

Computational Thinking and Technological Mediation in Vulnerable Early Childhood Education

Pensamiento computacional y mediación tecnológica en Educación Infantil vulnerable

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ABSTRACT

The growing integration of digital technologies in early childhood education requires an understanding not only of their effectiveness, but also of their role as mediators of learning and communication processes, particularly in socially vulnerable contexts. Although computational thinking has gained increasing attention in early education, few empirical studies comparatively analyse how different technological modalities mediate learning within a single educational intervention. This study addresses this gap by examining the educational impact of a multimodal computational thinking intervention based on unplugged activities, mobile applications and educational robotics, implemented with five-year-old children in a high-needs public school. A quasi-experimental single-group pretest–posttest design was adopted (N=16), assessing six computational thinking dimensions: decomposition, pattern recognition, abstraction, modelling and simulation, algorithms and evaluation. The results reveal significant improvements across all analysed dimensions, with differentiated effects depending on the modality used. Unplugged activities promoted reflection, verbalisation and pattern recognition; mobile applications strengthened sequencing and symbolic prediction; and educational robotics produced the strongest gains in abstraction and evaluation, while also reducing performance variability among learners. These findings conceptualise computational thinking as a technologically mediated pedagogical and communicative practice and provide empirical evidence to inform the design of inclusive and equitable early childhood interventions in socially vulnerable educational contexts.

RESUMEN

La creciente integración de tecnologías digitales en Educación Infantil plantea la necesidad de comprender no solo su eficacia, sino también su papel como mediadoras de los procesos de aprendizaje y comunicación, especialmente en contextos de vulnerabilidad social. Aunque el pensamiento computacional ha adquirido una relevancia creciente en las primeras etapas educativas, existen escasos estudios empíricos que analicen comparativamente cómo distintas modalidades tecnológicas median el aprendizaje dentro de una misma intervención educativa. Este estudio aborda este vacío mediante el análisis del impacto educativo de una intervención multimodal de pensamiento computacional basada en actividades desenchufadas, aplicaciones móviles y robótica educativa, desarrollada con alumnado de cinco años en un centro público de difícil desempeño. Se adoptó un diseño cuasi-experimental con medidas pretest–posttest en un único grupo (N=16), evaluando seis dimensiones del pensamiento computacional: descomposición, reconocimiento de patrones, abstracción, modelado y simulación, algoritmos y evaluación. Los resultados muestran mejoras significativas en todas las dimensiones analizadas, con efectos diferenciados según la modalidad empleada. Las actividades desenchufadas favorecieron la reflexión, la verbalización y el reconocimiento de patrones; las aplicaciones móviles reforzaron la secuenciación y la predicción simbólica; y la robótica educativa generó los mayores avances en abstracción y evaluación, además de reducir la variabilidad entre el alumnado. Los hallazgos permiten conceptualizar el pensamiento computacional como una práctica pedagógica y comunicativa mediada tecnológicamente, y aportan

evidencias empíricas para el diseño de intervenciones inclusivas y equitativas en Educación Infantil, especialmente en contextos socioeducativos vulnerables.

KEYWORDS | PALABRAS CLAVE

Child Education, Computational Thinking, Mediation, Educational Technology, Robotics, Vulnerable Groups.
Educación infantil, pensamiento computacional, mediación, tecnología educativa, robótica, grupos vulnerables.

1. Introduction

The progressive digitalisation of contemporary societies has placed education before the challenge of integrating technologies not merely as instrumental tools, but as mediating elements of learning and communication processes. This challenge is particularly significant in Early Childhood Education, a critical stage for cognitive, linguistic and socio-emotional development, in which educational experiences have a decisive influence on future learning trajectories (Plowman & McPake, 2013; UNESCO, 2021). At this stage, the ways in which children interact with symbolic systems, language and cultural tools are especially relevant for the construction of meaning and knowledge.

Within this context, computational thinking has emerged as a key educational construct that transcends the acquisition of technical or programming skills. Rather than being understood as a disciplinary competence linked exclusively to computer science, computational thinking refers to a set of cognitive and metacognitive processes related to problem-solving, planning, abstraction, anticipation and evaluation (Brennan & Resnick, 2012; Wing, 2006). These processes are deeply connected to communication, as they involve the organisation of actions, the verbalisation of strategies, the interpretation of symbols and the negotiation of meanings in social interaction. From this perspective, computational thinking can be conceptualised as a pedagogical and communicative practice that is constructed through mediated activity (Brennan & Resnick, 2012).

Recent research highlights that early computational thinking development is particularly effective when embedded in playful, active and contextualised pedagogical approaches that combine analogue and digital experiences (Bers, 2017; Papadakis, 2021). Approaches that combine bodily action, dialogue, symbolic representation and feedback appear to be especially suitable for young learners, whose learning is grounded in interaction and experience. In this sense, educational technology should not be conceived as a homogeneous category, but rather as a set of mediational resources that configure different relationships between learners, tasks and learning environments (Resnick, 2006).

The concept of mediation is central to understanding the educational role of technology. From a sociocultural perspective, learning is always mediated by cultural tools that shape how individuals perceive, interpret and act upon the world (Vygotsky, 1978). In educational settings, technologies function as mediating artefacts that structure learning experiences, influence communication patterns and support the construction of shared knowledge (Wertsch, 1998). Different technological modalities offer distinct forms of mediation: some prioritise verbalisation and collective reasoning, others emphasise visual-symbolic representation, while others enable embodied and tangible interaction (Papert, 1980).

This distinction becomes particularly relevant when considering the diversity of educational contexts in which computational thinking is implemented. In schools serving vulnerable groups, educational interventions must address not only learning effectiveness but also issues of equity, accessibility and inclusion. In such contexts, schools play a compensatory role, and pedagogical approaches need to provide multiple entry points to learning in order to accommodate diverse cognitive, linguistic and socio-cultural profiles (Buckingham, 2007; UNESCO, 2013). Technological mediation can contribute to this goal when it is guided by clear pedagogical intentions and grounded in inclusive principles.

Previous research has documented the educational potential of different technological resources for fostering computational thinking in early childhood, including unplugged activities, mobile applications and robotics (Bell et al., 2009; Bers, 2017; Sullivan & Bers, 2016). However, much of this research has focused on isolated tools or single modalities, without sufficiently examining how different forms of mediation operate within the same educational intervention. As a result, there is limited empirical evidence on the differentiated pedagogical contributions of each modality and on how their combined use may support learning and communication processes, particularly in socially vulnerable contexts (Grover & Pea, 2013; Papadakis & Kalogiannakis, 2022).

In response to this gap, the present study analyses the educational impact of a multimodal computational thinking intervention implemented in Early Childhood Education with children from a high-needs public school. By integrating unplugged activities, mobile applications and educational robotics within a single pedagogical sequence, the study aims to examine how different technological modalities mediate the development of computational thinking and related communicative processes. By adopting an educommunicative perspective, this study contributes empirical evidence on the differentiated pedagogical value of unplugged activities, mobile applications and educational robotics, advancing current knowledge on how multimodal technological mediation can foster computational thinking in socially vulnerable early childhood contexts.

2. Theoretical framework

2.1. Computational Thinking as an Educational and Communicative Practice

computational thinking has progressively evolved from a concept associated with computer science to a broader educational framework that supports problem-solving, reasoning and communication across disciplines. Wing (2006) initially defined computational thinking as a way of formulating problems and expressing their solutions in a form that can be carried out by an information-processing agent. Subsequent educational research has expanded this definition, emphasising its cognitive, metacognitive and communicative dimensions, particularly in non-formal programming contexts (Barr & Stephenson, 2011; Grover & Pea, 2013).

In Early Childhood Education, computational thinking should not be approached as an early introduction to formal programming languages, but rather as a set of thinking practices that enable children to organise actions, anticipate outcomes, reflect on errors and communicate strategies. Brennan and Resnick (2012) conceptualised computational thinking as a multidimensional construct comprising concepts (such as sequences and loops), practices (such as testing and debugging) and perspectives (such as expressing and connecting). This framework is especially relevant for early childhood, as it aligns with developmental characteristics that prioritise action, play, language and social interaction.

From an educational communication perspective, computational thinking can be understood as a form of meaning-making that relies on multiple representational systems. Children engage in computational thinking not only when they solve problems, but also when they explain procedures, negotiate strategies with peers and reflect on errors. These processes are inherently communicative and dialogic, as they rely on language, shared attention and social interaction to construct understanding (Vygotsky, 1978). Consequently, computational thinking in early childhood education involves both cognitive operations and communicative practices that are socially and culturally situated.

Empirical research has shown that early exposure to computational thinking supports the development of executive functions such as planning, cognitive flexibility and inhibitory control (Castro et al., 2024; Chevalier et al., 2022). These abilities are closely related to children's capacity to communicate intentions, follow shared rules and adapt strategies in collaborative learning situations. Thus, computational thinking should be framed as a pedagogical practice that integrates cognition and communication, rather than as a purely technical skill detached from social interaction.

2.2. Technological Mediation and Multimodality in Early Childhood Education

The concept of mediation is central to sociocultural theories of learning and provides a valuable lens for analysing the educational role of technology. According to Vygotsky (1978), human learning is always mediated by cultural tools and signs that shape how individuals interact with their environment and with others. In educational contexts, technologies function as mediating artefacts that structure learning activities, influence communication patterns and support the construction of shared knowledge (Wertsch, 1998).

In Early Childhood Education, technological mediation must be understood in relation to children's developmental needs and preferred modes of learning. Young learners construct knowledge through multimodal experiences that integrate bodily action, visual representation, oral language and symbolic manipulation. Papert (1980) highlighted the importance of concrete and manipulable materials for supporting abstract thinking, a principle that remains relevant in contemporary digital learning environments. Different technological modalities provide distinct forms of mediation that shape how children engage with tasks and concepts. In this study, multimodality is understood as the intentional pedagogical integration of complementary forms of mediation, verbal, visual-symbolic and embodied, rather than as the mere accumulation of technological tools.

Unplugged activities constitute a form of low-tech mediation that relies on physical materials, gestures and verbal interaction to represent computational concepts. Research has shown that such activities promote reflection, shared reasoning and the verbalisation of strategies, making them particularly suitable for early childhood settings (Bell et al., 2009; Sáez-López et al., 2016). By minimising technological interfaces, unplugged tasks foreground communication and collective problem-solving, allowing children to focus on the structure of actions rather than on device operation.

Mobile applications introduce a visual-symbolic form of mediation through interfaces based on icons, sequences and immediate feedback. Well-designed educational applications can scaffold computational

thinking by externalising cognitive processes and supporting prediction, sequencing and error correction in non-literate learners (Papadakis, 2021; Papadakis & Kalogiannakis, 2022). These environments mediate learning by making abstract processes visible and by enabling children to test hypotheses through trial and feedback.

Robotics adds a tangible and embodied dimension to technological mediation. Educational robots enable children to translate symbolic instructions into physical movement, making the consequences of their decisions concrete and observable. Studies have reported that robotic activities enhance engagement, collaboration and spatial reasoning, while also fostering abstraction and evaluative thinking through debugging processes (Bers, 2017; Sullivan & Bers, 2016). The physical presence of robots encourages dialogue, negotiation and shared attention, reinforcing the communicative aspects of learning.

Multimodal approaches that integrate unplugged activities, mobile applications and robotics have been identified as particularly effective for fostering computational thinking in early childhood education. By combining complementary forms of mediation, such approaches provide multiple entry points to learning and accommodate diverse cognitive and communicative profiles (Alonso-García et al., 2024; Zhang et al., 2025). This is especially relevant in educational contexts serving vulnerable groups, where multimodal technological mediation can contribute to more equitable and inclusive learning opportunities.

Taken together, these perspectives highlight the importance of analysing not only whether technology is used in Early Childhood Education, but how it mediates learning and communication processes. Understanding the differentiated pedagogical contributions of various technological modalities is essential for designing meaningful, inclusive and context-sensitive computational thinking interventions in early childhood education.

3. Objectives and Research Questions

The aim of this study is to analyse the educational impact of a multimodal computational thinking intervention in Early Childhood Education, with particular attention to the mediational role of different technological modalities in a context of social vulnerability. The study is grounded in an educommunicative perspective that conceptualises computational thinking as a pedagogical and communicative practice shaped by interaction, mediation and meaning-making processes.

More specifically, the study pursues the following objectives:

1. Examine the extent to which a multimodal intervention based on unplugged activities, mobile applications and robotics contributes to the development of computational thinking in Early Childhood Education.
2. Analyse the differentiated effects of each technological modality on key computational thinking dimensions, including decomposition, pattern recognition, abstraction, modelling and simulation, algorithms and evaluation.
3. Explore how different forms of technological mediation support cognitive and communicative processes involved in problem-solving, planning and reflection in early childhood learning contexts.
4. Identify the pedagogical value of combining analogue and digital resources in the design of inclusive and equitable educational interventions for vulnerable groups.

Based on these objectives, the study is guided by the following research questions:

- RQ1. Does a multimodal computational thinking intervention produce significant improvements in computational thinking skills in Early Childhood Education?
- RQ2. Are there differences in learning outcomes associated with unplugged activities, mobile applications and educational robotics?
- RQ3. How does each technological modality mediate cognitive and communicative processes related to computational thinking in a vulnerable educational context?

4. Methodology

4.1. Research Design

The study adopts a quasi-experimental research design with a single group and pretest–posttest measures. This design was selected due to the educational nature of the intervention and the contextual constraints of the research setting, in which the use of control groups or random assignment was not feasible. Quasi-

experimental designs are widely used in educational research, particularly in early childhood contexts, as they allow for the examination of learning gains while preserving ecological validity and authentic classroom dynamics (Cohen & Morrison, 2017).

The intervention followed a multimodal pedagogical sequence that intentionally integrated different forms of technological mediation. This design choice responds directly to the study's objectives and aligns with previous research highlighting the value of combining analogue and digital resources to support computational thinking development in early childhood education (Bers, 2017; Papadakis, 2021).

4.2. Context and Participants

The study was conducted in a public school classified as a high-needs educational context, characterised by socio-economic vulnerability and a high risk of educational exclusion. Research has shown that schools in such contexts play a compensatory role and require pedagogical approaches that prioritise inclusion, accessibility and meaningful learning opportunities (Buckingham, 2007; UNESCO, 2013).

Participants were 16 children (8 girls and 8 boys) enrolled in the third year of Early Childhood Education (five years old). All children in the classroom participated in the intervention. Prior to data collection, informed consent was obtained from families, and the study complied with ethical standards for educational research involving minors. To ensure confidentiality, all identifying information related to the school and participants was anonymised, following established ethical guidelines for educational research (Cohen & Morrison, 2017).

4.3. Intervention Procedure

The intervention was implemented over a six-week period during regular school hours and was fully integrated into the classroom routine. It was structured in three consecutive phases, each corresponding to a specific form of technological mediation. The sequencing of phases was informed by previous studies indicating that gradual progression from unplugged to digital and embodied activities supports conceptual understanding and reduces cognitive overload in early learners (Bell et al., 2009; Bers, 2017).

The first phase consisted of unplugged activities designed to introduce computational thinking concepts without the use of digital devices. These activities focused on sequencing, logical reasoning, decomposition and pattern recognition through physical materials, oral instructions and collaborative problem-solving. Unplugged approaches have been shown to foster verbalisation, shared reasoning and metacognitive awareness in early childhood education (Bell et al., 2009; Sáez-López et al., 2016).

The second phase involved the use of mobile applications for visual programming on Android tablets. Applications were selected based on their pedagogical suitability for early childhood education, visual-symbolic interfaces and progressive challenge structures. Prior research has highlighted that well-designed mobile applications can scaffold computational thinking by externalising cognitive processes and supporting prediction and error correction in non-literate learners (Papadakis, 2021; Papadakis & Kalogiannakis, 2022).

The third phase incorporated robotics-based activities using a floor robot appropriate for early childhood learners. Robotics activities required children to translate symbolic instructions into physical movement, encouraging embodied interaction, collaborative planning and evaluative thinking. Previous studies have shown that educational robotics enhances engagement, collaboration and higher-order computational thinking processes such as abstraction and debugging (Castro et al., 2024; Sullivan & Bers, 2016). Table 1 summarises the structure of the multimodal intervention.

Table 1: Overview of the Multimodal Computational Thinking (CT) Intervention.

Intervention Phase	Technological Modality	Main Activities	CT Dimensions Addressed
Phase 1	Unplugged activities	Sequencing tasks, pattern games, logical reasoning	Decomposition, pattern recognition
Phase 2	Mobile applications	Visual programming challenges	Algorithms, modelling and simulation
Phase 3	Educational robotics	Robot-based navigation and problem-solving	Abstraction, evaluation

Source: Author's elaboration

4.4. Instruments and Data Collection

Data were collected using observation-based assessment instruments adapted to the developmental characteristics of the participants. Observation is considered particularly appropriate in early childhood education, as young learners often express understanding through action, interaction and verbalisation rather than through written responses (Cohen & Morrison, 2017).

A rubric was employed to assess six dimensions of computational thinking: decomposition, pattern recognition, abstraction, modelling and simulation, algorithms and evaluation. The dimensions were aligned with established computational thinking frameworks adapted for educational contexts (Brennan & Resnick, 2012; Grover & Pea, 2013). The same instrument was used for both pretest and posttest measures to ensure comparability.

4.5. Data Analysis

Given the small sample size, quantitative data were analysed using non-parametric statistical procedures, which are recommended when normality assumptions cannot be guaranteed (Cohen & Morrison, 2017). Pretest and posttest scores were compared to identify changes in computational thinking dimensions following the intervention, and descriptive statistics were used to examine performance patterns associated with each technological modality.

In addition, qualitative observational data were used to support the interpretation of quantitative findings, particularly in relation to children's interaction, engagement and communicative behaviour during activities. Combining quantitative and qualitative data is recommended in early childhood research to capture the complexity of learning processes and to strengthen the interpretive validity of results (Grover & Pea, 2013).

5. Results

The results are presented in relation to the overall effects of the multimodal intervention and the differentiated outcomes associated with each technological modality. The analysis focuses on changes observed between pretest and posttest measures across the six computational thinking dimensions: decomposition, pattern recognition, abstraction, modelling and simulation, algorithms and evaluation.

5.1. Overall Effects of the Multimodal Intervention

Comparison of pretest and posttest scores revealed a general improvement in computational thinking performance following the intervention. All six dimensions showed higher mean scores in the posttest assessment, indicating that the multimodal approach contributed positively to children's computational thinking development in Early Childhood Education. Table 2 summarises mean performance across Computational Thinking (CT) dimensions by intervention modality.

CT Dimension	Pretest (M)	Posttest (M)	Improvement Trend
Decomposition	Low	Moderate	Positive
Pattern recognition	Low	Moderate	Positive
Abstraction	Very low	High	Marked improvement
Modelling and simulation	Low	Moderate–High	Positive
Algorithms	Low	High	Marked improvement
Evaluation	Very low	High	Marked improvement

Source: Author's elaboration

The most pronounced improvements were observed in abstraction, algorithms and evaluation, which shifted from very low or low initial levels to moderate or high performance levels at posttest. These dimensions also showed a reduction in score dispersion, suggesting more homogeneous achievement among participants after the intervention. Improvements in decomposition and pattern recognition were also evident, although with slightly greater variability across learners.

These findings support previous research indicating that computational thinking can be effectively

fostered in early childhood through developmentally appropriate and play-based interventions, even in contexts characterised by social vulnerability (Alonso-García et al., 2024; Bers, 2017; Grover & Pea, 2013).

5.2. Differential Effects by Technological Modality

Analysis of performance across the three intervention phases revealed differentiated effects depending on the form of technological mediation employed, highlighting the complementary pedagogical value of unplugged activities, mobile applications and robotics.

Unplugged activities were particularly effective in supporting decomposition and pattern recognition. During these activities, children demonstrated an increased ability to break down tasks into sequential steps and to identify recurring structures. Observational data indicated that these tasks encouraged verbal explanation and shared reasoning, with children frequently articulating strategies aloud and negotiating solutions with peers. This aligns with previous studies emphasising the communicative and reflective potential of unplugged approaches in early computational thinking education (Bell et al., 2009; Sáez-López et al., 2016).

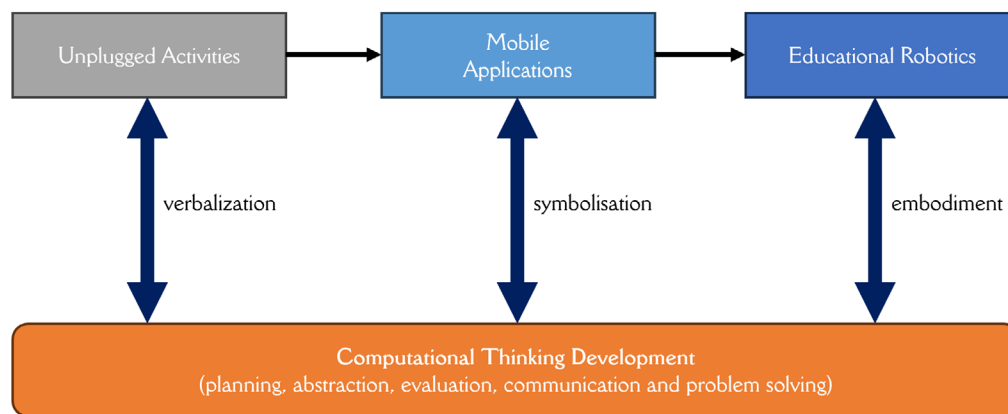
Mobile application-based activities produced notable improvements in algorithms and modelling and simulation. The visual-symbolic interfaces supported children's ability to sequence actions, anticipate outcomes and correct errors through immediate feedback. Over time, children displayed greater autonomy in task completion and more efficient problem-solving strategies. These results are consistent with prior research highlighting the affordances of visual programming environments for scaffolding computational thinking in non-literate learners (Papadakis, 2021; Papadakis & Kalogiannakis, 2022).

Robotics-based activities yielded the strongest effects in abstraction and evaluation. Tasks involving physical robots required children to translate symbolic instructions into embodied action, making errors visible and prompting reflective adjustment of strategies. Children frequently engaged in collective debugging processes, discussing why the robot did not behave as expected and proposing alternative solutions. These findings are in line with studies reporting the effectiveness of educational robotics in fostering higher-order computational thinking processes and collaborative learning in early childhood (Castro et al., 2024; Sullivan & Bers, 2016).

5.3. Communicative and Interactional Patterns

Beyond quantitative learning gains, qualitative observations revealed notable changes in children's communicative behaviour throughout the intervention. In later phases, children increasingly used temporal, causal and conditional language to explain their actions, such as references to order, direction and consequence. Peer interaction became more structured, with more frequent instances of turn-taking, shared planning and collective decision-making during tasks.

Figure 1: Multimodal Mediation Pathway for Computational Thinking Development.



Source: Author's elaboration

These interactional patterns suggest that the development of computational thinking was closely intertwined with communicative processes, reinforcing sociocultural perspectives that conceptualise learning as a dialogic and mediated activity (Vygotsky, 1978; Wertsch, 1998). The results indicate that technological mediation supported not only cognitive development, but also the emergence of shared meaning-making practices and collaborative problem-solving. Figure 1 illustrates the multimodal mediation pathway underlying the intervention.

Overall, the findings demonstrate that the multimodal intervention effectively supported computational thinking development in Early Childhood Education, while also revealing the specific pedagogical contributions of different technological modalities. These differentiated effects provide a foundation for interpreting how multimodal technological mediation can enhance learning and communication processes, particularly in educational contexts serving vulnerable groups.

6. Discussion

The aim of this study was to analyse how different technological modalities mediate the development of computational thinking in Early Childhood Education within a context of social vulnerability. This study contributes to the field by providing a comparative analysis of different technological modalities within a single early childhood intervention, highlighting their distinct mediational roles in cognitive and communicative processes. The findings indicate that the multimodal intervention produced significant improvements across all computational thinking dimensions, while also revealing differentiated pedagogical contributions associated with unplugged activities, mobile applications and robotics. These results contribute to current research by offering a comparative analysis of multiple forms of technological mediation within a single educational intervention, an aspect that has been largely overlooked in previous studies.

The overall improvement observed between pretest and posttest assessments supports existing evidence that computational thinking can be meaningfully fostered in early childhood through developmentally appropriate, play-based and structured interventions (Alonso-García et al., 2024; Bers, 2017; Grover & Pea, 2013). Importantly, the present findings demonstrate that such learning gains are achievable even in high-needs educational contexts, reinforcing the idea that Early Childhood Education can play a compensatory role when pedagogical interventions are intentionally designed to promote equity and inclusion (Buckingham, 2007; UNESCO, 2021).

A key contribution of this study lies in the identification of differentiated mediational effects associated with each technological modality. Unplugged activities proved particularly effective in supporting decomposition and pattern recognition, which aligns with prior research highlighting the value of screen-free approaches for fostering verbalisation, shared reasoning and metacognitive awareness in young children (Bell et al., 2009; Sáez-López et al., 2016). By foregrounding dialogue and collective problem-solving, unplugged activities appear to strengthen the communicative foundations upon which more abstract computational thinking processes can later be built. The differentiated pedagogical contributions of each modality are summarised in Table 3.

Tabla 3: Pedagogical Contributions of each Technological Modality.

Modality	Main Pedagogical Contribution	Dominant Mediation Process
Unplugged activities	Verbalisation and shared reasoning	Communicative mediation
Mobile applications	Symbolic sequencing and prediction	Visual-symbolic mediation
Educational robotics	Embodied abstraction and error evaluation	Tangible and embodied mediation

Source: Author's elaboration

Mobile application-based activities showed stronger effects on algorithmic thinking and modelling and simulation. These findings are consistent with studies emphasising the pedagogical affordances of visual programming environments, which externalise cognitive processes through symbolic representations and immediate feedback (Papadakis, 2021; Papadakis & Kalogiannakis, 2022). In the present study, the use of mobile applications supported children's ability to sequence actions, anticipate outcomes and refine strategies, suggesting that visual-symbolic mediation plays a crucial role in bridging concrete action and abstract reasoning in early childhood computational thinking.

Robotics-based activities yielded the strongest gains in abstraction and evaluation, dimensions associated with higher-order computational thinking. This result aligns with previous research indicating that embodied and tangible interactions facilitate abstraction by making cause–effect relationships visible and actionable (Castro et al., 2024; Sullivan & Bers, 2016). The need to translate symbolic instructions into physical movement encouraged children to engage in reflective debugging processes, often through collaborative dialogue. This highlights the role of robotics as a form of embodied mediation that integrates cognition, action and communication.

Beyond cognitive outcomes, the qualitative findings underscore the close relationship between computational thinking development and communicative processes. Increased use of temporal, causal and conditional language, as well as more structured peer interaction, supports sociocultural perspectives that conceptualise learning as a dialogic and mediated activity (Vygotsky, 1978; Wertsch, 1998). These results extend previous research by demonstrating that computational thinking in early childhood is not only a matter of problem-solving performance, but also a communicative practice shaped by interaction, negotiation and shared meaning-making.

The multimodal nature of the intervention emerges as a central factor in its effectiveness. Rather than relying on a single technological resource, the intentional combination of unplugged activities, mobile applications and robotics provided complementary forms of mediation that addressed diverse cognitive and communicative needs. This finding is particularly relevant in contexts serving vulnerable groups, where learners may present heterogeneous profiles in terms of language development, attention and prior exposure to technology. Multimodal technological mediation appears to offer multiple entry points to learning, thereby reducing barriers and supporting more equitable participation (Zhang et al., 2025). These findings support the need for early childhood educational policies that promote flexible, multimodal and communication-oriented approaches to computational thinking, particularly in schools serving vulnerable groups.

Nevertheless, the findings should be interpreted in light of certain limitations. The absence of a control group and the relatively small sample size limit the generalisability of the results. Additionally, the short duration of the intervention does not allow for conclusions regarding the long-term sustainability of learning gains. Future research could address these limitations by incorporating longitudinal designs, comparative groups and larger samples, as well as by examining the role of teacher mediation in greater depth.

In summary, the discussion highlights that computational thinking in Early Childhood Education is best understood as a mediated, multimodal and communicative practice. By analysing the differentiated contributions of various technological modalities, this study advances current knowledge on how educational technology can be strategically integrated to support inclusive and meaningful learning, particularly in socially vulnerable educational contexts.

7. Conclusions and Implications

This study analysed the mediational role of different technological modalities in the development of computational thinking in Early Childhood Education within a context of social vulnerability. By examining a multimodal intervention that integrated unplugged activities, mobile applications and robotics, the research provides empirical evidence that computational thinking can be effectively fostered in early childhood through pedagogically grounded and communicatively rich learning experiences, even in high-needs educational settings.

One of the main conclusions of the study is that computational thinking in early childhood should be understood as a pedagogical and communicative practice rather than as a purely technical skill. The learning gains observed were not limited to task performance, but were closely linked to children's ability to plan actions, anticipate outcomes, explain strategies and collaboratively solve problems. This reinforces sociocultural perspectives that emphasise the role of mediation, interaction and language in early learning processes.

The differentiated effects identified across technological modalities highlight the importance of intentional pedagogical design. Unplugged activities proved especially valuable for fostering verbalisation, decomposition and pattern recognition, providing a communicative foundation for subsequent symbolic work. Mobile applications supported algorithmic reasoning and modelling by externalising cognitive processes through visual-symbolic representations and immediate feedback. Robotics contributed most strongly to abstraction and evaluation by enabling children to connect symbolic instructions with embodied action

and reflective debugging. These findings underscore that no single modality is sufficient on its own; rather, their combined use enhances learning effectiveness and inclusivity.

From an educational perspective, the results suggest that multimodal technological mediation can function as an equity-oriented strategy in Early Childhood Education. In contexts serving vulnerable groups, where learners may present diverse linguistic, cognitive and socio-cultural profiles, multimodal interventions provide multiple entry points to understanding and participation. When technology is integrated with clear pedagogical intent, it can support more inclusive and meaningful learning opportunities.

The study also has implications for teacher education and educational policy. Teacher training programmes should move beyond a tool-centred approach to technology and instead emphasise the mediational role of different technological resources, focusing on how they shape interaction, communication and meaning-making. At the policy level, early childhood curricula should recognise computational thinking as a cross-cutting competence that can be developed through play-based, communicative and multimodal pedagogies, rather than through early formalisation of programming skills.

Despite its contributions, the study has several limitations. The small sample size and the absence of a control group limit the generalisability of the findings, and the short duration of the intervention does not allow conclusions regarding long-term effects. Future research could address these limitations by incorporating longitudinal designs, comparative groups and larger samples. Further studies could also explore the role of teacher mediation and examine how multimodal computational thinking interventions impact other developmental domains, such as language or socio-emotional skills.

In conclusion, this research contributes to the field of educational communication by demonstrating that multimodal technological mediation constitutes a meaningful and inclusive pathway for fostering computational thinking in Early Childhood Education. By foregrounding communication, mediation and pedagogical intentionality, this study shows that multimodal technological approaches offer a robust and equitable pathway for fostering computational thinking in early childhood education.

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