Distance Teaching of Computational Thinking Through Mobile Games and Applications. Literature Review.

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Abstract

The rapid advancement of technology has transformed education, enhancing accessibility and engagement. Mobile learning, driven by widespread smartphone adoption, has become essential in distance education. Simultaneously, computational thinking (CT) has emerged as a key 21st-century skill, encompassing problem-solving, algorithmic reasoning, and abstraction. This study examines how mobile games and applications foster CT in distance learning. Through a literature review, it explores the effectiveness of mobile game-based learning strategies, identifies key challenges, and assesses their potential for innovation. The research highlights the pedagogical implications of integrating mobile technologies into CT instruction, emphasizing benefits like portability, accessibility, and real-time feedback. Findings contribute to understanding the impact of mobile game-based learning on CT education, addressing emerging trends, research gaps, and best practices. By exploring how mobile technologies enhance CT instruction, this study provides insights into accessibility, equity, and the future of digital education.

Keywords: Distance Learning, Serious Games, Mobile Learning, Computational Thinking.

1. Introduction

The rapid advancement of technology has profoundly reshaped the educational landscape, introducing new ways to teach and learn that leverage portability, interactivity, and accessibility. One such innovation is mobile learning, which has gained prominence due to the widespread adoption of smartphones and applications. This flexible mode of education has proven particularly valuable in distance learning, where quality education can be achieved without physical classroom presence. Within this context, computational thinking (CT) has emerged as an essential skill for the 21st century, equipping learners with critical problem-solving, algorithmic reasoning, and abstraction abilities that transcend computer science and are applicable to a myriad of disciplines, including biology, economics, and the social sciences. The convergence of distance learning, computational thinking, and mobile technology offers a promising avenue for exploration, with mobile games and applications demonstrating substantial potential as educational tools to foster these critical skills.

This paper focuses on exploring the distance teaching of computational thinking through mobile games and applications as documented in existing literature. It examines how these tools are employed to enhance computational thinking within distance learning environments, situated at the intersection of education, technology, and cognitive development. Computational thinking, as described by Wing (2008), involves framing problems and expressing solutions in ways that computational processes can execute, making it a vital competency for learners in today's digital age. Mobile games and applications, designed with an emphasis on engagement and interactivity, provide an effective means of teaching CT principles through game-based learning approaches. Their unique affordances—such as portability, accessibility, and immediate feedback—further reinforce their relevance in remote educational settings.

The aim of this research is to provide a comprehensive review of the literature on integrating mobile games and applications into computational thinking education for distance learning.

Specifically, the study analyzes the effectiveness of these tools in developing CT skills, identifies challenges in their implementation, and evaluates their potential to innovate and shape future educational practices. By synthesizing findings from diverse studies, this paper seeks to highlight trends, gaps, and opportunities within this field, offering insights into how mobile technologies can advance computational thinking education while addressing accessibility and equity in educational settings. The primary research question guiding this investigation is: How effective are mobile games and applications in teaching computational thinking in distance learning contexts, and what are the associated challenges and pedagogical implications?

The structure of the paper is designed to systematically address this question. Chapter 2 focuses on game-based learning strategies, exploring how mobile games and applications are used to foster CT skills, with particular attention to assessment methods. Chapter 3 discusses the pedagogical implications of these findings, including learning outcomes and implementation challenges. The paper concludes by synthesizing these insights and outlining the potential role of mobile technologies in transforming computational thinking education within distance learning environments.

2. Teaching Through Mobile Games

The dynamic landscape of mobile games serves as a powerful tool for enhancing computational thinking (CT) skills, offering innovative approaches that align educational principles with engaging gameplay. Exploring various game-based learning strategies, this section delves into the efficacy of mobile games in fostering problem-solving abilities and algorithmic reasoning. By examining effective methodologies and assessment techniques, it highlights the potential of these interactive platforms to transform CT education, addressing diverse learner needs while promoting inclusivity and active participation.

2.1 Game-Based Learning Approaches

Game-based learning approaches harness the motivational and interactive qualities of games to foster the development of computational thinking (CT) skills. Mobile games integrate various educational elements, such as rules, goals, feedback, and challenges, which align closely with CT principles like decomposition, pattern recognition, and algorithmic thinking. These components collectively create structured learning environments that promote engagement while reinforcing essential CT concepts. For example, decomposition is inherently supported through game structures, where players must break down complex tasks into smaller steps to progress (Candrawati et al., 2024). These design elements not only make learning more interactive and enjoyable but also enhance the retention of critical computational concepts. However, despite their effectiveness, the successful implementation of game-based learning strategies requires careful consideration of how these elements are tailored to match diverse learner needs, ensuring accessibility and inclusivity.

One particularly effective category of game-based learning is constructionist video games, which emphasize active learner engagement through the creation of meaningful artifacts within the game itself. These games integrate educational content with hands-on problem-solving, requiring players to employ CT strategies to overcome challenges and refine their skills. Learners are encouraged to construct artifacts such as game characters, environments, or in-game tools, thereby applying principles like abstraction and decomposition in a tangible context (Weintrop et al., 2016). The learner-directed exploration allowed by these games provides significant opportunities for experimenting with computational strategies, enabling players to navigate complex problems while achieving game objectives. Moreover, constructionist games offer valuable educational benefits by blending theoretical and practical aspects of CT, preparing learners to apply these skills in broader contexts such as academic and real-world problem-solving scenarios (Weintrop et al., 2016). However, future research should address the scalability of these games to ensure they remain effective across various educational levels and disciplines.

Mobile games explicitly designed for younger learners, such as "Rusty Rusty," exemplify the successful integration of storytelling and problem-solving to teach CT skills and computer science terminology. For instance, "Rusty Rusty" incorporates adaptive challenges and immediate feedback, which not only enhance students' memorization abilities but also sustain their motivation throughout the learning process (Alipova et al., 2024). By embedding educational objectives within engaging narratives, the game makes abstract CT concepts more relatable and manageable for primary school students. Its adaptive mechanics ensure that tasks are appropriately matched to learners' skill levels, thereby reducing frustration and encouraging continuous participation. Furthermore, the game’s immediate feedback system allows students to learn from their mistakes in real-time, fostering a deeper understanding of problem-solving methods and computational concepts. Quantitative data from the study highlights the positive correlation between increased motivation and improved learning outcomes, underlining the game’s potential as an innovative tool for computational and computer science education (Alipova et al., 2024). However, to further validate these findings, longitudinal studies focusing on long-term skill retention would be beneficial.

Voice-guided applications, such as StoryCoder, represent another innovative approach, particularly for teaching CT concepts like loops, sequences, and variables to young learners aged 5–8. Combining storytelling with CT instruction, these applications provide an engaging entry point for young children to explore computational concepts. The voice-guided feature, which offers auditory learning, ensures the tool is accessible even for learners with minimal reading skills, addressing inclusivity in CT education (Dietz et al., 2021). The storytelling elements enhance comprehension by contextualizing abstract concepts within engaging narratives, thereby simplifying complex ideas like loops and variables (Dietz et al., 2021). Iterative design and usability testing have shown that such applications are well-received by children, enabling effective navigation and learning (Dietz et al., 2021). Moreover, the app's effectiveness was demonstrated through above-chance performance in computational tasks, highlighting its value in early childhood education. Future developments could explore additional scaffolding mechanisms to further support learners’ progression in grasping advanced CT concepts.

Gamification, as another strategy in game-based learning, demonstrates both its strengths and limitations in CT education. Elements like points and rewards commonly increase engagement by incentivizing quick problem-solving. However, they can also encourage impulsive behaviors, as learners may prioritize speed over fully understanding the underlying concepts (Saavedra-Sánchez et al., 2021). In contrast, non-gamified environments promote more reflective problem-solving approaches, often resulting in deeper conceptual understanding and fewer errors (Saavedra-Sánchez et al., 2021). These contrasting outcomes emphasize the importance of designing balanced educational games that integrate gamified elements without compromising cognitive depth. Collaborative game-based environments, where peer interactions play a significant role, provide an additional layer of support by fostering collective problem-solving and mutual learning (Saavedra-Sánchez et al., 2021). This collaborative aspect is particularly useful for addressing disparities in learners' abilities, ensuring inclusivity across diverse educational settings. Overall, further research is needed to explore hybrid game designs that effectively combine gamified and non-gamified elements to optimize outcomes.

The use of visual programming languages (VPLs) like Scratch and MIT App Inventor in mobile games has proven effective in simplifying CT concepts and engaging learners. VPLs eliminate syntax-related barriers by presenting programming as visual blocks, which are easier to manipulate and understand, particularly for beginners (Attard & Busuttil, 2020). These platforms also provide immediate visual feedback, encouraging iterative problem-solving and reinforcing computational concepts (Attard & Busuttil, 2020). However, their lack of flexibility for advanced learners highlights the need for progression from block-based tools to text-based programming environments to ensure comprehensive learning (Attard & Busuttil, 2020). For example, tools like MIT App Inventor not only teach algorithm design but also allow learners to create mobile applications, fostering creativity and innovation. To address the limitations of VPLs, scaffolded approaches should be implemented, progressively introducing learners to more complex programming environments. This ensures that foundational CT skills are built upon effectively, facilitating a seamless transition to higher levels of computational education.

Mobile games grounded in constructivist principles offer significant advantages in CT education by encouraging active exploration and real-time feedback. These games empower learners to experiment with algorithms and debugging processes, fostering a hands-on approach to CT skill development (Attard & Busuttil, 2020). Real-time feedback mechanisms further enhance learning by allowing learners to test hypotheses and refine their solutions iteratively (Sırakaya, 2020). Such dynamic environments are particularly effective for students with diverse learning needs, as they accommodate various levels of prior experience and problem-solving skills (Sırakaya, 2020). Additionally, constructivist games promote active participation, addressing the passive information reception often observed in traditional teaching methods (Attard & Busuttil, 2020). Empirical evidence demonstrates that these educational strategies significantly improve learners' abilities to apply CT principles in novel contexts, validating their practical applications in education (Sırakaya, 2020; Attard & Busuttil, 2020). Future research should investigate how these principles can be extended to create cross-disciplinary learning opportunities.

The intersection of game-based learning and CT education is further highlighted by research that identifies core CT principles—such as abstraction, decomposition, and algorithmic thinking—as key elements embedded within digital games. For instance, games often integrate abstraction by emphasizing relevant information while minimizing extraneous details, aiding learners in the creation of computational models (Kalelioğlu et al., 2016). Decomposition is similarly supported through stage-based challenges, where players must divide complex objectives into smaller, manageable tasks to progress (Kalelioğlu et al., 2016). Algorithmic thinking, integral to game design, is developed as players evaluate and refine their strategies through iterative gameplay, further enhancing their problem-solving skills (Kalelioğlu et al., 2016). These principles demonstrate how game-based platforms can broaden the accessibility of CT education, particularly in remote or underserved regions where traditional educational resources may be limited. However, it is crucial to ensure that these games are designed with inclusivity in mind, addressing the diverse needs of learners across various contexts.

In sum, game-based learning approaches offer a dynamic and adaptable method for teaching computational thinking skills, leveraging the interactive and motivational qualities of games to engage diverse learners effectively. By integrating structured CT principles with interactive gameplay, these approaches have demonstrated significant potential in enhancing problem-solving abilities and fostering deeper engagement with educational content. However, further innovation is needed to address existing challenges, such as balancing gamified and non-gamified elements and ensuring scalability across different learning contexts.

2.2 Assessment Methods

The assessment of computational thinking (CT) via mobile games and applications has evolved into a multifaceted process. Researchers often employ both quantitative and qualitative methods to capture the complex nature of CT skills (Allsop, 2019). For instance, pre- and post-tests enable educators and researchers to measure students' progress over time, providing tangible metrics for evaluating skill development. These tests are particularly beneficial in identifying the effectiveness of educational interventions, as they quantify improvements in learners' ability to apply CT principles. While pre- and post-tests yield critical insights, they may not fully capture the depth of learners' engagement with CT processes. To address this limitation, observational techniques are frequently used to better understand the sequence of learners' interactions with mobile games. These observations provide a qualitative layer of analysis, highlighting students' problem-solving strategies and identifying challenges they encounter during gameplay (Allsop, 2019). Semi-structured interviews further contribute to the assessment process by delving into learners' attitudes, thought processes, and metacognitive practices. This approach enhances the understanding of how students internalize computational thinking and transfer these skills to various contexts. The diversity and triangulation of these methods allow for a more comprehensive evaluation of CT and underscore the importance of employing multidimensional approaches to assess this complex skill set (Allsop, 2019).

Quantitative analysis of adaptive educational games, such as AutoThinking, has demonstrated their superior efficacy in advancing both computational thinking skills and conceptual knowledge compared to conventional instructional methods (Hooshyar et al., 2021). For example, statistical methods like MANCOVA and ANCOVA effectively control for prior differences in learners' abilities, offering robust evidence of the advantages brought by adaptive educational tools. These approaches have revealed that students in experimental groups using AutoThinking showed significantly greater gains in CT skills than their peers in control groups. Interestingly, the data highlights that students with lower prior knowledge benefit disproportionately from such interventions, as personalized learning pathways and progressive challenges embedded in adaptive games help bridge existing knowledge gaps (Hooshyar et al., 2021). The positive outcomes extend beyond skill development, with improved learner attitudes toward computational thinking being documented as well. By fostering these dual benefits—cognitive and affective—adaptive educational games hold the potential to create more equitable learning environments, even for students with diverse starting points. Nevertheless, such findings call for further exploration into how adaptive systems can be scaled effectively while maintaining their personalized learning advantages.

Collaborative environments present another promising avenue for assessing computational thinking. Visual programming platforms, such as Scratch and Alice, have been employed successfully to measure students' ability to identify and apply programming patterns like loops and conditionals (Lockwood & Mooney, 2017; Allsop, 2019). Quizzes and project outcomes serve as key measures of learners' comprehension of CT concepts. These methods emphasize not only individual skill acquisition but also collaborative problem-solving, where learners interact actively with peers within structured team settings. Project-based assessments, in particular, offer insights into how well students can apply abstract CT principles to real-world contexts, as evidenced by completed programming tasks or digital games (Lockwood & Mooney, 2017). Such approaches reveal not only the strengths but also the areas requiring further focus for developing computational thinking skills. The collaborative aspect, when combined with project outcomes, underscores the importance of peer learning, particularly in bridging gaps in students' understanding of complex concepts. These insights highlight the effectiveness of visual programming platforms as both tools for teaching CT and frameworks for comprehensive assessment.

Mobile platforms like MIT App Inventor offer unique capabilities for assessing computational thinking through features such as procedural abstraction, event handling, and data sharing (Lockwood & Mooney, 2017). Investigations into app-based projects have revealed students' ability to reuse and generalize programming constructs, demonstrating procedural abstraction. Furthermore, their proficiency in event handling reflects an understanding of interaction design and its alignment with user-centric principles. Mobile-specific functionalities, such as managing persistent data and sharing information through app interfaces, are also crucial metrics that underscore the relevance of computational thinking in a mobile-dominated technological landscape. These detailed evaluative frameworks not only validate CT learning outcomes but also align with the affordances of mobile technologies, making them indispensable for assessing the nuances of CT education in mobile learning contexts. However, future assessments could integrate additional criteria to explore advanced aspects of mobile app development, such as cross-platform compatibility or network optimization, to further enrich the evaluation process.

The integration of augmented reality (AR) into computational thinking assessments demonstrates the potential to combine immersive environments with problem-solving tasks. By merging virtual and physical realities, AR platforms like those developed using Unity 3D allow students to actively engage with abstract concepts in a tangible manner (Lilis et al., 2024). For example, AR-based tasks enable real-time performance assessments, such as measuring students' ability to solve algorithmic problems by manipulating 3D objects. This dual engagement with virtual and physical elements fosters a deeper understanding of CT principles while also encouraging innovative problem-solving strategies. Research has shown that AR technologies are particularly effective in enhancing mathematical computational thinking, with significant performance gains observed across various student proficiency levels (Lilis et al., 2024). These insights highlight the value of AR not only as a teaching tool but also as a comprehensive assessment mechanism. Nonetheless, the integration of AR into classroom contexts requires further investigation to address challenges such as accessibility and the need for specialized training in AR tool usage.

The dual use of unplugged and plugged methods in computational thinking education offers unique benefits and corresponding challenges. Unplugged activities, such as cup-stacking algorithms, emphasize hands-on, kinesthetic engagement, which is both accessible and effective for introducing fundamental CT concepts like sequencing and decomposition to learners in resource-limited settings (Luo et al., 2022). These activities allow students to practice computational thinking in a tactile manner, making abstract concepts more relatable. However, their reliance on physical interaction may limit scalability in formal educational settings. On the other hand, plugged activities employ tools like Scratch, emphasizing coding practices and iterative problem-solving, which foster a comprehensive understanding of CT principles such as loops and conditionals (Candrawati et al., 2024). The combined use of these methods ensures that learners not only build foundational skills through unplugged tasks but also apply those skills to more complex scenarios using digital tools. Despite their complementary nature, a balanced approach requires careful calibration to address varying technological access and learner preferences. Future research must focus on refining the frameworks for integrating these dual approaches into CT education to maximize their effectiveness and accessibility.

A notable gap in the empirical assessment of computational thinking through mobile platforms has been identified in recent studies. Kalelioğlu et al. (2016) emphasize that a significant proportion of research in this area relies on conceptual or idea-based approaches rather than rigorous, data-driven methodologies. This limitation underscores the necessity for standardized, evidence-based assessment frameworks that can validate the effectiveness of mobile-based CT interventions. Collaborative research aimed at bridging theoretical and practical applications could contribute significantly to this goal, ensuring that findings are both scientifically robust and applicable in real-world educational contexts (Kalelioğlu et al., 2016). By addressing this gap, future efforts could pave the way for more nuanced and replicable insights into the impact of mobile technologies on computational thinking education.

Research has also highlighted disparities in CT skill acquisition based on age and gender, which diminish over time but remain significant in early stages of learning (Atmatzidou & Demetriadis, 2016). For instance, younger learners and girls often require additional instructional support to achieve parity with their peers in computational thinking (Atmatzidou & Demetriadis, 2016). These findings suggest that targeted interventions, such as extended practice sessions or differentiated instructional strategies, could help mitigate these disparities and promote more equitable learning outcomes. Furthermore, the influence of assessment modalities on performance must be acknowledged, as tools that do not account for age- or gender-specific challenges may inadvertently reinforce biases. Refining these tools to minimize bias and tailor feedback to diverse learner needs is imperative for creating inclusive CT education environments. These efforts serve as a reminder of the critical need for inclusivity and equity in designing both instructional strategies and assessment frameworks.

In conclusion, the assessment of computational thinking via mobile games and applications offers a diverse array of approaches, each contributing uniquely to evaluating CT skills. From observational techniques to mobile-specific metrics and AR-based tasks, these methods highlight the multifaceted nature of computational thinking. Despite significant progress, gaps in empirical research, disparities in learner outcomes, and challenges in integrating innovative tools remain areas for future exploration and refinement.

3. Pedagogical Implications

The exploration of mobile game-based learning opens up new avenues for enhancing computational thinking skills among diverse learners. By examining both the learning outcomes achieved through interactive platforms and the implementation challenges encountered in educational settings, insights will emerge on how to effectively leverage these tools in various contexts. The subsequent sections will delve into practical strategies for fostering computational skills while addressing the barriers to successful integration, ultimately contributing to a more inclusive and effective educational landscape. This discussion ties seamlessly into the broader narrative of transforming educational practices through innovative technology.

3.1 Learning Outcomes

Game-based learning has been demonstrated to significantly enhance computational thinking (CT) skills by integrating interactive elements with core CT principles, such as pattern recognition, problem decomposition, and algorithm design. Research by Candrawati et al. (2024) highlights that mobile games, through their incorporation of rules, feedback, and challenges, provide a highly engaging medium for teaching computational thinking. The alignment of these game mechanics with CT principles ensures that learners not only understand CT concepts but also apply them effectively. These design elements motivate learners and create an interactive environment conducive to skill acquisition. However, challenges such as scalability and adaptability to unique educational contexts remain critical issues that must be addressed. While current game-based learning platforms are highly effective for many, they could benefit from more tailored designs to accommodate specific learner needs, ensuring educational equity and broader applicability.

Mobile games have also shown a direct impact on students' performance, as seen in Chao et al.'s (2022) findings regarding the mobile game "Guess My Rule." This game combines pattern recognition and algebraic thinking within an engaging environment, significantly boosting learners' computational reasoning skills. The study also found that the game maintained high motivation levels and reduced anxiety, underscoring the importance of designing games that strike a balance between challenge and accessibility. These results suggest that such games are particularly useful for learners who struggle with foundational CT concepts, offering them a structured yet adaptable learning process. Nevertheless, Chao et al. (2022) identified variability in learners' completion rates, pointing to the role that individual differences, such as sensitivity to numerical patterns, play in influencing performance outcomes. Addressing this variability requires further research into game design adjustments that can accommodate a diverse range of cognitive abilities and Preferences

Evidence from studies involving pre-service teachers further supports the efficacy of mobile learning in enhancing computational thinking skills and learner confidence. Connolly et al. (2021) explored the use of mobile apps in computational thinking education for pre-service teachers and found that those utilizing app-based learning scored higher on CT tests than those who did not. While statistical significance was limited due to the small sample size, the findings strongly suggest the potential of mobile learning tools to empower future educators with CT competencies. Mobile apps offer unique advantages, including accessibility and flexibility, enabling learners to practice CT skills autonomously and consistently. Connolly et al. (2021) also noted a strong interest among participants in further developing CT-specific mobile applications, reflecting a gap in the educational resources currently available. Expanding this field of research with larger and more diverse sample sizes would provide more comprehensive insights into the utility of mobile apps for teacher education and other demographics.

The simplicity and accessibility of game-based learning platforms like Scratch have proven effective for fostering computational thinking among diverse learners, including those with educational disadvantages. Israel et al. (2015) emphasize how Scratch's drag-and-drop interface enables learners to explore CT concepts, such as loops and conditionals, without being hindered by complex syntax. This accessibility reduces barriers for learners with limited prior programming experience, making computational thinking education more inclusive. Furthermore, the collaborative features of Scratch promote peer-to-peer learning, as students discuss their projects and collectively solve problems, enhancing both individual and group understanding of CT principles. The study also highlights the success of scaffolding and flexible instruction methods in accommodating learners from underserved or academically challenged backgrounds. However, given the varying classroom dynamics observed, such as whole-classroom versus center-based instruction, it becomes evident that effective implementation of CT education requires alignment with specific organizational strategies within the classroom.

Interactive storytelling in mobile games, such as StoryCoder, has been particularly effective in engaging younger learners and introducing them to foundational computational thinking concepts. Dietz et al. (2021) demonstrate how StoryCoder employs voice-guided narration to teach essential principles such as loops, sequences, and variables. This method contextualizes abstract concepts within relevant narratives, thereby simplifying their understanding for children aged 5 to 8. The voice-guided feature not only makes the application accessible to learners with minimal reading skills but also enhances their focus during tasks. As a result, young learners experience significant improvements in their computational thinking performance. The study illustrates the potential of combining storytelling with interactive gameplay to create an engaging and inclusive educational tool. While highly effective, future iterations of such methods could explore integrating adaptive feedback mechanisms to further enhance learners' progression and address varying levels of prior knowledge among young children.

Robotics and visual programming tools offer additional avenues for enriching CT education, allowing learners to engage in hands-on problem-solving and iterative testing. Chalmers (2018) studied the use of LEGO® WeDo® 2.0 robotics kits in primary education and found that they not only improved students' computational thinking skills, such as sequencing and debugging, but also increased teachers' confidence in delivering CT-focused curricula. The project-based nature of these activities encouraged students to actively design, construct, and program robots, helping to contextualize abstract computational concepts in tangible and meaningful ways. However, the study also identified challenges in teacher training and access to technological resources, emphasizing the need for comprehensive professional development programs and institutional investment to fully realize the potential of robotics in computational thinking education.

Combining plugged and unplugged methods amplifies the acquisition of computational thinking skills by catering to diverse learning preferences and environments. Candrawati et al. (2024) noted the efficacy of integrating coding platforms like Scratch with unplugged activities, such as the Meta-Mind Table Game, to provide a comprehensive understanding of CT concepts. These approaches equip learners with both theoretical and practical skills, ensuring their ability to transition seamlessly between non-digital and digital learning environments. Additionally, unplugged activities offer significant advantages in resource-constrained settings, while plugged activities reinforce the applied aspects of CT education. This dual approach allows students to develop skills such as pattern recognition and decomposition in both accessible and interactive formats. Future research in this area should aim to refine the balance between these methods and investigate strategies for broader implementation across different educational settings.

Digital platforms like Dr. Scratch enhance CT learning outcomes by providing detailed feedback and fostering skill improvement. Moreno-León et al. (2015) demonstrated how the tool's analytical features helped learners identify coding errors and improve their understanding of computational principles such as abstraction and iteration. The program’s ability to generate standardized CT scores offers educators a robust framework for assessing student progress. Importantly, the study found that learners with lower initial CT scores benefited most from using the platform, thereby addressing educational disparities in computational thinking education. The scalability of such tools makes them particularly valuable for large classrooms where direct feedback from instructors may not be feasible. While effective, future iterations of these platforms could incorporate features to assess advanced programming concepts, such as modularization and code efficiency, thereby ensuring a more comprehensive evaluation of learners' computational thinking abilities.

Game-based learning also addresses motivational barriers while bridging knowledge gaps, particularly in cross-disciplinary contexts like science education. Basu et al. (2016) found that scaffolded computational thinking programs helped students overcome challenges in scientific domains, such as kinematics and ecology, by integrating CT concepts with subject-specific content. Adaptive scaffolding tools, such as targeted prompts and examples, were critical in aiding students’ understanding and enabling smoother transitions between disciplines. This approach not only enriched learners’ comprehension of computational models but also demonstrated the broader applicability of CT skills in academic domains. Future research should explore how adaptive scaffolds can be tailored further to meet individual learning needs, particularly for students transitioning between unfamiliar subject areas.

Mobile technologies, due to their adaptability and accessibility, provide flexible learning opportunities for computational thinking across diverse contexts. Park (2011) emphasized the unique portability and context-awareness of mobile devices, enabling learners to engage in CT activities in both formal and informal environments. These devices support both independent problem-solving and collaborative teamwork, fostering a well-rounded computational skill set. However, challenges such as screen size, network limitations, and device accessibility must be addressed to ensure that the benefits of mobile CT education are equitably distributed. Innovative solutions, such as optimizing applications for low-resource settings, could significantly extend the reach and impact of computational thinking education initiatives.

In summary, game-based learning, robotics, storytelling, digital platforms, and mobile technologies collectively demonstrate immense potential in enhancing computational thinking skills among diverse learner groups. While each approach offers unique advantages, challenges such as scalability, inclusivity, and resource availability require ongoing investigation and innovation to unlock their full educational potential.

3.2 Implementation Challenges

Limited access to resources and technologies is a primary barrier to implementing mobile game-based computational thinking (CT) education, particularly in underprivileged educational settings. The constraints of mobile devices, including limited screen sizes, memory capacities, and network speeds, often hinder their usability. Park (2011) emphasized that such limitations are especially problematic in rural and underserved areas, where consistent access to internet connectivity is scarce, rendering certain applications and mobile games inaccessible. Financial challenges also play a significant role, as the affordability of mobile devices remains a critical issue in low-income communities. While mobile platforms are often considered cost-effective tools, the financial burden associated with acquiring and maintaining such devices can exclude economically disadvantaged students from the benefits of CT education (Connolly et al., 2021). Infrastructural gaps, such as inadequate power supplies for device charging and a lack of secure storage spaces, further exacerbate these challenges, particularly in resource-constrained regions (Eguchi, 2014). To address these issues, collaborative efforts involving policymakers, non-governmental organizations, and private enterprises are necessary to subsidize digital tools, improve infrastructure, and design lightweight, resource-efficient educational applications optimized for low-resource environments (Eguchi, 2014; Park, 2011).

Another significant obstacle lies in teacher preparedness and training for integrating mobile game-based learning into CT instruction. Many educators lack both the technical proficiency and the pedagogical knowledge required to effectively utilize mobile applications for teaching computational thinking. Connolly et al. (2021) highlighted the need for comprehensive training programs designed to equip teachers with the skills to incorporate mobile game-based tools into their curriculum. The lack of understanding of CT concepts among educators often leads to missed opportunities for aligning game-based activities with learning objectives, reducing the effectiveness of these tools (Buitrago Flórez et al., 2017). Professional development programs, including certification courses and hands-on workshops, can address these gaps by fostering technical expertise and confidence among educators. Peer-based learning communities for teachers can also facilitate the exchange of best practices, enabling educators to collaboratively navigate the challenges of teaching computational thinking using mobile tools (Eguchi, 2014). Furthermore, resistance to adopting new technologies, often stemming from perceived additional workload or unfamiliarity, could be mitigated by designing intuitive, user-friendly mobile applications that require minimal preparation and technical expertise (Connolly et al., 2021). Hsu et al. (2018) further emphasized the need to train educators in diverse pedagogical techniques, such as Project-Based Learning and Cooperative Learning, as these methodologies are frequently utilized in CT education and align well with mobile game-based approaches.

The diversity of learners' abilities presents additional complexities when designing and deploying mobile games for CT learning. Candrawati et al. (2024) emphasized the importance of adaptive learning environments that cater to varying skill levels. Without such customization, advanced learners may find the tasks overly simplistic, while beginners could struggle with challenges that exceed their capacities. Artificial intelligence-powered adaptive game designs can personalize learning paths to match individual learners' skill levels, thereby fostering engagement for all participants (Candrawati et al., 2024). Mobile games should also include scalable challenges and real-time feedback mechanisms, which can assist beginners while maintaining adequate difficulty for more experienced learners. Additionally, socially collaborative game elements, such as group challenges or peer-to-peer interactions, can bridge skill gaps by encouraging collective problem-solving and mutual learning among students (Eguchi, 2014). Modular game designs also offer a solution by allowing learners to focus on specific computational thinking elements, such as abstraction or decomposition, enabling a more tailored educational experience (Grover & Pea, 2013). Addressing these diverse learner needs requires deliberate design choices that balance inclusivity with academic rigor.

Overemphasis on gamification elements like points, rewards, and leaderboards has also been criticized for encouraging impulsive and superficial problem-solving behaviors. Saavedra-Sánchez et al. (2021) cautioned that such designs may prioritize extrinsic motivation over intrinsic understanding, potentially detracting from the depth of students' engagement with CT concepts. To mitigate these risks, educators and game designers should aim for a balance between gamified elements and cognitive depth. For example, integrating reflective prompts or narrative-driven challenges that connect game mechanics to computational principles can promote deeper learning (Candrawati et al., 2024). Linking gamification incentives to demonstrable educational milestones, such as mastering specific CT concepts, ensures that rewards reinforce learning objectives rather than distract from them (Connolly et al., 2021). Additionally, implementing formative assessments within mobile games can provide constructive feedback on students' problem-solving approaches, thereby encouraging more thoughtful and deliberate engagement with computational thinking tasks (Sırakaya, 2020).

The challenge of balancing plugged (digital) and unplugged (non-digital) methods in CT education also requires careful consideration. Candrawati et al. (2024) demonstrated that integrating unplugged activities, such as the Meta-Mind Table Game, with digital tools like Scratch significantly enhances learning outcomes. However, each approach has its limitations; unplugged activities, while accessible and effective for introducing fundamental concepts, often lack the scalability and interactivity of digital tools. Conversely, plugged activities can be inaccessible in resource-constrained environments due to a lack of modern devices or reliable internet connections (Park, 2011). A blended curriculum that combines unplugged and plugged activities can bridge these gaps by using tangible, hands-on methods to teach foundational skills before transitioning to digital platforms for more advanced learning (Eguchi, 2014). Mobile applications designed to simulate unplugged tasks in offline settings represent another innovative solution, offering a seamless integration of both approaches (Candrawati et al., 2024). For educators to effectively implement these blended methodologies, professional development programs should provide structured guidance on aligning unplugged and digital approaches with overall learning objectives (Connolly et al., 2021). Moreover, as Hsu et al. (2018) noted, combining hands-on and digital approaches enables learners to transfer computational thinking concepts across real-world and virtual contexts, creating a more holistic understanding.

Students' varying familiarity with mobile technology further complicates the implementation of mobile game-based CT education. According to Sırakaya (2020), learners with greater experience using mobile devices exhibit higher computational thinking performance, underscoring the need for preparatory training to level the playing field. Introductory sessions focusing on essential navigational skills, app usage, and interactive features can ensure equitable participation among students with diverse technological backgrounds. Additionally, mobile games should feature intuitive, user-friendly interfaces to minimize the learning curve for beginners (Eguchi, 2014). Pre-assessment tools that gauge students’ technology skills can help educators identify learners in need of additional support and tailor instructional methods accordingly (Candrawati et al., 2024). Embedding tutorials within mobile games and encouraging peer mentoring among students can further bridge technological disparities while fostering collaborative learning environments (Grover & Pea, 2013).

The financial and logistical challenges of implementing robotics and coding platforms also pose significant barriers. Eguchi (2014) noted that programs like RoboCupJunior and WaterBotics, although effective in fostering CT skills, require substantial investments in hardware, software, and ongoing maintenance, which are often beyond the reach of resource-constrained schools. These logistical demands, including the storage, upkeep, and periodic updates of robotics kits, add to the difficulty of sustaining such programs in the long term. Cost-effective alternatives, such as virtual simulations or low-tech coding platforms, offer a viable solution by providing similar educational benefits at a fraction of the cost (Eguchi, 2014). Collaborative funding models involving schools, technology companies, and community organizations can also help offset expenses and make these tools more accessible to underprivileged communities (Grover & Pea, 2013).

Finally, the absence of a universally accepted framework for assessing CT development through mobile games represents a critical limitation. Grover and Pea (2013) highlighted inconsistencies in current assessment methods, which often fail to capture the multifaceted nature of computational thinking. Most frameworks rely on isolated metrics, such as gameplay analytics or post-test scores, which provide limited insights into learners’ broader problem-solving abilities. Developing standardized rubrics that evaluate diverse CT skills, including abstraction, decomposition, and algorithmic reasoning, can ensure more comprehensive assessments (Candrawati et al., 2024). The integration of augmented reality (AR) technologies into assessment frameworks, as demonstrated by Lilis et al. (2024), offers innovative approaches to evaluate CT skills dynamically and interactively. Moreover, cross-platform collaboration among game developers and educators is essential for harmonizing assessment tools, enabling consistent evaluation across different educational settings (Grover & Pea, 2013). By addressing these gaps, new frameworks could align with diverse learning contexts while maintaining scientific rigor and practical applicability.

In conclusion, the implementation of mobile game-based computational thinking education is both promising and fraught with challenges. Financial, technological, pedagogical, and assessment-related limitations must be addressed through collaborative efforts, innovative designs, and comprehensive training programs. By critically examining these obstacles and proposing viable solutions, the field can advance toward more equitable and effective CT education methods.

4. Conclusion

The primary objective of this research was to explore the potential of mobile games and applications in teaching computational thinking (CT) within distance learning environments, addressing their effectiveness, implementation challenges, and broader educational implications. This study set out to examine how mobile technologies, particularly game-based learning strategies, can be leveraged to democratize access to computational thinking education while fostering engagement, adaptability, and inclusivity. Through a comprehensive review of existing literature and analysis of diverse approaches, the findings demonstrate that mobile platforms offer transformative opportunities for teaching CT skills, aligning interactive and portable learning methods with the pedagogical goals of modern education. The research underscores that mobile applications, through innovative tools such as visual programming platforms, storytelling-based games, and constructivist designs, hold immense potential to foster critical computational thinking principles like abstraction, decomposition, and algorithmic reasoning, even in distance learning contexts.

The main findings of the study highlight the effectiveness of mobile games and applications in promoting computational thinking by offering adaptable and interactive learning environments that cater to diverse learner needs. Mobile platforms stand out for their portability, enabling learning to occur across formal and informal settings, and their interactivity, which fosters active engagement with educational content. Evidence from tools such as Scratch, Alice, and MIT App Inventor demonstrates how visual programming languages remove barriers associated with technical complexity, rendering computational thinking concepts more accessible to learners from various educational and social backgrounds. Game-based learning approaches that integrate challenges, feedback, and storytelling further enhance motivation and cognitive engagement, allowing learners to apply CT skills in real-world scenarios. Additionally, adaptive elements in mobile games, such as personalized feedback or scalable challenges, ensure that learners of differing abilities can progress within structured and supportive frameworks, thereby addressing gaps in educational equity.

Despite these promising outcomes, the study also identifies critical challenges in implementing mobile game-based CT education effectively. A significant barrier lies in the technological and financial constraints that limit access to mobile devices and reliable internet connectivity, particularly in underserved or rural settings. The limited screen sizes, memory capacities, and network dependencies of mobile devices are practical limitations that educators and developers need to address to ensure broader accessibility. In addition, teacher preparedness emerged as a recurring issue, with many educators lacking the technical proficiency or pedagogical familiarity necessary to incorporate mobile tools into their instructional practices. This underscores the need for comprehensive professional development programs that equip teachers with the necessary skills to use mobile games effectively while integrating computational thinking into curricula. Furthermore, the diversity of learners' abilities poses design challenges, as games must strike a balance between simplicity for beginners and complexity for advanced users. Too much reliance on gamification elements, such as points and rewards, may also risk superficial engagement at the expense of deeper cognitive understanding.

By situating the findings within the broader research context, this study contributes to an evolving body of work that explores the intersection of mobile learning, game-based education, and computational thinking. The results align with foundational studies by researchers like Wing, who emphasized the multidisciplinary relevance of computational thinking, and Kukulska-Hulme and Traxler, who highlighted the potential of mobile technologies in bridging formal and informal learning contexts. Additionally, this research extends the existing literature by emphasizing the importance of distance learning environments and exploring how mobile games designed with adaptive and narrative-driven elements can enhance cognitive and motivational outcomes. Tools such as StoryCoder and Rusty Rusty exemplify the integration of storytelling with computational tasks, demonstrating that immersive, narrative-based approaches significantly simplify abstract concepts like loops and algorithms for younger learners. Similarly, evidence from adaptive educational games like AutoThinking illustrates how personalized learning pathways can close knowledge gaps, particularly for students with limited prior experience in computational thinking. These results collectively highlight the potential of mobile games to promote skill acquisition across a variety of disciplines while fostering equity in education by targeting underserved populations.

The study acknowledges its limitations, particularly the reliance on secondary research and existing empirical studies, which restricts the generalizability of the findings. The absence of primary data collection or longitudinal analysis limits the ability to assess the long-term effectiveness of mobile game-based CT education comprehensively. Furthermore, the variability in mobile game design and adaptability to different learner profiles poses challenges in ensuring consistent educational outcomes across diverse contexts. The lack of a standardized framework for assessing computational thinking in mobile environments remains a critical gap, as existing evaluation methods often fail to capture the full range of skills, including abstraction, decomposition, and algorithmic reasoning. Additionally, while the research identifies tools and strategies for teaching foundational computational thinking concepts, it highlights the need for further exploration of methods to address advanced learners' needs and more complex applications of CT education.

Looking ahead, future research should prioritize empirical investigations, particularly longitudinal studies that examine the impact of game-based mobile learning on computational thinking over sustained periods. These studies should include diverse learner populations to validate the scalability and adaptability of mobile games across varying educational contexts. Developing tools that integrate plugged and unplugged approaches more seamlessly would also enhance their applicability in resource-constrained settings, offering a comprehensive framework that combines tangible, hands-on learning with digital interactivity. To address the identified challenges, further innovation in game design is essential, particularly the incorporation of artificial intelligence-driven adaptive mechanisms that can personalize learning experiences for a broader range of abilities. Additionally, teacher training programs must expand to include workshops and certifications that build both pedagogical and technological competencies, enabling educators to use mobile CT tools more effectively in blended and distance learning environments.

Standardizing assessment frameworks for computational thinking remains another critical area for future research. To ensure consistent evaluation, these frameworks should incorporate metrics that capture both cognitive and affective outcomes, such as problem-solving strategies, learner engagement, and skill transferability across disciplines. Interdisciplinary collaboration among researchers, educators, and game developers is essential for creating tools that are both scientifically rigorous and practically applicable. Finally, exploring the broader educational implications of mobile games and applications could pave the way for their integration beyond computational thinking, fostering transferable skills in areas like STEM education, language acquisition, and social sciences.

Through this research, significant insights have emerged about the transformative potential of mobile games and applications in democratizing access to computational thinking education, particularly within distance learning contexts. The findings underscore the importance of collaboration among policymakers, educators, and developers to address existing challenges and harness the opportunities presented by innovative mobile learning technologies. This work contributes to advancing the conversation around equitable education by highlighting how mobile platforms can bridge gaps in access, foster diverse learner engagement, and prepare students for the demands of a digital world. By building on these findings and addressing the challenges outlined, the field can continue to evolve, offering innovative and inclusive solutions that effectively transform educational practices worldwide.

Bibliography

Alipova, A., Turganbayeva, A., Alimzhanova, L., Savelyeva, V., & Malybayev, R. (2024). Evaluating the effectiveness of gaming practices in enhancing computer science terminology learning among primary school students. International Journal of Information and Education Technology, 14(6), 865–875. https://doi.org/10.18178/ijiet.2024.14.6.2112

Allsop, Y. (2019). Assessing computational thinking process using a multiple evaluation approach. International Journal of Child-Computer Interaction, 19, 30-55. https://doi.org/10.1016/j.ijcci.2018.10.004

Atmatzidou, S., & Demetriadis, S. (2016). Advancing students' computational thinking skills through educational robotics: A study on age and gender relevant differences. Robotics and Autonomous Systems, 75(B), 661–670. https://doi.org/10.1016/j.robot.2015.10.008

Attard, L., & Busuttil, L. (2020). Teacher perspectives on introducing programming constructs through coding mobile-based games to secondary school students. Informatics in Education, 19(4), 543–568. https://infedu.vu.lt/journal/INFEDU/article/664/file/pdf

Basu, S., Biswas, G., Sengupta, P., Dickes, A., Kinnebrew, J. S., & Clark, D. (2016). Identifying middle school students' challenges in computational thinking-based science learning. Research and Practice in Technology Enhanced Learning, 11(1), 13. https://doi.org/10.1186/s41039-016-0036-2

Brennan, K., & Resnick, M. (2012). New frameworks for studying and assessing the development of computational thinking. In Paper presented at annual American Educational Research Association meeting. Vancouver, BC, Canada. http://scratched.gse.harvard.edu/ct/files/AERA2012.pdf

Buitrago Flórez, F., Casallas, R., Hernández, M., Reyes, A., Restrepo, S., & Danies, G. (2017). Changing a generation's way of thinking: Teaching computational thinking through programming. Review of Educational Research, 87(4), 834–860. https://doi.org/10.3102/0034654317710096

Candrawati, E., Sardjono, R. E., Rohman, I., & Prahani, B. K. (2024). Implementation of computational thinking through game-based learning: A systematic literature review. KnE Social Sciences, 9(8), 807-813. https://doi.org/10.18502/kss.v9i8.15653

Chalmers, C. (2018). Robotics and computational thinking in primary school. International Journal of Child-Computer Interaction, 17, 93–100. https://doi.org/10.1016/j.ijcci.2018.06.005

Chao, C. Y., Chen, Y. C., & Hou, H. T. (2022). The development and preliminary evaluation of a mobile game for pattern recognition learning. In S. Iyer et al. (Eds.), Proceedings of the 30th International Conference on Computers in Education (pp. 653-655). Asia-Pacific Society for Computers in Education. https://icce2022.apsce.net/uploads/P2_WIPP_095.pdf

Connolly, C., Hijón-Neira, R., & Ó Grádaigh, S. (2021). Mobile learning to support computational thinking in initial teacher education: A case study. International Journal of Mobile and Blended Learning, 13(1), 49–62. https://doi.org/10.4018/IJMBL.2021010104

Dietz, G., Le, J. K., Tamer, N., Han, J., Gweon, H., Murnane, E. L., & Landay, J. A. (2021). StoryCoder: Teaching computational thinking concepts through storytelling in a voice-guided app for children. In CHI Conference on Human Factors in Computing Systems (CHI '21) (pp. 1–15). ACM. https://doi.org/10.1145/3411764.3445039

Eguchi, A. (2014). Robotics as a learning tool for educational transformation. Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics & 5th International Conference Robotics in Education, 27-34. https://www.terecop.eu/TRTWR-RIE2014/files/00_WFr1/00_WFr1_04.pdf

Grover, S., & Pea, R. (2013). Computational thinking in K–12: A review of the state of the field. Educational Researcher, 42(1), 38-43. https://doi.org/10.3102/0013189X12463051

Hooshyar, D., Malva, L., Yang, Y., Pedaste, M., Wang, M., & Lim, H. (2021). An adaptive educational computer game: Effects on students' knowledge and learning attitude in computational thinking. Computers in Human Behavior, 114, 106575. https://doi.org/10.1016/j.chb.2020.106575

Hsu, T. C., Chang, S. C., & Hung, Y. T. (2018). How to learn and how to teach computational thinking: Suggestions based on a review of the literature. Computers & Education, 126, 296–310. https://doi.org/10.1016/j.compedu.2018.07.004

Israel, M., Pearson, J. N., Tapia, T., Wherfel, Q. M., & Reese, G. (2015). Supporting all learners in school-wide computational thinking. Computers & Education, 82, 263–279. https://lists.mste.illinois.edu/lists/arc/ctrl-shift/2015-02/msg00009/Computers_%26_Education_Israel_et_al_2014.pdf

Kalelioğlu, F., Gülbahar, Y., & Kukul, V. (2016). A framework for computational thinking based on a systematic research review. Baltic Journal of Modern Computing, 4(3), 583–596. https://www.bjmc.lu.lv/fileadmin/user_upload/lu_portal/projekti/bjmc/Contents/4_3_15_Kalelioglu.pdf

Lilis, M. A., Noto, M. S., & Muhammad, I. (2024). Augmented reality-based learning media on mathematical computational thinking ability. The International Journal of Science, Mathematics and Technology Learning, 31(2), 89–118. https://doi.org/10.18848/2327-7971/CGP/v31i02/89-118

Lockwood, J., & Mooney, A. (2017). Computational thinking in education: Where does it fit? A systematic literary review. Maynooth University. https://arxiv.org/pdf/1703.07659

Luo, F., Israel, M., & Gane, B. (2022). Elementary computational thinking instruction and assessment: A learning trajectory perspective. ACM Transactions on Computing Education, 22(2), 19–44. https://doi.org/10.1145/3494579

Marcelino, M. J., Pessoa, T., Vieira, C., Salvador, T., & Mendes, A. J. (2018). Learning computational thinking and Scratch at distance. Computers in Human Behavior, 80, 470–477. https://doi.org/10.1016/j.chb.2017.09.025

Moreno-León, J., Robles, G., & Román-González, M. (2015). Dr. Scratch: Automatic analysis of Scratch projects to assess and foster computational thinking. RED-Revista de Educación a Distancia, 46, 1–23. https://revistas.um.es/red/article/download/240251/182971/

Papadakis, S. (2021). The impact of coding apps to support young children in computational thinking and computational fluency. Frontiers in Education, 6, 657895. https://doi.org/10.3389/feduc.2021.657895

Park, Y. (2011). A pedagogical framework for mobile learning: Categorizing educational applications of mobile technologies into four types. International Review of Research in Open and Distributed Learning, 12(2), 78–102. https://doi.org/10.19173/irrodl.v12i2.791

Saad, A., & Zainudin, S. (2022). A review of Project-Based Learning (PBL) and Computational Thinking (CT) in teaching and learning. Learning and Motivation, 78, 101802. https://doi.org/10.1016/j.lmot.2022.101802

Saavedra-Sánchez, D., Vidal-Sepúlveda, M. y C., & Olivares-Rodríguez. (2021). Effort analysis of computational thinking process over a gamified and non-gamified environments. CEUR Workshop Proceedings, 2825, 1-13. https://ceur-ws.org/Vol-2425/paper06.pdf

Sırakaya, D. A. (2020). Investigation of computational thinking in the context of ICT and mobile technologies. International Journal of Computer Science Education in Schools, 3(4), 1-16. https://files.eric.ed.gov/fulltext/EJ1256231.pdf

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining computational thinking for mathematics and science classrooms. J Sci Educ Technol, 25(1), 127–147. https://doi.org/10.1007/s10956-015-9581-5

Weintrop, D., Holbert, N., Horn, M. S., & Wilensky, U. (2016). Computational thinking in constructionist video games. International Journal of Game-Based Learning (IJGBL), 6(1), 1–17. https://doi.org/10.4018/IJGBL.2016010101

Wing, J. M. (2008). Computational thinking and thinking about computing. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 366(1881), 3717–3725. https://doi.org/10.1098/rsta.2008.0118