytic, reflective and problem solving skills in one integrated activity, in line with the demands of 21st century skills.

Contribution of CT-based Assessment to Deep Learning

Computational Thinking (CT)-based assessment has a strategic role in encouraging deep learning, because essentially, this approach assesses more than just mastery of material. This kind of assessment targets students' ability to construct, reflect and transfer knowledge into various contexts, which is the main characteristic of deep learning.

Conceptually, deep learning emphasizes not only on know-what (factual knowledge), but also on know-how (thinking strategies) and know-why (understanding the meaning behind concepts). The five main components of CT, namely decomposition, abstraction, pattern recognition, algorithm design, and generalization, facilitate students' more complex, structured, and reflective cognitive engagement (Langer, 2016; Tim Pengembang Pembelajaran Mendalam, 2024).

For example, decomposition encourages students to look at a problem from multiple angles and break it down into smaller elements, which is the foundation of analytical skills. Abstraction trains students to filter out relevant information, improves thinking efficiency, and helps them focus on the heart of the matter. Meanwhile, pattern recognition strengthens students' inferential and predictive abilities, while algorithms encourage students to think systematically in structuring problem-solving steps. The generalization component allows students to transfer solutions from one context to another, an important indicator of deep conceptual understanding.

Furthermore, CT-based assessment also encourages learning that is centered on the process, not just the outcome. When students are asked to create flowcharts, compile pseudocode, or break down cases into logical structures, they are actually building higher-order thinking structures. This is in line with the assessment for learning approach, where assessment is used to foster the learning process itself, not just measure it (B. Gane et al., 2020; B. D. Gane et al., 2021).

In the context of a project-based assignment such as the design of an AI-integrated automatic air purifier system, CT-based assessment provides an opportunity for students to combine interdisciplinary knowledge with a systematic and reflective approach to thinking. The project requires them to break down the problem into functional modules, develop automatic control algorithms, and evaluate the efficiency of the designed system. These activities not only deepen conceptual understanding, but also build future competencies relevant to the 21st century workplace, such as collaboration, adaptation and innovation (Grover et al., 2014; Touretzky et al., 2019).

Thus, Computational Thinking-based assessment is not only an adaptive evaluation method, but also a pedagogical instrument capable of encouraging students to experience meaningful, reflective and transformative learning. It bridges the gap between critical thinking skills, problem solving, and the need for contextualized learning that is relevant to the challenges of the modern world.

CONCLUSION

The development of Computational Thinking (CT)-based assessments is a strategic step in encouraging the realization of deep learning in accordance with the demands of the 21st century. CT not only functions as an approach to learning, but also as a conceptual framework that is able to represent critical, systematic and reflective ways of thinking in solving complex problems. Through the integration of the main components of CT, namely decomposition, abstraction, pattern recognition, algorithms, and generalization—assessments can be designed to assess students' thinking processes more meaningfully and contextually. In the educational context, CT-based assessment has been proven to surpass conventional evaluative functions. It not only measures surface learning outcomes, but also stimulates deep cognitive engagement, encouraging students to build creative solutions, organize knowledge strategically, and transfer understanding to various real situations. Thus, this assessment is not just a measuring tool, but also a pedagogical instrument that encourages transformation of students' ways of learning and thinking. Therefore, the development of Computational Thinking-based assessments needs to be encouraged more systemically, both in curriculum development, teacher training and classroom learning practices. This is the key to creating an educational ecosystem that is capable of producing a generation of reflective, adaptive and solution learners in facing the complex challenges of the modern world which is dominated by technology and artificial intelligence.

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