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Systematic Review of Educational Level and Evaluation Tools for Computational Thinking Skill

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Abstract: The primary aim of this research was to conduct a systematic review on the assessment of computational thinking skills. The employed research method involved a thorough exploration of diverse databases through Google Scholar, employing the keyword "computational thinking" to retrieve pertinent articles. A total of 96 articles were chosen as research samples and subjected to analysis using content analysis techniques to scrutinize education level and evaluation tools variables. The research revealed that the education level variable was classified into four tiers: elementary school (26.17%), junior high school (29.91%), senior high school (19.63%), and college (24.30%). Simultaneously, the evaluation tool variable was categorized into four segments, comprising traditional tools (22.73%), portfolios (33.33%), interviews (15.91%), and surveys (28.03%). Computational thinking (CT) is predominantly assessed among children due to their developmental stage, fostering receptiveness to novel concepts. This facilitates the teaching of fundamental CT principles, such as programming basics, logic, and algorithms. Regarding evaluation tools, portfolios are frequently employed to assess CT as they can depict a student's proficiency in solving intricate problems, showcasing evidence of their work and completed projects for a more holistic assessment.

Keywords: Assessment; Computational thinking; Evaluation tools; Educational level; SLR

Introduction

Computational Thinking (CT) has attracted public attention in the field of science, technology, engineering, and mathematics (STEM) education. CT was first introduced by Wing (Wing, 2006), defined as a way of thinking involved in formulating a problem and finding its solution, so that the solution can be effectively applied by people or information processing machines (Teo et al., 2021). CT is not only the foundation of computer science (Wing, 2008), but also plays a crucial role in modern research related to STEM (Henderson et al., 2007; Surbakti et al., 2023). Therefore, CT should be incorporated into the education system as one of the steps to prepare students' competencies to compete in the future (Sholihah & Firdaus, 2023; Su & Zhong, 2022).

CT refers to the ability to think logically, algorithmically, and analytically to solve problems and design systems in a way that leverages the power and insights provided by computers and computational methods (Ridlo et al., 2022; Weintrop et al., 2016). It involves breaking down complex problems into smaller, more manageable ones, identifying patterns and connections between different pieces of information, and using abstractions and models to represent real-world phenomena. It is a fundamental skill that enables individuals to better understand and navigate the increasingly digital and data-driven world we live in.

In 2011, ISTE & CSTA (International Society for Technology in Education and Computer Science Teachers Association) collaborated to create resources that focus on an approach that integrates CT into the K-12 environment (CSTA & ISTE, 2011). Meanwhile, the

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National Research Council (NRC) organized two workshops with college alumni in the fields of education and computer science regarding the scope, nature, and pedagogical aspects of CT (Council, 2010, 2011). All of these are efforts to promote CT in STEM education. In 2013, the *Next Generation Science Standards* (NGSS) included "*mathematics and Computational Thinking*" as one of the competencies that integrate both core disciplinary concepts in STEM.

In response to the increasing interest in integrating Computational Thinking (CT) into STEM education, the field has undertaken various initiatives aimed at promoting and assessing students' CT skills. Notable efforts include the design of curricula that seamlessly incorporate CT principles (P. Chen et al., 2023; Rich et al., 2020). Additionally, there has been a focus on the development of learning tools inspired by CT (Grover, 2017b, 2017a; Relkin, 2021; Weintrop, 2014). To create conducive learning environments, researchers have explored the integration of CT (Riva et al., 2020). Furthermore, the field has seen endeavors in constructing assessments specifically tailored to target students' CT skills (González, 2015). Collectively, these initiatives have produced a substantial body of literature that contributes to understanding the fundamental nature of CT, its implementation in STEM classrooms, and the key attributes influencing students' CT performance.

Several previous researchers have aggregated information related to CT. For instance, Lockwood and Mooney have condensed CT research in secondary education by presenting information on the subjects utilized to teach CT, tools used to teach and evaluate CT, as well as the benefits and challenges of incorporating CT in secondary education (Lockwood & Mooney, 2018). In addition, Hsu and colleagues have investigated teaching and learning activities and strategies that may foster CT (Hsu et al., 2018). However, neither of these studies has demonstrated a comprehensive review of assessment tools for students' CT competencies, which could impact the future development and evaluation of CT. Therefore, further research is needed to show in detail the evaluation tools for CT skills at all levels of education. This research particularly focuses on CT research that applies assessments for education levels ranging from pre-school to college.

In this study, a systematic review will be conducted with the aim of reflecting on previous studies and proposing further research related to CT assessment. The following research questions (RQ) form the basis of this review: RQ1: How is the implementation of CT assessment at each level of education? RQ2: What are the evaluation tools used to measure CT?

Method

This research was a Systematic Literature Review. The literature review was conducted by collecting, selecting, extracting, and reviewing relevant scientific articles on the topic. Articles were obtained from the Google Scholar digital database (http://www.scholar.google.com/) using the Publish or Perish application. Selection of literature sources using PRISMA (Figure 1), as the author has done in previous articles (Fauza et al., 2023). Article selection was done using eligibility criteria. The criteria employed for article selection were multifaceted. Firstly, articles had to explicitly incorporate the term "Computational Thinking" in their title, abstract, or keywords. Additionally, inclusion criteria encompassed articles published within the timeframe from 2013 to March 2023, ensuring a contemporary relevance. Furthermore, only articles available in full text were considered, aiming for a comprehensive examination. Another pivotal criterion was the focus on empirical studies specifically addressing the assessment of Computational Thinking (CT) skills. Lastly, the language criterion stipulated that selected article should be written in English. Upon the initiation of the literature search, a substantial pool of 383 journal articles emerged as potential candidates meeting these defined criteria.

Table 1. The educational context and assessment instruments of CT assessment.

Variable	Category	Number of articles	Percentage (%)
Education level	Preschool - elementary school	28	26.17
	Junior high school	32	29.91
	Senior high school	21	19.63
	College	26	24.30
Evaluation tools	Traditional	30	22.73
	Portfolio	44	33.33
	Interview	21	15.91
	Survey	37	28.03

Next, the author eliminated articles based on several criteria, namely: (EC1) CT was not the main topic of the research; (EC2) no information about the RQ. Based on these two factors, the author obtained 96 articles to be reviewed. The collected literature was then given codes and systematically classified into two categories based on Education level and evaluation tools. Table 1 shows the frequency and proportion for each category.

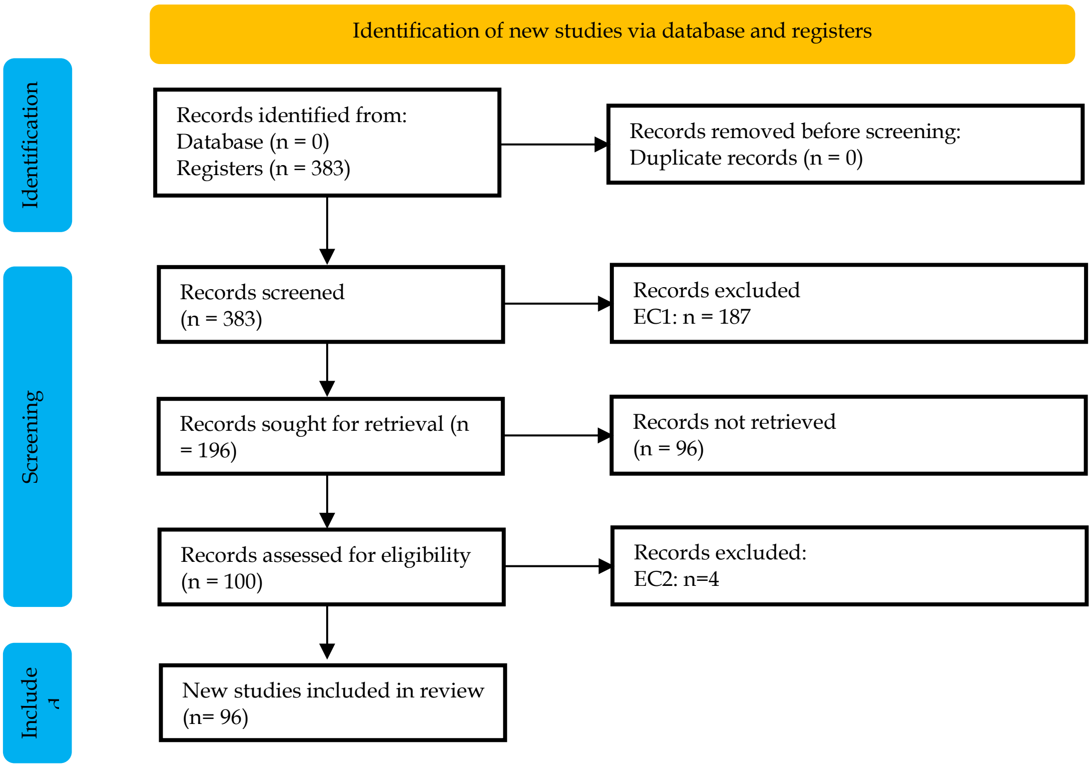

Figure 1. Flowchart of literature selection process

Result and Discussion

Results

RQ1: How is the implementation of CT assessment at each level of education?

The research results indicate that CT has been implemented at various education levels. As shown in Table 1, junior high school and elementary school are the most frequently researched education levels, each representing more than 26%, followed by higher education institutions at 24.30%. Meanwhile, senior high school has a percentage of 19.63%.

RQ2: What are the evaluation tools used to measure CT?

There are four categories of evaluation tools used in the literature, namely traditional tests, portfolios, interviews, and surveys. Some studies in the literature use more than one type of evaluation tool to collect data on students' CT skills. The frequency in each category is revealed in Table 1. The use of portfolio evaluation tools has a more dominant percentage (44%) while assessment using interviews is the least (21%) among other evaluation tools.

Discussion

RQ1: How is the implementation of CT assessment at each level of education?

In general, many studies on CT assessment have been specifically focused on K-8 schools, exceeding those on senior high schools and beyond. Essentially, it is difficult to develop CT assessment tools that are appropriate for children and early adolescents' developmental level due to their limitations in reading and comprehension abilities (Zhang & Nouri, 2019). However, researchers have attempted to implement CT in the early stages of students' cognitive development. The research was then continued by reviewing literature on CT assessment instruments for senior high school and higher education to enrich the previously obtained data.

There are several reasons why elementary and junior high school students are the most researched. Children at elementary school are at a developmental stage where they are more responsive to new concepts and ideas (Taupik & Fitria, 2023). This makes it easier to introduce and teach CT skills, which can provide a strong foundation for students to learn and understand more complex concepts in the future. Children are taught basic programming concepts, logic, algorithms, and so on at an early age. This allows them to learn and understand these concepts better in the future.

Providing CT skill interventions to students in high schools and universities can be challenging for various reasons (Handayani et al., 2022; Hanidar et al., 2023; Ridlo et al., 2022; Sulsilah et al., 2023). CT is a relatively new concept that is not yet fully integrated into traditional curricula: This means that teachers may not have experience teaching these concepts, and may not have access to relevant teaching materials or resources.

Additionally, schools may not have dedicated courses or programs for teaching CT, which can make it difficult to incorporate into existing classes.

Furthermore, many educators may not have the necessary training or resources to effectively teach CT skills: While some teachers may have experience with coding or other aspects of CT, many may not. Without adequate training, educators may struggle to develop and deliver effective lessons and activities that build CT skills in students. In addition, there may be a lack of consensus on the definition and scope of CT, making it difficult to develop effective interventions: There is still some debate within the field of education about what constitutes CT and what specific skills should be emphasized. Without a clear definition and scope, it can be challenging for educators to develop appropriate interventions and assessments.

Finally, cultural and institutional barriers may prevent the adoption of CT interventions: This could include resistance to change, a lack of resources, or competing academic priorities. In some cases, there may be a perception that CT is not relevant to certain subjects or fields, which can make it difficult to incorporate into curricula.

Overall, these challenges highlight the need for collaborative and interdisciplinary approaches to developing and implementing interventions for teaching CT skills. By working together to define and articulate the scope of CT, providing training and resources for educators, and integrating these concepts into existing curricula, we can help students develop the critical thinking and problem-solving skills they need to succeed in the 21st century (Ridlo et al., 2022).

RQ2: What are the evaluation tools used to measure CT?

The use of traditional assessment methods tends to treat CT as a learning outcome, although CT is actually a cognitive thinking process. Therefore, CT skills are often measured as mastery of knowledge related to CT components. In this case, teachers and researchers can find reliable and valid knowledge assessments to measure students' CT knowledge. However, from another perspective, traditional assessment is considered insufficient to capture the CT learning process that occurs when students work on projects. Therefore, Fields recommends the use of formative assessment to promote ongoing learning experiences, allowing students to receive continuous feedback and make changes to their projects during the learning process (García-Valcárcel-Muñoz-Repiso & Caballero-González, 2019).

The subsequent assessment tool is a portfolio, which is a type of systematic performance assessment that aims to gather and evaluate diverse student products to examine learning outcomes (McMillan, 2011). Over a third of the reviewed literature utilized portfolios for evaluating students' CT abilities. Portfolio assessment is accomplished through assignments, notes, or direct observation. To evaluate the level of achievement in each CT dimension, assessment rubrics, or a checklist indicating whether CT criteria have been met, are used, similar to performance assessment. The Scratch project analysis is a form of portfolio assessment that is commonly employed. Dr. Scratch's rubrics are frequently used by teachers and researchers to analyze student Scratch projects (Moreno-León, 2017; Zeevaarders & Aivaloglou, 2021). The rubric includes seven indicators, namely problem abstraction and decomposition, parallelism, logical thinking, synchronization, algorithmic ideas flow control, user interactivity, and data representation. Each dimension has three mastery levels: basic, intermediate, and advanced. Since this type of rubric is typically evaluated by human raters, a clear distinction between performance levels is needed to help raters identify the rank that best represents students' CT level. Another portfolio analysis technique is to compute the presence of each CT dimension. This method is beneficial for researchers interested in tracking the CT components that students use more frequently via verbal communication or analysis of their projects. In summary, portfolios provide an overview of the skills that students acquire through project activities.

In addition to assessing students' skills in project work, teachers and researchers can also evaluate students' communication skills in CT literacy, as described by Lui (García-Valcárcel-Muñoz-Repiso & Caballero-González, 2019), and provide useful formative feedback for future learning. Many researchers use portfolio assessment for programming-related learning activities. This poses a challenge in assessing performance to measure CT because so far CT has been implemented for programming or computing-based learning (G. Chen, 2018; G. Chen et al., 2017). However, with this portfolio, it can help assess students' CT for other fields of study.

The next evaluation tool is a survey. Surveys are usually used to investigate non-cognitive or affective learning outcomes, such as student motivation and attitudes towards CT learning. Surveys are developed using quantitative items such as Likert scales or open questions. Some surveys aim to collect student experiences or reflections, while others are conducted by teachers to gather student perceptions of CT during its implementation (Yadav et al., 2014). In addition to investigating student affective outcomes, surveys are also used to investigate cognitive outcomes, such as students' mastery of CT concepts (Bower et al., 2017). However, surveys are difficult to stand alone as respondents may not fully understand the survey questions. Therefore, other instruments such as interviews are needed to further explore respondents' answers.

However, currently, interviews are still underutilized in measuring CT. As CT functions as a complex set of mental operations, it is necessary to explain the components related to this cognitive process (Wong & Cheung, 2020). To determine the extent of students' CT abilities, teachers or researchers can conduct more interviews or think-alouds to collect in-depth qualitative data as recommended by Werner (Tang, 2020). These methods can provide in-depth qualitative data about a student's thought process, problem-solving skills, and decision-making strategies when working on computational tasks. By using these tools, teachers or researchers can gain a deeper understanding of a student's cognitive processes and CT skills, which can help inform instructional practices and improve student learning outcomes in CT. Moreover, as there are now many programs for transcription and automatic analysis, interviews or think-alouds can play a more important role than ever before in studying students' CT.

Assessment is a critical element in introducing CT into K-12 classrooms (Grover & Pea, 2013). Kalelioglu also calls for further discussion on how to assess students' CT mastery and skills in real-life situations (Kalelioglu et al., 2016). This study categorizes CT assessment using McMillan's classroom assessment paradigm (McMillan, 2011). Some CT studies use selected response or constructed response tests. For example, Shell created a paper-based test to evaluate students' computer knowledge and CT skills (Shell & Soh, 2013). Similarly, Chen developed an instrument that included 15 multiple-choice questions and eight open-ended questions to evaluate the application of students' CT skills in everyday problem-solving situations (G. Chen, 2018; G. Chen et al., 2017; Sulsilah et al., 2023).

Performance assessment or portfolio is an assessment tool frequently employed by researchers. They design CT activities for students to complete and then use an assessment rubric to evaluate their work products. For instance, students can create a digital portfolio to complete e-textiles projects using CT, and their work can be analyzed by researchers (Fields et al., 2021; Lui, 2020). Scratch projects based on visual programming environment can also be evaluated using this method (Garneli & Chorianopoulos, 2018).

Researchers have utilized questionnaires and interviews as assessment tools. For instance, Sáez used a questionnaire to evaluate elementary school students' understanding of computational concepts after being taught visual programming languages on the Scratch platform (Sáez-López et al., 2016). Additionally, previous studies have examined the accuracy of CT assessment. For example, Gülbahar conducted exploratory and confirmatory factor analysis to assess the reliability and validity of the self-efficacy perception scale for CT skills (Gülbahar et al., 2018). Similarly, Weintrop used interviews to analyze students' approaches to designing video games utilizing block-based programming languages (Litts et al., 2020).

CT can be integrated into all subjects at all levels of education and requires various types of appropriate assessment tools for different educational purposes. Based on the assessment objectives, teachers can use traditional tests with selected or constructed response questions to evaluate students' CT knowledge for summative purposes. In addition, researchers can use traditional CT tests in pretest-posttest mode to evaluate the effects of CT interventions. The portfolio-based approach is particularly suitable for evaluating students' CT skills while working on projects directly and providing formative feedback to students to enhance their understanding and experience in CT.

The use of surveys can help teachers and researchers better understand students' attitudes and perceptions towards CT, and identify areas for improvement to align with their motivation and self-efficacy in learning CT. Interviews can provide a qualitative approach to studying individual cases and provide a detailed understanding of students' problem-solving processes using CT, as well as the difficulties they may encounter. The think-aloud method can also be used to gain insight into how students approach and solve CT problems, and whether they apply CT skills measured by the test. By combining different assessment tools, researchers can perform triangulation and provide a comprehensive evaluation of students' CT learning.

Several effective strategies can be employed to gather precise and relevant information about students' Computational Thinking (CT) abilities using evaluation tools. Firstly, it is essential to align these tools with the learning objectives of the lesson to ensure that they accurately assess the CT skills students are meant to acquire. Employing multiple evaluation tools, such as portfolios, interviews, and surveys, is a second approach, providing a more comprehensive understanding of students' CT abilities. Designing evaluation tools with open-ended questions, which prompt students to articulate their thinking processes, offers valuable insights into how they approach and solve problems—a crucial facet of CT. Clear instructions are pivotal; educators should ensure that students comprehend the purpose and expectations of the evaluation tools, offering explicit guidance and examples (Akhsan et al., 2023; Alvianita et al., 2022). Lastly, regular evaluation of the tools is necessary to maintain their validity and reliability (Juita et al., 2023;

Novatania & Kamaludin, 2021). This involves analyzing student responses, comparing them to learning objectives, and considering other assessment data. By implementing these strategies, educators can acquire precise and relevant information about students' CT abilities, enabling informed instructional decisions.

Conclusion

The conclusion from the research findings is that there are four education levels studied in 96 articles, ranging from kindergarten to elementary school, junior high school, high school, and university with each percentage of 26.17%, 29.91%, 19.63%, and 24.30%, respectively. The commonly employed evaluation tools for assessing Computational Thinking (CT) include traditional tools, portfolios, interviews, and surveys. Portfolios and surveys have the highest percentages, exceeding 28%, while interviews have the lowest, around 19.63%. CT is predominantly evaluated in children due to their developmental responsiveness to new concepts, facilitating the teaching of foundational CT principles like programming basics and algorithms. Portfolios emerge as the preferred evaluation tool, offering a detailed insight into students' problem-solving abilities and showcasing evidence of their work. The use of portfolios also encourages reflection, enhancing students' understanding of CT.

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Fanny Rahmatina Rahim: writing-original draft preparation, result, discussion, methodology, conclusion; Ari Widodo, Andi Suhandi, Minsu Ha: analysis, proofreading, review, and editing.

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Conflicts of Interest
The authors declare no conflict of interest.

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