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Computational thinking in early childhood education: a review of theoretical and empirical perspectives

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Abstract

The rapid advancement of 21st-century technology demands the mastery of new skills, one of which is computational thinking, an essential component of basic literacy that should be introduced from early childhood. This study employs a literature review method with a qualitative approach, analyzing sources published between 2016 and 2025 to examine the development of computational thinking in early childhood education, the data collection thecniques in study were carried out through a systematic process include stages literature identification, inclusion an expanding criteria, screening an selection, data analysis was conducted using the thematic analysis method. The findings reveal that this skill can be fostered through both plugged approaches (using technology such as robots and learning applications) and unplugged approaches (games and project-based activities), which effectively enhance children's logical reasoning, creativity, and problem-solving abilities. The success of implementation is influenced by teachers' understanding, policy support, and parental involvement. Therefore, the introduction of computational thinking should be designed to be engaging and developmentally appropriate, serving as a strong foundation for children to face the challenges of the digital era.

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INTRODUCTION

The rapid development of information and communication technology in the 21st century demands that society acquire new skills relevant to the challenges of the times. One of the key skills that has gained major attention in the field of education is computational thinking. Computational thinking is not only essential for professionals in the field of technology but is also increasingly recognized as a fundamental literacy that should be developed from an early age. This skill encompasses the ability to solve problems logically, recognize patterns, perform abstraction, and construct algorithms(Ibrohim et al., 2023). In other words, computational thinking trains children to think systematically and find solutions to various problems.

Early childhood represents a critical stage in cognitive development(Hijriati, 2016; Kamiliyah et al., 2025) During this period, the child's brain develops rapidly(Uce, 2015; Jannah, 2023) and has a great capacity to absorb information and form thinking habits. A published study revealed that Unplugged Coding activities can enhance children's understanding of basic programming concepts and logical thinking skills(Mutoharoh et al., 2021). Therefore, early childhood is considered an ideal time to instill foundational skills that support long-term learning, including computational thinking. Introducing this skill early on is also believed to strengthen STEM literacy (Science, Technology, Engineering, and Mathematics) (Mulyati, 2023) and prepare children for an increasingly digitalized world. However, fostering computational thinking in early childhood requires approaches that differ from those used for older children or adults.

The implementation of computational thinking in early childhood education faces several challenges. These include limited teacher understanding of the concept (Harahap & Eliza, 2022; Harahap & Eliza, 2022; Rahmawati & Kurniati, 2024), and concerns that the concept may be too complex for young children. Nevertheless, various studies have shown that young children can comprehend and apply the basic principles of computational thinking when taught through methods aligned with their developmental characteristics—such as games, picture stories, or unplugged (non-digital) activities. Hence, it is important to further explore how these approaches can be applied effectively.

Research and educational practices in several countries demonstrate that computational thinking can be integrated into early childhood curricula in fun and interactive ways. The use of educational robots (Ananda, 2024), learning applications (Mursyidah & Mardiana, 2023; Papadakis, 2022) and problem-solving-based games such as programming boards (Budiyanto et al., 2021; Zeng et al., 2023) are popular and proven-effective strategies. However, more empirical evidence is needed to evaluate the success of these approaches in significantly improving children's computational thinking skills. Moreover, factors such as teacher training, policy support, and parental involvement play crucial roles in ensuring successful implementation. Therefore, mapping existing studies becomes an important first step.

This literature review aims to collect and analyze findings from various studies on the development of computational thinking skills in early childhood. The focus includes the definition and characteristics of computational thinking in early childhood contexts, the learning methods used, as well as the supporting and inhibiting factors in its implementation. Through this approach, the article seeks to provide a comprehensive overview of how computational thinking is developed in early childhood education across different parts of the world. In addition, this review aims to identify research gaps that can serve as a basis for future studies. A systematic approach to relevant literature will provide both theoretical and practical foundations for advancing early childhood education.

Thus, this article not only contributes to the development of knowledge in the field of early childhood education but also offers concrete recommendations for educators, researchers, and policymakers. It is hoped that the findings of this review will encourage the implementation of effective, adaptive, and engaging computational thinking learning strategies for children. In today's digital era, equipping young children with computational thinking skills is no longer an option but a necessity. Education that prioritizes the future development of children must respond proactively to the changing times. Therefore, this study is an important part of the collective effort to build a relevant and transformative foundation for education from an early age.

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METHOD

This research utilizes the Systematic Literature Review (SLR) method, which is a structured approach to identify, evaluate and interpret all relevant research related to a particular topic. In this context, the research focuses on the role of policy in building equal access to early childhood education (ECD). Through this method, the research collects sources of various types such as books, journal articles, research reports, and other relevant sources to gain a comprehensive understanding of the topic (Waruwu, 2023).

This type of research is qualitative research. The Systematic Literature Review focuses on collecting and analyzing published scholarly literature sources, with the aim of identifying trends, key findings, and research gaps on the topic of the role of policy in expanding equal access to early childhood education. This research does not conduct experiments or direct primary data collection, but rather reviews existing studies. The approach used in this research is desk-based research, where data is obtained through searching, collecting and analyzing published literature.

The research subjects in this study are scientific works that are relevant to the topic of the role of policy in building equal access to early childhood education. The subject literature consists of:

1. Books and Monographs: A search was conducted for books related to early childhood education and education policy. This included academic books, monographs and publications from educational institutions relevant to the topic of equal access to ECD.
2. Journal Articles: Articles from academic journals that address topics related to education policy, equal access to ECD, and policy implementation in 3T areas. Preferably, articles that have gone through a peer-review process so that they have high validity and credibility
3. Research Report: Reports on research conducted by government agencies, NGOs, and international organizations related to early childhood education policy implementation in Indonesia and 3T areas.

The data collection techniques in this study were carried out through a systematic procedure that included several stages:

1. Literature Identification: A literature search was conducted through academic databases such as Google Scholar, JSTOR, Scopus, and ERIC. The keywords used included “early childhood education policy,” “equitable access,” “3T areas,” “education policy in Indonesia,” and other relevant terms. In addition, policy reports and books published by education organizations such as UNESCO, the World Bank, and the Indonesian Ministry of Education and Culture were searched.
2. Inclusion and Exclusion Criteria: Inclusion criteria included publications relevant to the topic of the role of policy in expanding access to ECD, publications published within the last 10 years, and articles that underwent a peer-review process. Exclusion criteria include publications that are irrelevant, not focused on ECD policy, or published more than 10 years ago unless considered a major influence in the field.
3. Screening and Selection: After the initial identification, the researcher will conduct an initial selection of relevant articles based on the abstract, keywords, and research objectives. After that, further screening is done to ensure suitability to the research topic.

Data analysis was conducted using the thematic analysis method. This process involved several stages: The researcher collected key data from selected sources, including information on the main topic, methodology used, research findings, and policy recommendations.

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RESULTS AND DISCUSSION

The literature review indicates a growing interest in the integration of *computational thinking* (CT) within early childhood education (ECE) over the past few years. Studies published between 2013 and 2025 show a significant rise in empirical research exploring how the concept of computational thinking can be introduced to children aged 3–8 years. The peak of publications occurred in 2022, with data from Hong Kong identifying it as the most productive region in the field of CT implementation in early education(Zafrullah et al., 2024).

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In Indonesia, this trend has also been increasing from 2023 to 2025. Since 2020, the Ministry of Education and Culture has published a *Technical Guidance Teaching Module for Coding Implementation in ECE* as part of the early literacy strengthening program(Hasbi et al., 2020). This initiative was further reinforced by the decree of the Head of the National Standards, Curriculum, and Assessment Agency (No. 046/H/KR/2025), which included computational thinking as an element in the coding and artificial intelligence skills subjects. Although these subjects are not yet applied at the ECE level, this policy has inspired educators to introduce computational thinking at an early stage, while still aligning with children's developmental stages across foundational literacy, mathematics, science, technology, engineering, and the arts(Kemendikdasmen, 2025). This aligns with previous findings showing that young children are capable of developing STEM and basic coding skills through enjoyable and developmentally appropriate learning experiences (Papadakis, 2022).

As awareness of computational thinking's importance grows, research and educational policy increasingly emphasize the need for pedagogical approaches tailored to the developmental characteristics of young learners. At this stage, children learn most effectively through direct experiences, exploration, and concrete, enjoyable activities (Holis, 2016). Therefore, the introduction of computational thinking in early childhood education should not focus on the technical aspects of programming (Ibrohim et al., 2023), but rather on activities that naturally foster logical reasoning, problem-solving, and pattern recognition. For instance, (Salamah et al., 2025) found that the *Hijaiyah Coding* learning innovation enhanced children's enthusiasm, active participation, positive emotional expression, collaboration, and problem-solving discussions. Age-appropriate and adaptive teaching methods are essential to ensure that computational concepts are introduced effectively, meaningfully, and in alignment with cognitive and socio-emotional development principles.

Two main approaches are commonly used to develop computational thinking in young children: *plugged* and *unplugged* learning (Fajriyah et al., 2022)(Hartono et al., 2025). The *plugged* approach involves digital tools such as computers, tablets, visual programming applications (e.g., ScratchJr) (Hardiyanti et al., 2023; Nurjanah et al., 2021), educational games (Mursyidah & Mardiana, 2023), and programmable robots (Budiyanto et al., 2021). These activities introduce children to concepts like sequencing, pattern recognition, and programming logic in an interactive way that allows them to observe the cause-and-effect relationship between commands and outcomes.

In contrast, the *unplugged* approach does not rely on digital devices but uses games, simulations, command cards, and physical activities that represent programming principles. This method has proven effective in introducing fundamental computational concepts in a concrete and enjoyable way (Rahmawati & Kurniati, 2024), particularly for children in the preoperational cognitive stage (Novitasari & Prastyo, 2020 ;Wati et al., 2024). Research on *unplugged coding* shows it as an effective means of enhancing logical and critical thinking and problem-solving abilities. Combining both approaches provides balance between conceptual understanding and practical application, helping children grasp systematic and algorithmic thinking processes without being burdened by technical aspects of digital technology. A study in Spain by del Olmo-Muñoz et al. (2020) further confirmed that integrating unplugged and plugged activities benefits computational reasoning, motivation, and gender inclusivity.

The effective implementation of computational thinking in early education is closely linked to teachers' roles as facilitators. Early childhood teachers are responsible for creating supportive and enjoyable learning environments that suit children's developmental stages. However, many studies reveal that teachers often have limited understanding of computational thinking concepts and how to integrate them into play-based learning. Similar conditions are reported in Hong Kong, where early childhood teachers' content knowledge (CK) and pedagogical knowledge (PK) related to programming and CT remain limited (Zeng et al., 2023). Therefore, continuous professional development and mentoring programs are essential to help teachers design simple, contextual learning activities that embed CT principles. Effective training should not only focus on technical skills, such as using digital tools, but also on pedagogical strategies that stimulate analytical, logical, and creative thinking through play, experimentation, and project-based learning. Workshops on coding implementation in early childhood education have proven to improve teachers' understanding and ability to integrate coding lessons into the curriculum, making learning more engaging and developmentally supportive (Lamatokan et al., 2025). Similarly, workshop series, self-learning, and microteaching activities have enhanced

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teachers' conceptual knowledge, though technical proficiency and computational task design still require improvement.

Beyond teacher capacity, supportive educational policies are equally crucial for the successful integration of CT in early education. The Indonesian Ministry of Education, Culture, Research, and Technology has taken positive steps by embedding computational elements into the national curriculum and providing technical training materials. However, successful implementation requires cross-sector coordination among educational institutions, technology providers, and parents as learning partners. Collaboration between technology sectors, communities, government, and education stakeholders is essential to establish a curriculum that fosters a generation capable of thriving in the digital era (Aminiati & Rohmalina, 2025). Such collaboration creates an educational ecosystem that supports the sustainable development of digital literacy and computational thinking while remaining centered on the needs and characteristics of young children.

From a research perspective, further studies are needed to evaluate the effectiveness of different CT learning models for early childhood in the Indonesian context. Most existing research remains descriptive and small-scale, providing limited insight into the long-term impact of CT on children's cognitive, social, and emotional development. Future research should employ more comprehensive designs, including longitudinal and controlled experimental studies, to measure learning outcomes more precisely. The development of valid and age-appropriate assessment instruments also remains a priority to ensure that computational thinking skills are measured objectively and sustainably.

Overall, the literature demonstrates that early exposure to computational concepts can significantly enhance children's logical reasoning, sequential thinking, problem-solving, and collaboration skills. Furthermore, CT-based learning has been shown to increase engagement, motivation, and creativity when delivered through play-based and story-driven educational experiences.

CONCLUSION

Based on the literature review, it can be concluded that integrating *computational thinking* (CT) into early childhood education has great potential to foster logical, critical, creative, and problem-solving skills from an early age. Research trends indicate increasing global and national attention to this integration, supported by educational policies that promote digital literacy in the curriculum. Its successful implementation largely depends on teachers' ability to apply pedagogical approaches suited to children's developmental stages, along with supportive policies and cross-sector collaboration. Both *plugged* and *unplugged* learning methods have proven effective in cultivating computational reasoning in a balanced and enjoyable way. Therefore, strengthening teachers' competencies and conducting further studies are essential to ensure the sustainability and meaningful application of these concepts in early learning environments.

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