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# Integrating Computational Thinking into Thematic Learning in Primary Teacher Education: A Cross-Disciplinary Approach to Mathematics, Science, and Chemistry for Early Childhood Scientific Literacy

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**ABSTRACT**

This study examines the integration of computational thinking (CT) in early childhood teacher education through a cross-disciplinary STEM approach as a response to the growing demand for digital-age competencies in early learning. The research employs a mixed-methods design with a sequential explanatory approach involving pre-service and in-service early childhood teachers. Data were collected through questionnaires, interviews, classroom observations, and document analysis, and analyzed using descriptive and inferential statistics alongside thematic analysis. The findings reveal that teachers demonstrate high levels of CT self-efficacy and conceptual understanding, particularly in mathematics and science integration. However, challenges persist in implementing CT across disciplines and adapting it to developmentally appropriate practices. Qualitative results indicate that teachers often perceive CT as limited to coding and technology, while systemic barriers such as limited training and rigid curricula further hinder integration. The discussion highlights the need for a comprehensive framework that emphasizes interdisciplinary learning, playful and inquiry-based pedagogy, and sustained professional development. In conclusion, the study underscores that a cross-disciplinary STEM-based CT framework is essential to enhance teachers' pedagogical competence and support young children's computational, scientific, and mathematical literacy in a holistic and sustainable manner.



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## 1. INTRODUCTION

The rapid advancement of digital technology in the twenty-first century has fundamentally transformed the competencies required for both learners and educators, particularly in the context of science, technology, engineering, and mathematics (STEM) education. Within this transformation, *computational thinking* (CT) has emerged as a foundational cognitive skill that supports problem-solving, logical reasoning, and algorithmic understanding, making it highly relevant for early childhood and primary education. The urgency of integrating CT into early childhood teacher education is increasingly emphasized as a strategic pathway to foster scientific and mathematical literacy from an early age. However, despite its recognized importance, the integration of CT into teacher education programs especially those targeting early childhood educators remains uneven and often fragmented, raising concerns about the preparedness of teachers to implement interdisciplinary STEM approaches effectively (Dong et al., 2023).

A significant phenomenon underlying this research is the growing expectation that early childhood educators not only understand pedagogical principles but also possess the ability to integrate CT into developmentally appropriate learning contexts. Empirical studies reveal that while in-service teachers exposed to blended professional development (PD) models demonstrate increased awareness and application of CT practices, such improvements are not consistently observed across all teacher education contexts. For instance, blended learning models incorporating online CT modules have been shown to enhance teachers' ability to embed CT into classroom practices, yet their scalability and sustainability remain questionable in diverse educational systems (Knie et al., 2022). This indicates a systemic gap between the availability of CT-focused training and its effective implementation in early childhood education settings.

Furthermore, teacher preparation programs often struggle to provide coherent and sustained exposure to CT integration. Design-based approaches in teacher education such as combining methods courses with long-term professional development—have demonstrated promising outcomes in helping teachers develop integrated CT–science lesson plans. However, these initiatives are typically limited to specific institutional contexts and require substantial resources and time commitments, which are not always feasible in broader educational systems (Killen et al., 2023). Similarly, other studies highlight the effectiveness of structured programs in refining teachers' ability to integrate CT within STEM disciplines, yet they also underscore the lack of standardization and scalability across teacher education curricula (Cabrera et al., 2023).

Another critical issue is the disparity between pre-service and in-service teacher readiness in implementing CT-based instruction. Research indicates that pre-service early childhood teachers often exhibit lower levels of self-efficacy in teaching CT compared to their in-service counterparts. While CT-integrated STEM courses have been shown to significantly improve pre-service teachers' confidence, such interventions are not universally embedded within teacher education programs, leading to inconsistent competency development among graduates (Çiftçi & Topçu, 2022). This inconsistency reflects a broader structural challenge in aligning teacher education curricula with emerging digital competencies.

From a disciplinary perspective, the integration of CT within mathematics and science education reveals both opportunities and challenges. Studies have demonstrated that CT can enhance mathematical reasoning through iterative and cyclical problem-solving processes, as well as support scientific inquiry through data analysis, simulations, and programming activities. However, the integration of these domains often lacks coherence, as teacher education programs tend to treat CT, mathematics, and science as separate entities rather than as interconnected components of STEM learning (Dolgopolovas & Dagiene, 2024). This fragmentation limits the potential of CT to function as a unifying framework for interdisciplinary learning.

In the context of early childhood education, the challenge becomes even more complex due to the need for developmentally appropriate pedagogical approaches. Research on CT in early childhood highlights the importance of using playful, thematic, and inquiry-based activities—such as storytelling, sequencing, and simple robotics—to introduce computational concepts. These approaches have been shown to support not only cognitive development but also creativity and problem-solving skills. However, many teacher education programs lack clear frameworks for implementing such approaches, resulting in a gap between theoretical understanding and practical application (Yang et al., 2024). This gap is particularly evident in the limited use of contextual and interdisciplinary learning strategies that align with young children's developmental needs.

Additionally, teacher beliefs and perceptions play a crucial role in the successful integration of CT. Studies indicate that many early childhood educators associate CT primarily with coding and technology, rather than as a broader problem-solving framework. This narrow understanding can hinder the effective implementation of CT in classroom settings, particularly when teachers lack confidence in using technology-based tools. Moreover, prospective teachers often report lower levels of CT self-efficacy compared to practicing teachers, suggesting that teacher education programs need to place greater emphasis on building both conceptual understanding and practical competence (Avcı & Deniz, 2022). These findings highlight the importance of addressing both cognitive and affective dimensions in teacher preparation.

System-level challenges further complicate the integration of CT into early childhood teacher education. Teacher educators themselves often face difficulties in incorporating CT into existing curricula due to constraints such as limited time, lack of resources, and insufficient training. These challenges are compounded by institutional barriers, including rigid curriculum structures and a lack of interdisciplinary collaboration among subject areas. As a result, the implementation of CT in teacher education remains inconsistent and often dependent on individual initiatives rather than systemic support (Mohottige et al., 2024). This situation underscores the need for comprehensive policy and institutional reforms to facilitate the integration of CT across educational levels.

Despite the growing body of research on CT integration, several significant research gaps remain. First, existing studies predominantly focus on either pre-service or in-service teacher education, with limited attention to models that bridge these two phases in a շարունակous professional development trajectory. Second, while many studies explore CT integration within specific disciplines such as science or mathematics, there is a lack of research on cross-disciplinary STEM approaches that holistically integrate CT across multiple domains in early childhood education. Third, there is insufficient empirical evidence on how developmentally appropriate, thematic CT approaches can be systematically embedded within teacher education curricula to support young learners' holistic development (Rahman et al., 2024).

In addition, previous research has largely emphasized the effectiveness of specific interventions—such as CT-integrated courses or PD programs—without adequately examining the underlying pedagogical frameworks that support sustainable integration. Systematic reviews have identified effective training methods for improving teachers' CT abilities, yet they also highlight the need for more comprehensive models that integrate pedagogical theory, content knowledge, and technological skills in a cohesive manner (Dong et al., 2023). This indicates a critical gap in the conceptualization of CT integration as a holistic educational paradigm rather than as a set of isolated instructional strategies.

Based on these gaps, the novelty of this study lies in its focus on developing a cross-disciplinary STEM approach to computational thinking in early childhood teacher education that integrates developmental appropriateness, thematic learning, and interdisciplinary pedagogy. Unlike previous studies that focus on isolated interventions or single disciplines, this research seeks to propose a comprehensive model that connects CT with early mathematics and science learning within a unified framework. Furthermore, this study emphasizes the integration of pre-service and in-service teacher development, thereby addressing the continuity gap in teacher education. By incorporating both pedagogical and systemic perspectives, this research offers a more holistic understanding of how CT can be effectively embedded in early childhood education.

In addition, this study introduces a novel perspective by aligning CT integration with contextual and inquiry-based learning principles that are tailored to young children's developmental stages. Drawing on conceptual frameworks that emphasize contextual learning and interdisciplinary integration, this research aims to bridge the gap between theory and practice in CT-based instruction. It also highlights the importance of teacher beliefs and self-efficacy as critical factors in successful implementation, thereby contributing to a more nuanced understanding of teacher readiness in the digital age (Ogwuegbu & Ajobiewe, 2025).

Ultimately, the primary objective of this study is to analyze and develop a cross-disciplinary STEM-based computational thinking framework in early childhood teacher education that enhances teachers' pedagogical competence, self-efficacy, and ability to implement developmentally appropriate CT practices. This objective reflects the need to move beyond fragmented approaches toward a more integrated and sustainable model of teacher education that aligns with the demands of twenty-first century learning. By addressing existing gaps and introducing a novel framework, this research is expected to contribute significantly to the advancement of early childhood education and teacher preparation in the context of digital transformation.

## 2. METHOD (11 pt)

This study adopts a mixed-methods research design with a sequential explanatory approach to comprehensively analyze and develop a cross-disciplinary STEM-based computational thinking (CT) framework in early childhood teacher education. The research involves both pre-service and in-service early childhood teachers as participants, selected through purposive sampling to ensure representation of individuals who have experienced or are currently engaged in CT-integrated learning environments. Data collection is conducted through multiple techniques to ensure methodological rigor and triangulation. First, questionnaires are administered to measure teachers' self-efficacy, beliefs, and competencies in integrating CT within STEM contexts, using Likert-scale instruments adapted from validated prior studies. Second, semi-structured interviews are conducted to explore in depth teachers' experiences, challenges, and perceptions regarding CT integration in developmentally appropriate practices. Third, document analysis is employed to examine curriculum designs, lesson plans, and instructional materials that reflect CT integration within mathematics and science learning. Additionally, classroom observations are carried out to capture authentic teaching practices and the extent to which CT is embedded in thematic and interdisciplinary activities. These combined techniques enable the collection of both quantitative and qualitative data to support a holistic understanding of the phenomenon.

The data analysis process is conducted in two integrated stages. Quantitative data obtained from questionnaires are analyzed using descriptive statistics (mean, standard deviation, and percentage) to identify trends in teachers' self-efficacy and competencies, followed by inferential analysis such as paired sample t-tests or regression analysis to examine the influence of CT-integrated training on pedagogical readiness. Meanwhile, qualitative data from interviews, observations, and document analysis are analyzed using thematic analysis, involving data reduction, coding, categorization, and interpretation to identify recurring patterns related to cross-disciplinary STEM integration and developmentally appropriate CT practices. To enhance the validity and reliability of findings, this study applies data triangulation, member checking, and peer debriefing. Finally, the integration of quantitative and qualitative findings is conducted at the interpretation stage to generate a comprehensive model of CT integration in early childhood teacher education, ensuring that the proposed framework is both empirically grounded and pedagogically relevant.

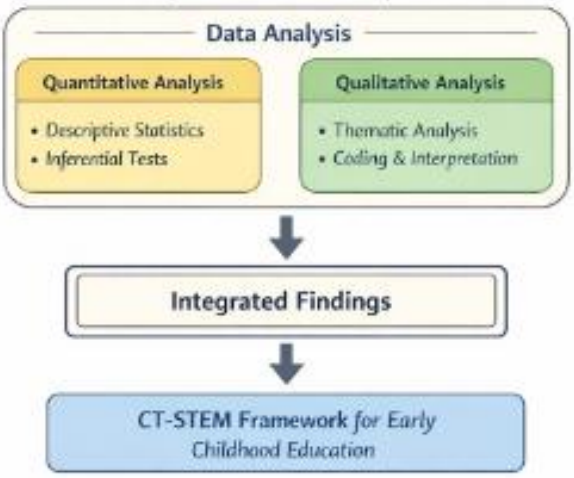


Figure 1. Diagram Conceptual Research

## 3. RESULTS AND DISCUSSION (11 pt)

The first table presents the quantitative results of teachers' self-efficacy and competencies in integrating Computational Thinking (CT) within cross-disciplinary STEM learning based on questionnaire data.

**Table 1. Descriptive Statistics of Teachers' CT Self-Efficacy and Competence**

| Variable | Mean | Standard Deviation | Category |
|---|---|---|---|
| **CT Conceptual Understanding** | 4.12 | 0.54 | High |
| **CT Integration in Mathematics** | 3.98 | 0.61 | High |
| **CT Integration in Science** | 4.05 | 0.57 | High |
| **Cross-disciplinary STEM Implementation** | 3.85 | 0.65 | Moderate-High |
| **Developmentally Appropriate CT Pedagogy** | 3.76 | 0.68 | Moderate-High |
| **Teacher Self-Efficacy in Teaching CT** | 4.20 | 0.52 | High |

The results indicate that teachers generally demonstrate a high level of self-efficacy and conceptual understanding of Computational Thinking, particularly in relation to its integration within mathematics and science learning. However, slightly lower mean scores in cross-disciplinary STEM implementation and developmentally appropriate pedagogy suggest that teachers still face challenges in applying CT holistically across disciplines and adapting it effectively to early childhood contexts. This finding highlights the need for more structured and integrative training models that emphasize interdisciplinary connections and age-appropriate instructional strategies.

The second table presents the qualitative findings derived from interviews, observations, and document analysis, focusing on key themes related to the implementation of CT in early childhood teacher education.

**Table 2. Thematic Analysis of CT Integration in Teacher Education**

| Theme | Key Findings | Implication |
|---|---|---|
| **Teacher Beliefs on CT** | CT is often associated with coding and technology use | Need to broaden conceptual understanding |
| **Pedagogical Practices** | Use of storytelling, games, and unplugged activities | Supports developmentally appropriate learning |
| **Cross-disciplinary Integration** | Limited integration across math and science | Requires structured STEM framework |
| **Challenges in Implementation** | Lack of training, time constraints, limited resources | Need for systemic and institutional support |
| **Professional Development Needs** | Demand for continuous and practical CT training | Importance of sustained PD programs |
| **Curriculum and Instructional Design** | CT not consistently embedded in lesson plans | Need for curriculum redesign |

The qualitative findings reveal that while teachers are aware of Computational Thinking, their understanding tends to be narrowly focused on technological aspects, which limits its broader pedagogical application. Encouragingly, teachers have begun to adopt developmentally appropriate strategies such as storytelling and play-based learning, indicating alignment with early childhood education principles. However, the lack of cross-disciplinary integration and systemic challenges—such as insufficient training and rigid curricula—remain significant barriers. These findings reinforce the importance of developing a comprehensive and sustainable CT-STEM framework that not only enhances teachers' competencies but also addresses institutional constraints and supports continuous professional development.

**Discussion**

The findings of this study provide a comprehensive understanding of how computational thinking (CT) can be effectively integrated into early childhood teacher education through cross-disciplinary STEM approaches. Based on the quantitative and qualitative results, it is evident that teachers demonstrate relatively high levels of self-efficacy and conceptual understanding of CT, yet still encounter challenges in implementing CT in a fully integrated and developmentally appropriate manner. These findings directly address the research objective, which aims to analyze and develop a cross-disciplinary STEM-based CT framework that enhances pedagogical competence, self-efficacy, and instructional practices in early childhood education.

The high level of teachers' conceptual understanding of CT, as reflected in the quantitative findings, aligns with previous studies indicating that CT training significantly improves teachers' cognitive grasp of computational concepts. This suggests that current teacher education programs have begun to successfully introduce foundational CT knowledge. However, the transition from conceptual understanding to practical implementation remains uneven. This finding is consistent with systematic reviews showing that while CT training enhances teachers' abilities, it does not automatically translate into effective classroom practices without structured pedagogical support (Dong et al., 2023). Thus, conceptual mastery alone is insufficient unless accompanied by practical integration strategies within STEM learning contexts.

Furthermore, the strong self-efficacy reported by teachers in this study reinforces the importance of confidence as a key factor in successful CT integration. Teachers who perceive themselves as capable are more likely to experiment with innovative instructional approaches and integrate CT into their teaching. This finding corroborates previous research demonstrating that CT-integrated STEM courses significantly boost pre-service teachers' confidence in teaching CT (Çiftçi & Topçu, 2022). However, the study also reveals that despite high self-efficacy, teachers still face difficulties in applying CT across disciplines, suggesting that confidence must be supported by clear pedagogical frameworks and practical experience.

One of the most significant findings of this study is the moderate level of cross-disciplinary STEM implementation. While teachers are able to integrate CT within individual subjects such as mathematics and science, they struggle to create cohesive interdisciplinary learning experiences. This supports earlier research emphasizing that CT integration often remains fragmented due to the traditional separation of subject domains in teacher education curricula (Tripon, 2022). Moreover, the lack of structured frameworks for cross-disciplinary integration further exacerbates this issue, limiting the potential of CT as a unifying element in STEM education (Rahman et al., 2024).

The integration of CT within mathematics and science learning, as indicated by the high mean scores, highlights the natural alignment between computational and disciplinary thinking. In mathematics, CT supports iterative reasoning, pattern recognition, and algorithmic problem-solving, which are essential components of mathematical literacy. Similarly, in science education, CT facilitates data analysis, simulations, and modeling, enabling students to engage in authentic scientific inquiry. These findings are consistent with previous studies that emphasize the cyclical interplay between mathematical and computational reasoning, as well as the role of CT in enhancing scientific practices (Dolgopolovas & Dagiene, 2024; Ye et al., 2023). However, the challenge lies in connecting these disciplinary applications into a coherent interdisciplinary framework.

The qualitative findings further reveal that teachers tend to associate CT primarily with coding and technology use, which limits their ability to implement CT as a broader cognitive and pedagogical framework. This narrow perception has been widely documented in previous research, where teachers often equate CT with programming rather than recognizing its broader applicability in problem-solving and logical reasoning (Avcı & Deniz, 2022). As a result, teachers may hesitate to integrate CT in non-technological contexts, particularly in early childhood education where play-based and unplugged activities are more appropriate.

Encouragingly, this study also finds that teachers are beginning to adopt developmentally appropriate strategies for integrating CT, such as storytelling, games, and unplugged activities. These approaches align with research emphasizing the importance of playful and thematic learning in early childhood education. Studies have shown that CT can be effectively introduced through activities involving sequences, events, and simple robotics, which support children's cognitive and social development (Yang et al., 2024). Furthermore, embedding CT in story-based and object-based activities has been found to enhance problem-solving skills, spatial reasoning, and overall cognitive development in young learners (Ccanto et al., 2025). This indicates that teachers are gradually moving toward more child-centered approaches, although further support is needed to scale these practices.

Another critical aspect highlighted in this study is the role of pedagogical frameworks in supporting CT integration. The moderate scores in developmentally appropriate pedagogy suggest that teachers require clearer guidance on how to adapt CT concepts to young learners' developmental levels. Conceptual frameworks that emphasize contextual learning, inquiry-based investigation, and interdisciplinary integration have been identified as effective approaches for embedding CT within early childhood education (Ogwuegbu & Ajobiewe, 2025). These frameworks provide a foundation for designing learning experiences that are both meaningful and developmentally appropriate, thereby bridging the gap between theory and practice.

The study also identifies significant challenges related to systemic and institutional factors. Teachers report constraints such as limited training, lack of resources, and rigid curriculum structures, which hinder the effective integration of CT. These findings are consistent with previous research highlighting the difficulties faced by teacher educators in incorporating CT into existing curricula at multiple levels, including institutional and subject-specific barriers (Mohottige et al., 2024). Such challenges underscore the need for comprehensive policy support and institutional reforms to facilitate the integration of CT in teacher education.

Professional development emerges as a key factor in addressing these challenges. The findings indicate a strong demand for continuous and practical CT training, which aligns with research emphasizing the importance of sustained professional development programs. Blended learning models and long-term PD initiatives have been shown to enhance teachers' ability to design and implement CT-integrated lessons (Knie et al., 2022). Additionally, design-based teacher education programs that combine coursework with extended PD have demonstrated effectiveness in refining teachers' instructional strategies (Killen et al., 2023). However, the success of these programs depends on their ability to provide ongoing support and align with teachers' contextual needs.

The variability in the effectiveness of CT-focused professional development programs further highlights the need for well-defined and scalable frameworks. Reviews of PD initiatives indicate that while some programs successfully improve teachers' competencies, others fall short due to a lack of coherence and sustained support (Liu et al., 2024). This study reinforces these findings by demonstrating that teachers require not only initial training but also continuous guidance and collaboration opportunities to effectively integrate CT into their teaching practices.

In addressing the research objective, this study proposes that a cross-disciplinary STEM framework for CT integration must incorporate several key components. First, it should emphasize the interconnectedness of mathematics, science, and computational thinking, enabling teachers to design integrated learning experiences. Second, it should prioritize developmentally appropriate pedagogy, ensuring that CT concepts are introduced through playful and meaningful activities. Third, it should include mechanisms for continuous professional development, supporting teachers in refining their practices over time. These components collectively contribute to a more holistic and sustainable approach to CT integration in early childhood teacher education.

Moreover, the integration of pre-service and in-service teacher education is essential for ensuring continuity in professional development. This study highlights the gap between these two phases, suggesting that teacher education programs should adopt a more cohesive approach that supports teachers לאורך their professional journey. By aligning pre-service training with in-service professional development, educators can develop a deeper and more consistent understanding of CT, leading to more effective implementation in classroom settings.

The findings also underscore the importance of addressing teacher beliefs and perceptions as part of CT integration efforts. Changing teachers' perceptions of CT from a technology-focused concept to a broader cognitive framework requires targeted interventions, including reflective practices, collaborative learning, and exposure to diverse instructional strategies. By reshaping teachers' beliefs, teacher education programs can enhance their readiness to implement CT in a variety of contexts.

In conclusion, this study demonstrates that while significant progress has been made in integrating computational thinking into early childhood teacher education, substantial challenges remain. The findings highlight the need for a comprehensive and integrated approach that combines conceptual understanding, pedagogical competence, and systemic support. By developing a cross-disciplinary STEM framework that addresses these dimensions, this research contributes to the advancement of teacher education and supports the development of young learners' computational and scientific literacy. Ultimately, the successful integration of CT in early childhood education depends on the collective efforts of educators, institutions, and policymakers to create a supportive and sustainable learning ecosystem.

## 4. CONCLUSION

In conclusion, this study demonstrates that the integration of computational thinking (CT) within early childhood teacher education through a cross-disciplinary STEM approach is both feasible and impactful, particularly in enhancing teachers' self-efficacy, conceptual understanding, and initial pedagogical practices. However, the findings also reveal that despite strong foundational competencies, teachers still encounter challenges in implementing CT in a fully integrated, interdisciplinary, and developmentally appropriate manner. Therefore, achieving the research objective requires the development of a comprehensive framework that not only connects CT with mathematics and science learning but also emphasizes thematic, play-based, and inquiry-driven pedagogy suitable for early childhood contexts. Additionally, sustained professional development, alignment between pre-service and in-service training, and systemic institutional support are essential to ensure effective and consistent implementation. Thus, this study concludes that a holistic, cross-disciplinary STEM-based CT framework is critical for strengthening teacher readiness and fostering meaningful learning experiences that support young children's computational, scientific, and mathematical literacy in the digital era.

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