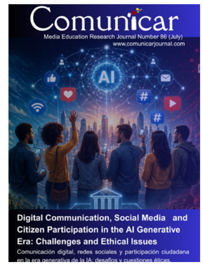
Comunicar, n. 86, v. XXXIV, 2026 | Media Education Research Journal | ISSN: 1134-3478; e-ISSN: 1988-3478
www.comunicarjournal.com



Computational Thinking Pathways in Preschool: A Multimodal Approach

Itinerarios de pensamiento computacional en Infantil: Un enfoque multimodal

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ABSTRACT
Computational Thinking (CT) is increasingly recognized as a foundational competence in early childhood education, supported by international digital literacy policies promoting equitable access to technological learning from early ages. However, research remains fragmented, as most studies examine a single pedagogical modality in isolation, leaving limited evidence on how young children progress across different types of CT experiences. This study aims to analyze how a sequential multimodal learning pathway—unplugged activities, block-based Android apps, and Blue-Bot tangible robotics—contributes to CT development in preschool children aged 4 to 6 years. A classroom-embedded intervention was implemented over nine weeks following three consecutive modalities. A total of 432 rubric-based observations were collected across six CT dimensions: abstraction, algorithms, decomposition, evaluation, modeling–simulation, and pattern recognition. Quantitative data were analyzed descriptively using means, standard deviations, and percentage distributions across performance levels, complemented by qualitative teacher notes for contextual interpretation. Findings reveal a clear progression across modalities, with initial-level performances decreasing (44% → 33% → 31%) and adequate–advanced levels increasing proportionally. Unplugged activities strengthened evaluation and pattern recognition, digital apps enhanced sequencing and modeling–simulation, and robotics produced the most balanced CT profile, with 50% of responses in adequate–advanced levels. Results highlight complementary contributions rather than competing effects across modalities. The study provides empirical evidence that sequential multimodal instruction supports CT development through a coherent progression from concrete to abstract reasoning. Pedagogical and policy implications include the need for structured CT pathways, teacher training in multimodal strategies, and early digital literacy initiatives aligned with international frameworks.

RESUMEN
El pensamiento computacional (PC) se reconoce cada vez más como una competencia esencial en Educación Infantil, respaldada por políticas internacionales de alfabetización digital que promueven un acceso equitativo al aprendizaje tecnológico desde edades tempranas. Sin embargo, la investigación sigue siendo fragmentaria, ya que la mayoría de estudios analiza una única modalidad pedagógica de forma aislada, lo que limita la comprensión sobre cómo progresan los niños a través de distintas experiencias formativas de PC. Este estudio tiene como objetivo analizar cómo un itinerario multimodal secuencial —actividades desenchufadas, aplicaciones Android basadas en bloques y robótica tangible Blue-Bot— contribuye al desarrollo del PC en alumnado de 4 a 6 años. Se implementó una intervención integrada en el aula durante nueve semanas, organizada en tres modalidades consecutivas. Se recogieron 432 observaciones rubricadas en seis dimensiones del PC: abstracción, algoritmos, descomposición, evaluación, modelado–simulación y reconocimiento de patrones. Los datos cuantitativos se analizaron de manera descriptiva (medias, desviaciones estándar y porcentajes por nivel), complementados con notas cualitativas de las docentes para contextualizar la interpretación. Los resultados muestran una clara progresión entre modalidades, con una reducción de los niveles iniciales (44% → 33% → 31%) y un aumento proporcional de los niveles adecuados–avanzados. Las tareas desenchufadas fortalecieron la evaluación y el reconocimiento de patrones, las apps digitales mejoraron la

Received: 2025-11-01 | Reviewed: 2025-11-23 | Accepted: 2026-02-27 | Online First: 2026-07-17 | Published: 2026-07-19
DOI: https://doi.org/10.5281/zenodo.21413970 | Pages: 103-113

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secuenciación y el modelado, y la robótica generó el perfil más equilibrado, con un 50% de respuestas en niveles adecuados–avanzados. La intervención evidencia que un itinerario multimodal secuencial favorece una progresión coherente desde el razonamiento concreto al abstracto. Se discuten implicaciones pedagógicas y políticas relacionadas con el diseño curricular, la formación docente y la alfabetización digital temprana.

KEYWORDS | PALABRAS CLAVE

Computational Thinking, Early Childhood Education, Multimodal Learning, Educational Robotics, Digital Literacy, Unplugged Activities.

Pensamiento computacional, educación infantil, aprendizaje multimodal, robótica educativa, alfabetización digital, actividades desenchufadas.

1. Introducción

Computational Thinking (CT) has become a fundamental component of early childhood education, supported by global and European digital literacy frameworks such as UNESCO's digital literacy framework (UNESCO, 2018) and the DigCompEdu Framework (Redecker & Punie, 2017). There is broad consensus that CT enhances foundational skills including logical reasoning, sequencing, problem-solving, and executive functioning, all of which are essential for later success in STEM and literacy domains (Bers, 2020; Grover & Pea, 2013; Hsu et al., 2018). Early exposure to CT also promotes metacognitive regulation and creativity through playful, exploratory learning experiences, as highlighted in recent empirical and systematic reviews (Su & Yang, 2023; Xu et al., 2023).

CT can be introduced through various pedagogical modalities widely documented in early-childhood research, such as unplugged activities (Bell & Vahrenhold, 2018), visual block-based programming apps (Tikva & Tambouris, 2021), and tangible robotics grounded in embodied cognition. However, existing studies tend to examine these modalities independently, focusing on single tools or activities without exploring how they might complement or reinforce each other within a coherent learning pathway. This fragmentation has been noted repeatedly in the literature, which calls for more integrated and comparative research designs (Ching & Hsu, 2024; Ouyang & Xu, 2024).

Consequently, a research gap remains regarding how young children transition from concrete, narrative, and manipulative experiences toward increasingly symbolic and algorithmic forms of CT. It is still unclear whether particular modalities support specific CT dimensions more effectively, or whether sequencing different modalities can generate cumulative learning effects. Given current policy demands for inclusive and developmentally appropriate digital literacy in early-childhood curricula, this lack of integrated evidence presents a significant challenge for educators and decision-makers.

The present study responds to this gap by examining a sequential multimodal CT pathway that combines unplugged tasks, Android block-based applications, and Blue-Bot tangible robotics. Drawing on constructionist approaches and multimodal learning theories (Bers, 2020; Brennan & Resnick, 2012), the study conceptualises CT development as a progressive trajectory in which children move through increasingly abstract representational systems supported by exploration, iteration, and reflection.

The objective of this research is to analyse how each modality contributes to CT development in preschool children aged 4 to 6, and to identify performance patterns that emerge when these modalities are implemented sequentially in authentic classroom conditions. To guide the analysis, the study addresses the following research questions:

1. How do unplugged activities, block-based apps, and tangible robotics contribute to CT development in preschool children?
2. What progression patterns emerge when these modalities are implemented sequentially within a multimodal learning pathway?
3. What pedagogical and policy implications arise from integrating multimodal CT instruction in early childhood curricula?

2. Literature Review and Theoretical Framework

2.1. Definitions and Conceptual Foundations of Computational Thinking

Computational Thinking (CT) is defined as a set of cognitive processes for structuring problems, identifying patterns, designing algorithms, and evaluating solutions. In early childhood education, CT supports logical reasoning, metacognitive regulation, creativity, and executive functions. Research shows that young learners can engage with CT meaningfully when guided by developmentally appropriate pedagogies grounded in exploration and play. CT is not limited to coding but includes multiple forms of problem-solving and symbolic representation.

2.2. Pedagogical Modalities for Introducing Computational Thinking

Unplugged activities introduce CT through storytelling, rule-based games and physical manipulation. These tasks support sequencing, pattern recognition and early debugging by engaging children in narrative reasoning and collaborative dialogue. Their accessibility and low cognitive load make them developmentally appropriate entry points, as classroom-based studies show that they help young learners detect errors and reason about actions within structured play (Curzon et al., 2014). Evidence also indicates that unplugged approaches can strengthen CT development when activities are structured around problem-solving and reflective discussion, even in early primary and preschool contexts (Brackmann et al., 2017).

Block-based coding applications extend these foundations by allowing children to manipulate symbolic commands using visual blocks. The drag-and-drop interface, combined with immediate feedback, helps children refine prediction, decomposition and modelling skills. Research indicates that such environments enhance early algorithmic reasoning and computational fluency because they scaffold causal understanding and iterative testing in ways that are accessible to young learners (Papadakis, 2021).

Tangible educational robotics, such as Blue-Bot, further strengthen CT through embodied interaction with programmable sequences. Robotics activities require children to plan movements, anticipate outcomes and collaboratively test and adjust commands, offering a concrete bridge to abstraction. Meta-analyses confirm that robotics interventions produce significant gains in algorithmic sequencing, abstraction and debugging across early and primary education, while promoting inclusion through multisensory and collaborative engagement (Hong, 2024). Recent evidence specifically focused on preschool settings also highlights the potential of robotics to support equitable and developmentally appropriate CT progression (Alonso-García et al., 2024).

Together, unplugged tasks, block-based apps and robotics constitute complementary modalities that provide a developmental progression from concrete to symbolic and embodied representations.

2.3. Multimodal Learning Frameworks

Theories of multimodal learning emphasise the value of engaging children in diverse representational systems, ranging from concrete physical activities to symbolic and embodied interactions. Constructionist approaches highlight iterative cycles of exploration, creation, and reflection. In CT education, multimodal progressions support learners as they transition from concrete and narrative representations to symbolic and algorithmic thinking. Despite strong theoretical grounding, empirical studies combining unplugged tasks, block-based tools, and robotics in a sequential pathway remain limited.

2.4. Policy, Legislation, and Institutional Frameworks

International and European policy frameworks emphasise early digital literacy and position CT as a key component of digital competence. UNESCO (2018) highlights equitable access and age-appropriate technological experiences, while the DigComp and DigCompEdu frameworks (Redecker & Punie, 2017) identify CT-related competencies as essential in early and primary education. Spanish curricular guidelines also integrate digital competence into early-childhood education, encouraging the development of logical relations, patterns, and technological exploration. However, policy documents offer limited guidance on how to structure CT progression across diverse modalities, revealing a need for empirically grounded models.

2.5. Summary and Conceptual Model Guiding the Study

The literature indicates that CT in early childhood benefits from multimodal engagement, guided transitions across representational forms, and constructionist learning experiences. A significant gap persists in understanding how unplugged, digital, and robotic modalities can be combined within a coherent instructional sequence. This study addresses that gap by examining a sequential multimodal pathway aligned with theoretical, empirical, and policy perspectives.

3. Methodology

3.1. Research Design

The study employed a classroom-based, sequential multimodal design to analyse how different instructional modalities contribute to the development of Computational Thinking (CT) in early childhood education. This approach aligns with previous CT research that emphasises the importance of developmentally appropriate, play-based and context-embedded methodologies (Hsu et al., 2018). The intervention was structured into three consecutive phases combining unplugged activities, block-based Android applications, and Blue-Bot tangible robotics. This progressive design was chosen to explore how children transition across representational systems and to address the research gap identified in the literature regarding integrated multimodal approaches. The study was conducted in authentic classroom conditions to ensure ecological validity and alignment with regular instructional practices.

3.2. Participants

Participants were 48 preschool children aged 4 to 6 years (M = 5.2; SD = 0.6) enrolled in a public early-childhood education centre located in a socioeconomically diverse urban area. All children participated in the regular classroom activities, and the intervention was implemented as part of the school's ordinary curriculum. Teachers received prior training on CT concepts, scaffolding strategies, and rubric-based assessment to ensure consistency and reliability throughout the intervention.

3.3. Instruments

CT development was assessed using a validated observation rubric adapted from conceptual frameworks commonly used in CT literature, particularly those developed by Brennan and Resnick (2012). The rubric evaluated six dimensions: abstraction, algorithms, decomposition, evaluation, modelling–simulation, and pattern recognition. Each dimension was rated on a five-point Likert scale ranging from 1 (Not Achieved) to 5 (Excellent). The instrument included behavioural indicators appropriate for early-childhood contexts, such as sequencing actions, identifying errors, predicting outcomes, and grouping patterns. Inter-rater reliability was ensured through a calibration process in which teachers jointly scored 20 percent of the sample, achieving an agreement index above 0.85.

3.4. Procedure

The intervention lasted nine weeks, with each of the three modalities implemented over three consecutive weeks. During the unplugged phase, children engaged in physical and narrative tasks designed to introduce foundational CT concepts. In the second phase, they used Android block-based applications that required sequencing, prediction, and iterative testing. The third phase involved Blue-Bot robotics, where children programmed directional movements and engaged in collaborative problem-solving. A total of 144 individual observations were recorded per modality, resulting in 432 observations overall. Teachers also kept brief qualitative notes to contextualise children's performance and capture engagement, social interaction, and emerging misconceptions.

3.5. Data analysis

Given the exploratory nature of the study and the developmental stage of the participants, data were analysed using descriptive statistics. For each CT dimension, the analysis included mean scores, standard deviations, and percentage distributions across the five performance levels. Figures and tables were used to illustrate progression trends across modalities. Qualitative notes were examined to support the interpretation of quantitative data, particularly regarding children's strategies, difficulties, and collaborative behaviours. No inferential statistics were applied, as the objective was to identify meaningful educational patterns rather than generalise to larger populations.

4. Findings

The findings describe the progression of Computational Thinking (CT) across the three instructional modalities: unplugged activities, block-based Android applications, and Blue-Bot tangible robotics. Results are presented using descriptive statistics, including percentage distributions across performance levels and mean scores for each CT dimension. The analysis focuses on identifying trends within each modality and comparative patterns across the multimodal pathway.

4.1. Performance in Unplugged Activities

Unplugged tasks produced intermediate performance levels across the six CT dimensions. Most children achieved scores within the initial and adequate categories, with fewer than one-third reaching advanced or excellent levels. Evaluation and pattern recognition were the strongest dimensions, suggesting that

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narrative and rule-based activities supported children's ability to check their own actions, identify errors, and recognise regularities. In contrast, decomposition and abstraction showed higher percentages in the initial level, indicating that young learners may require more structured scaffolding when engaging with tasks that involve breaking down problems or generalising ideas.

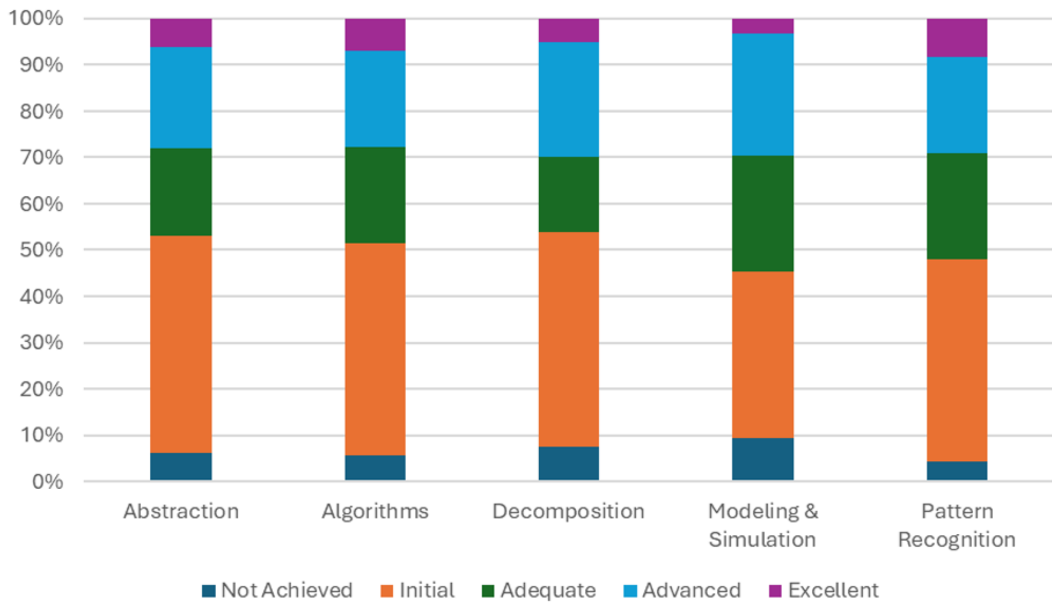
Table 1 and Figure 1 illustrate these distributions, showing initial-level values close to 44 percent and adequate-level values around 21 percent. These patterns indicate that unplugged activities provided a conceptual foundation but did not lead to high levels of performance across all dimensions.

Table 1: Percent distribution of Performance Levels in Unplugged Activities.

Skill	Not Achieved	Initial	Adequate	Advanced	Excellent
Abstraction	6.25	46.88	18.75	21.88	6.25
Algorithms	5.56	45.83	20.83	20.83	6.94
Decomposition	7.50	46.25	16.25	25.00	5.00
Modeling & Simulation	9.38	35.94	25.00	26.56	3.12
Pattern Recognition	4.17	43.75	22.92	20.83	8.33
Average	**6.57**	**43.73**	**20.75**	**23.02**	**5.93**

Source: Author's elaboration.

Figure 1: Performance Distribution Across six CT Skills in Unplugged Activities.



Percentage of students with 1 ≤ Likert value < 2 (Not Achieved); 2 ≤ Likert value < 3 (Initial); 3 ≤ Likert value < 4 (Adequate); 4 ≤ Likert value < 5 (Advanced); Likert value = 5 (Excellent).
Source: Author's elaboration

4.2. Performance in Block-based Android Applications

The Android phase showed a clear upward shift in CT performance. Adequate responses increased to approximately 36 percent, while initial levels decreased to just over 32 percent. Children demonstrated notable improvement in algorithms and modelling–simulation, reflecting increased accuracy in sequencing commands and predicting outcomes. The visual and interactive nature of the apps appeared to help learners refine procedural reasoning and build more precise mental models of the tasks.

Although evaluation improved, it remained the dimension with the most modest growth, suggesting that automatic visual feedback alone may not be sufficient to promote deeper reflection. Table 2 and Figure 2 show that children's performances in this phase were more evenly distributed across adequate, advanced, and excellent categories compared with the unplugged phase.

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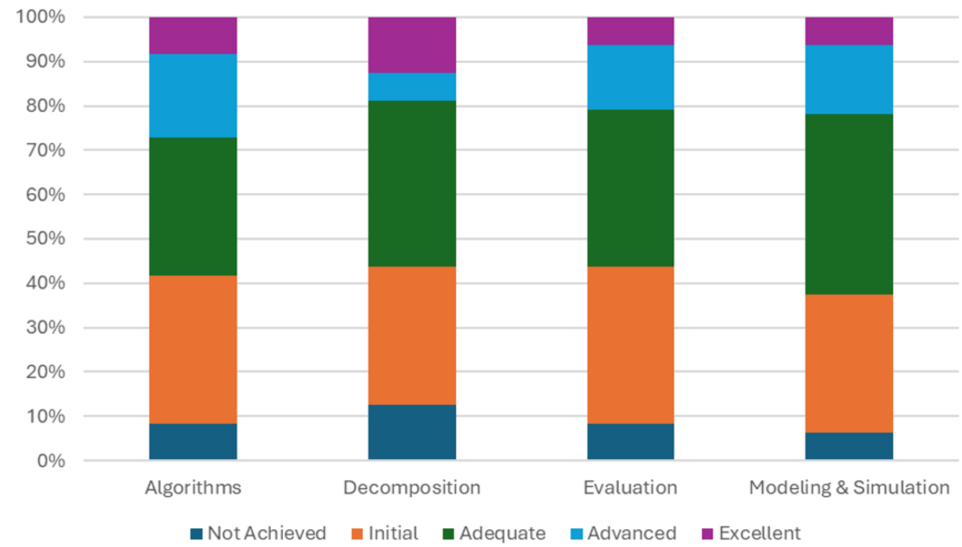
Table 2: Percentage Distribution of Performance Levels in Android App Activities.					
Skill	Not Achieved	Initial	Adequate	Advanced	Excellent
Algorithms	8.33	33.33	31.25	18.75	8.33
Decomposition	12.50	31.25	37.50	6.25	12.50
Evaluation	8.33	35.42	35.42	14.58	6.25
Modeling & Simulation	6.25	31.25	40.62	15.62	6.25
Average	**8.85**	**32.81**	**36.20**	**13.80**	**8.33**

Source: Author's elaboration.

Figure 2: Performance Distribution Across four CT Dimensions in Android App Activities.



Percentage of students with 1 ≤ Likert value < 2 (Not Achieved); 2 ≤ Likert value < 3 (Initial); 3 ≤ Likert value < 4 (Adequate); 4 ≤ Likert value < 5 (Advanced); Likert value = 5 (Excellent).
Source: Author's elaboration

4.3. Performance in Blue-Bot Tangible Robotics

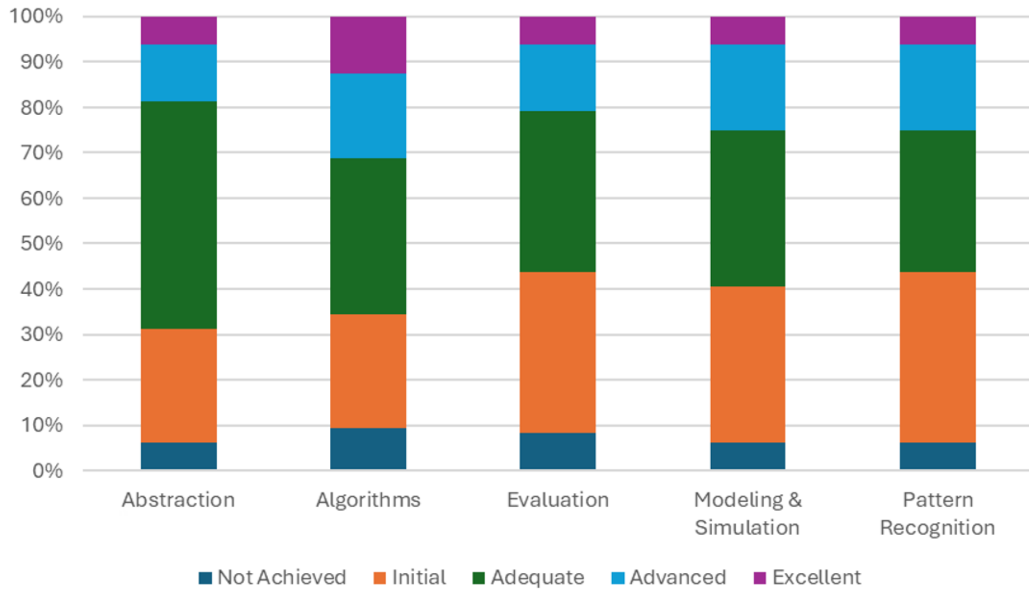
The Blue-Bot robotics phase produced the most balanced performance across CT dimensions. Adequate responses averaged 37 percent, while advanced performances increased to nearly 17 percent. This phase showed the highest consistency across dimensions such as abstraction, algorithms, and modelling–simulation. Robotics tasks appeared to support embodied cognition, enabling children to test hypotheses, revise commands, and understand directional sequences through physical manipulation.

Table 3 and Figure 3 indicate a continued reduction of initial-level scores to just over 31 percent and a parallel increase in higher performance bands. The multisensory feedback and collaborative nature of robotics activities seem to have contributed to these gains by providing concrete support for abstract reasoning processes.

Table 3: Percentage Distribution of Performance Levels in Blue-Bot Activities					
Skill	Not Achieved	Initial	Adequate	Advanced	Excellent
Abstraction	6.25	25.00	50.00	12.50	6.25
Algorithms	9.38	25.00	34.38	18.75	12.50
Evaluation	8.33	35.42	35.42	14.58	6.25
Modeling & Simulation	6.25	34.38	34.38	18.75	6.25
Pattern Recognition	6.25	37.50	31.25	18.75	6.25
Average	**7.29**	**31.46**	**37.09**	**16.67**	**7.50**

Source: Author's elaboration.

Figure 3: Performance Distribution Across five CT Dimensions in Blue-Bot Activities.



Percentage of students with 1 ≤ Likert value < 2 (Not Achieved); 2 ≤ Likert value < 3 (Initial); 3 ≤ Likert value < 4 (Adequate); 4 ≤ Likert value < 5 (Advanced); Likert value = 5 (Excellent).
Source: Author's elaboration

4.4. Comparative Trends Across Modalities

A clear progression emerged across the three modalities. Initial-level responses decreased steadily (44 percent in unplugged activities, 32 percent in digital apps, and 31 percent in robotics). Adequate and advanced levels increased proportionally across all modalities, indicating a positive cumulative effect of the sequential pathway. While unplugged tasks provided a conceptual and collaborative foundation, block-based apps reinforced sequential reasoning and predictive thinking, and robotics consolidated abstraction and debugging through embodied learning.

Overall, the findings support the hypothesis that multimodal CT instruction enables children to build progressively on prior skills, transitioning from concrete and narrative reasoning toward increasingly abstract and algorithmic thinking.

5. Discussion

The purpose of this study was to examine how a sequential multimodal learning pathway—comprising unplugged activities, block-based Android applications, and Blue-Bot tangible robotics—contributes to the development of Computational Thinking (CT) in early childhood education. The findings reveal a clear progression across modalities and demonstrate the complementary nature of each pedagogical approach. This section interprets these results in light of previous research and discusses their implications for educational practice and policy.

5.1. Interpretation of Findings in Relation to Previous Research

The progression observed across the three modalities is consistent with CT literature emphasising that young children develop computational competencies most effectively when exposed to diverse representational forms. The increase in adequate and advanced levels across modalities aligns with research showing that unplugged activities promote foundational skills such as pattern recognition and metacognitive monitoring. Bell and Vahrenhold highlight that these activities create accessible entry points allowing children to reason with symbols and narratives before encountering more abstract tasks.

The improvements observed in the digital app phase support findings by Su and Yang, who reported medium-to-large effects of visual block-based tools on sequencing and modelling. The predictability and immediate feedback of these apps appear to support children's procedural reasoning, as suggested by Tikva and Tambouris, who argue that visual scaffolding reduces cognitive load and facilitates iterative learning.

The robotics phase produced the most balanced performance, confirming research by Ching and colleagues, and by Ouyang and Xu (2024), who found that tangible technologies enable embodied cognition and support abstraction and debugging. These results are also consistent with findings from early-childhood meta-analyses showing that robotics promotes CT development and reduces performance disparities among young learners (Alonso-García et al., 2024; Hong, 2024). The multisensory, collaborative nature of robotics activities may explain the increased performance across CT dimensions, especially in algorithms and modelling–simulation. These findings indicate that each modality reinforces different aspects of CT and that the sequential combination provides cumulative benefits.

5.2. Pedagogical Implications

The results suggest several implications for early-childhood practice. First, multimodal CT instruction supports the developmental progression from concrete to abstract reasoning, emphasising the value of sequencing learning experiences rather than using isolated tools. Educators may benefit from designing CT learning itineraries that begin with accessible, collaborative activities and gradually introduce symbolic and embodied programming tasks.

Second, scaffolding strategies are essential at each stage. Unplugged activities should incorporate guided reflection to strengthen decomposition and abstraction. Digital apps require teacher mediation to deepen evaluation skills, and robotics sessions should include verbal planning and prediction to reinforce algorithmic reasoning. These findings also support the use of micro-reflection moments during transitions between modalities to help children make conceptual connections.

Third, multimodal CT instruction can enhance inclusion. The variety of representational forms may accommodate different learning preferences and reduce barriers associated with purely digital or purely physical approaches. Robotics, in particular, offers collaborative opportunities that may be especially beneficial in diverse classrooms.

5.3. Policy Implications

International frameworks increasingly encourage early integration of CT, yet curricular guidelines often lack specificity regarding multimodal progression. The results of this study offer empirically grounded insights for operationalising policy objectives in early childhood settings. Educational policies may consider recommending structured CT pathways that include unplugged, digital, and tangible modalities, ensuring developmental coherence and alignment with official competence descriptors. Schools may also require support to acquire age-appropriate technologies and provide professional development focused on CT pedagogy rather than tool-specific training.

6. Conclusion

This study examined how a sequential multimodal pathway combining unplugged activities, block-based Android applications, and Blue-Bot tangible robotics contributes to the development of Computational Thinking (CT) in preschool children. The results reveal a clear pattern of progression, with steady reductions in initial-level performance and increases in adequate and advanced levels across modalities. Unplugged tasks provided foundational opportunities for pattern recognition and evaluation, digital applications supported the refinement of sequencing and modelling skills, and robotics produced the most balanced outcomes across CT dimensions through embodied, collaborative problem-solving.

These findings demonstrate that multimodal instruction offers meaningful advantages over isolated approaches by guiding children through representational transitions that align with early cognitive development. The study provides evidence that CT learning is strengthened when instructional experiences move from concrete and narrative tasks toward symbolic and embodied programming challenges.

6.1. Recommendations and Practical Implications

The results highlight the value of designing structured CT pathways in early-childhood education.

Teachers may benefit from integrating unplugged activities as initial conceptual grounding, followed by digital tasks that introduce symbolic representation, and concluding with robotics to consolidate abstract reasoning. Professional development should emphasise multimodal scaffolding strategies, reflective questioning, and the alignment of CT experiences with curricular goals. Schools should consider ensuring access to a balanced combination of low-tech and high-tech resources to support inclusion and equitable participation.

6.2. Policy Implications

Educational policies that promote early digital literacy would benefit from clearer guidance on how to implement CT across multiple modalities. The findings support the integration of multimodal CT sequences into official curricula and teacher training programmes, in line with international frameworks such as UNESCO (2018) and the DigComp and DigCompEdu frameworks (Redecker & Punie, 2017). Policymakers may also consider strategies to enhance resource provision and ensure that schools can effectively adopt multimodal approaches.

6.3. Limitations and Future Research

This study was conducted in a single school, which limits the generalisability of the findings. The use of descriptive statistics does not support inferential conclusions, and the short duration of the intervention prevents the examination of long-term effects. Future research could employ longitudinal designs, include larger and more diverse samples, and explore the transfer of CT skills to other domains such as mathematics and language. Additional studies may also analyse how multimodal CT pathways influence motivation, inclusion, and social interaction in early-childhood settings.

Funding

This publication has been funded by the research project "Creative Programming in Primary Education. Development of Materials and Proposals for Block Coding, Game Engines, Machine Learning and Robotics" (PID2022-136442OB-I00), within the Knowledge Generation Projects 2022 program, funded by the Ministry of Science, Innovation and Universities of Spain (MICINN).

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