Robotics Intervention to Enhance Computational Thinking in Pre-Service Teacher Education

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Abstract

This study evaluates the impact of an educational robotics intervention on Computational Thinking (CT) development in pre-service Early Childhood Education teachers and its effect on disparities related to gender and family background. A quasi-experimental design with a control group was employed with 127 participants. The experimental group undertook a multi-session robotics program integrating theory and practice, while the control group received conventional instruction. Results indicate the intervention group achieved significantly higher and substantial gains across all five assessed CT dimensions: creativity, algorithmic thinking, cooperativity, critical thinking, and problem-solving. Importantly, a strong equalizing effect was observed. Performance gaps based on gender and the initial advantage for students with STEM-educated relatives, both present in the control group, were eliminated in the experimental cohort. These findings affirm educational robotics as a powerful pedagogical tool, effective both for building essential 21st-century competencies and for fostering greater equity in the foundational training of educators.

Keywords: *Computational thinking, Educational robotics, Teacher training, Early childhood education, STEM education, Gender gap, Equity in education.*

Introduction

The twenty-first century has ushered in a paradigm shift in the field of education, driven by globalization, digitalization, and the pressing need to equip new generations with the skills required to navigate an increasingly complex world. The integration of technology into teaching and learning environments has prompted profound transformations in the conceptualization of educational processes, positioning digital competence as a central pillar in the holistic development of students.

In the Spanish context, this emphasis is reflected in successive legislative reforms. The Organic Law of Education (LOE, 2006) introduced, for the first time, a competency-based curriculum, incorporating digital competence among the essential learning outcomes. Subsequently, the Organic Law for the Improvement of Educational Quality (LOMCE, 2013) expanded upon this framework, reinforcing the importance of cultivating transversal competencies related to technology and innovation. Most recently, the Organic Law amending the LOE (LOMLOE, 2020) explicitly introduced the concept of computational thinking, recognizing its critical role in the development of key twenty-first-century competencies. Despite its formal inclusion in policy, however, empirical research on computational thinking remains limited, and educational interventions continue to lack well-established methodological frameworks.

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Computational Thinking

The concept of computational thinking was initially introduced by Papert (1980), who, based on his research with young children, highlighted the significance of cognitive plasticity and childhood creativity as fundamental elements for problem-solving. From his perspective, teaching critical, structured, and sequential approaches from an early age would enable children to develop advanced programming skills compared to adults. In this way, Papert attributed considerable educational value to computational thinking, viewing it not merely as a technical competency but as a means to enhance logical reasoning, creativity, and problem-solving abilities.

Subsequently, Papert's vision was expanded and systematized by Wing (2006, 2008), who conferred a transversal character to computational thinking, defining it as a set of skills and a cognitive disposition applicable universally, beyond the field of computer science. Wing identified essential cognitive processes, such as abstraction, pattern recognition, problem decomposition, and algorithm design, emphasizing that programming constitutes a consequence of developing these capacities rather than an end in itself. This conceptualization allowed computational thinking to be regarded as a key competency in the holistic education of students, with potential applications across multiple domains of knowledge.

Since then, scientific production on computational thinking has experienced exponential growth. According to George-Reyes (2023), it has emerged as a prominent trend within educational research worldwide. Recent studies have highlighted the relationship between computational thinking and active learning methodologies, such as project-based learning, in which processes of planning, design, and execution enable students to effectively exercise the cognitive skills identified by Wing (Jeong, 2025; Zhang et al., 2024; Saad & Zainudin, 2024). Complementarily, innovative approaches such as unplugged computational thinking have been explored, which do not rely on technological devices and instead focus on analog and collaborative activities, fostering the development of cognitive skills in a tangible manner (Zapata-Ros, 2019; Moreno Palma et al., 2024).

Furthermore, research has examined the relationship between computational thinking and STEM disciplines, highlighting its value as a transversal competency that supports learning in mathematics, science, and engineering (Hsieh et al., 2021). Nevertheless, despite the diversification of approaches and methodologies, much of the literature continues to focus on programming and robotics as the predominant strategies for developing this competency (Valls Pou et al., 2022; Weng et al., 2022; Alalawi et al., 2025). This concentration underscores both the effectiveness of these tools and the need to continue exploring pedagogical alternatives that broaden the contexts for applying computational thinking, consolidating it as a transversal axis in contemporary education.

Educational Interventions with Robotics and Their Relationship to Computational Thinking

Within the range of educational tools, educational robotics has established itself as one of the most effective strategies for developing computational thinking. Its relevance extends beyond the technological dimension, functioning as an integrated pedagogical medium that promotes active learning, problem-solving, creativity, critical thinking, and peer collaboration. The interdisciplinary nature of robotics allows for the integration of knowledge from mathematics, science, technology, and engineering, in line with the principles of the STEM approach (Angeli et al., 2023; Gerosa et al., 2022), positioning it as a resource capable of connecting abstract concepts with practical and contextualized experiences.

Empirical evidence consistently supports its educational potential. At early educational levels, such as preschool and primary education, several studies including those by Caballero-González and García-Valcárcel (2021), Angeli et al. (2023), and Gerosa et al. (2022) document significant improvements in student motivation, mathematics performance, logical problem-solving skills, and cognitive autonomy. Active participation in the construction and programming of robots enables students to concretely experience abstract concepts, plan sequences of actions, anticipate consequences, and critically reflect on errors, thereby fostering meaningful, deep learning that is transferable to other academic contexts and everyday life.

At a broader level, recent meta-analyses confirm the effectiveness of educational robotics as a tool for enhancing both cognitive and socio-emotional competencies. Alonso-García et al. (2024) highlight positive outcomes in the majority of the studies reviewed; however, they also note methodological limitations, heterogeneity in research designs, and the lack of unified evaluation criteria, which complicates comparisons across studies and the replication of interventions in different educational contexts. This scenario underscores the need to establish a robust conceptual and methodological framework that allows for the systematization of results, the standardization of achievement indicators, and the optimization of educational robotics implementation across diverse curricular settings.

A persistent challenge in adopting educational robotics is the insufficient training of teachers. Many educators lack specific knowledge of computational thinking and are unfamiliar with effective pedagogical strategies to integrate robotics into the classroom, thus limiting the potential of these tools to generate meaningful learning experiences (Ortuño Meseguer & Serrano, 2024). Overcoming this barrier requires educational policies focused on continuous professional development, the provision of appropriate teaching resources, and guidance in implementing interdisciplinary projects, so that educational robotics can be consolidated as a comprehensive formative resource that integrates cognitive, creative, and collaborative skills within the framework of contemporary STEM education.

Inequalities In Stem Education

One of the most relevant factors in the study of computational thinking is the existence of inequalities in access to and participation in STEM disciplines. The scientific literature has repeatedly documented the persistence of a gender gap, characterized by higher representation and performance of men in these fields, compared to the relatively lower participation of women (Txabarri & Villamor, 2014; Gallego et al., 2024; Álvarez Arregui et al., 2023). This phenomenon demonstrates that, despite advances in equity policies and inclusion programs, gender inequalities continue to shape educational and professional trajectories in technological and scientific disciplines.

The explanation for this gap is multifactorial, involving social, cultural, and educational factors. Among these, the scarcity of female role models in STEM stands out. Although the majority of teachers in early childhood and primary education are female, as students progress to higher educational stages such as secondary and upper-secondary education, the proportion of women decreases significantly in areas such as mathematics, technology, and engineering, while it remains relatively balanced in biology (Font et al., 2023; Mas García et al., 2024). This reduction in female models within technical and scientific disciplines contributes to the difficulty female students, particularly girls, face in identifying role models with whom to project their academic and professional aspirations, thereby limiting their engagement and motivation in these areas.

Furthermore, school curricula and teaching materials have been shown to reproduce gender stereotypes, assigning differentiated roles or reinforcing the notion that certain skills are "for

boys" or "for girls." This curricular bias perpetuates inequalities in the acquisition of digital and computational competencies, affecting both the development of technical skills and female students' perceptions of self-efficacy (Lledó et al., 2024; Franco-Llanos et al., 2025). Nonetheless, recent studies indicate that women may exhibit specific strengths in key dimensions of computational thinking, such as creativity, analytical capacity, and collaborative problem-solving (De-Vicente-Yagüe-Jara et al., 2023), underscoring the importance of inclusive pedagogical strategies that recognize and foster these abilities.

Beyond gender, the family environment is a determining factor in the development of computational thinking. Research indicates that students with family members educated in STEM fields tend to exhibit higher performance and greater predisposition toward these disciplines, highlighting the importance of family cultural capital and the influence of educational agents outside the classroom (Hsieh et al., 2021). This relationship suggests that the promotion of computational and technological competencies cannot be limited solely to school-based strategies; rather, it requires comprehensive interventions that actively involve families and the broader educational community in the creation of an inclusive and equitable learning ecosystem.

1.1. ROBOTICS EDUCATION AS A STRATEGY TO REDUCE THE STEM GAP

In this context, initial teacher training emerges as a strategic and crucial element for overcoming inequalities in the development of computational thinking and access to STEM disciplines. However, recent literature indicates that teacher education programs exhibit significant shortcomings in systematically incorporating this competency, as there is still no standardized methodological framework to integrate it coherently and progressively into curricula (Ortuño Meseguer & Serrano, 2024). This limitation restricts the capacity of future educators to design learning experiences that foster computational skills in an inclusive and equitable manner.

Within this framework, it is particularly relevant to revisit the comprehensive approach proposed by Wing (2006), which conceptualizes computational thinking as a transversal competency applicable beyond programming. This multidimensional perspective provides a conceptual framework for the design, implementation, and assessment of educational experiences, promoting the development of cognitive, creative, and collaborative skills. In line with this, Korkmaz et al. (2017) identify five key dimensions of computational thinking: creativity, algorithmic thinking, cooperativity, critical thinking, and problem-solving. These dimensions not only allow for the structured and progressive organization of learning but also offer clear criteria for evaluating the development of computational competencies across different educational stages.

In this regard, educational robotics emerges as a privileged tool for teacher training. Its implementation enables future educators to experiment with active methodologies, support interdisciplinary learning, and simultaneously contribute to reducing gender gaps and socio-familial inequalities. Robotics provides an inclusive learning environment that allows pre-service teachers to act as positive role models for their students and promote balanced and equitable access to STEM knowledge (Caballero-González & García-Valcárcel, 2021; Angeli et al., 2023; Alonso-García et al., 2024). Furthermore, working with robotics enables the practical integration of computational thinking dimensions, fostering skills in planning, analysis, cooperation, and problem-solving that teachers can subsequently transfer to their own classrooms.

Objetives

General Objective: To evaluate the impact of an educational robotics intervention on the development of computational thinking in pre-service Early Childhood Education teachers, analyzing its effectiveness in enhancing cognitive competencies and reducing inequalities linked to gender and family educational background in STEM.

Specific Objective 1: To determine the effect of robotics-based intervention on the development of the five dimensions of computational thinking (creativity, algorithmic thinking, cooperativity, critical thinking, and problem-solving) among pre-service teachers.

Specific Objective 2: To compare the performance of students in experimental and control groups in order to assess the effectiveness of structured robotics-based activities versus traditional instruction.

Specific Objective 3: To analyze whether the intervention reduces gender differences in computational thinking skills traditionally observed in STEM education.

Specific objective 4: To explore the potential of educational robotics as an inclusive pedagogical tool that not only strengthens cognitive skills but also promotes equity in access to STEM-related competencies during initial teacher training.

Material and Methods

In line with the objectives and developmental framework, an intervention was designed accordingly. The present study is structured around a quasi-experimental design with a control group and post-test only, following classical and well-established methodological proposals from recognized authors in educational and experimental research, such as Campbell and Stanley (1963), Cook and Campbell (1979), Shadish et al. (2002), and Hernández Sampieri et al. (2014). This type of design is particularly suitable for contexts in which full experimental manipulation is not feasible due to ethical, logistical, or practical constraints, as occurs in real educational settings where external variables cannot be fully controlled or manipulated.

In this regard, the choice of a quasi-experimental design with a control group and post-test responds to the need to maximize internal validity within a naturalistic and complex context, characteristic of early childhood education. The adopted methodology acknowledges the presence of multiple external variables, such as individual differences among students, variations in group dynamics, or environmental factors, which impede the execution of a classical experiment with random assignment. Therefore, the aim of the research is not to establish definitive causal relationships, but rather to generate initial and preliminary evidence to guide future studies and enhance understanding of the integration of technological tools specifically educational robotics into teaching and learning processes.

Moreover, the quasi-experimental approach is justified by the fact that the study is conducted in a real academic setting, where methodological flexibility and adaptability are crucial to ensure the feasibility of the research. The objective is thus to evaluate the effectiveness and potential effects of the technological intervention on the development of computational thinking in early childhood students through a structured intervention, while also identifying challenges, limitations, and relevant contextual factors for its practical application.

Sample

The sample was selected through non-probabilistic convenience sampling, primarily determined by the availability of groups and the feasibility of coordinating the allocation of class hours for the implementation of the intervention sessions. This approach aligns with the practical and contextualized nature of the study, which requires the active collaboration and commitment of participating teachers to integrate the intervention into the regular curriculum. Accordingly, two

afternoon groups from the course Applied Didactic-Technological Resources in Early Childhood Education at the University of Granada were chosen, and the experimental group (N = 63) and control group (N = 64) were randomly assigned.

Although the intervention is described in greater detail later, it is necessary to note that it was conducted over the course of one month, covering content relevant to the course and consistent with the syllabus guidelines. For the control group, no modifications were made to regular classes; however, during that month, two syllabus topics closely related to the present study specifically, educational robotics, maker spaces, and fablabs were covered. Therefore, this can be considered a passive intervention for the control group.

Although convenience sampling limits the generalizability of the results, it is appropriate in this case, as the selected groups meet the established inclusion criteria: first-year students of the Early Childhood Education degree, aged between 18 and 25, with access to the technological resources required for the intervention. Additionally, groups were prioritized to ensure similar characteristics in terms of size, composition, and academic performance level, in order to minimize differences between the experimental and control groups.

It is also considered essential that participating teachers are informed and committed to the process, as their collaboration facilitates session logistics, student monitoring, and the management of unforeseen events and necessary adaptations during the intervention. This approach aims to ensure the highest possible fidelity to the original plan and to obtain reliable data for subsequent analysis.

Intervention Design

- ### *Initial Sessions: Theoretical and Reflective Block (Sessions 1–2)*

These initial sessions are primarily theoretical and reflective in nature. The objective is to establish a solid conceptual foundation regarding computational thinking and educational robotics, contextualizing both within the framework of Early Childhood Education. Emphasis will be placed on the importance of computational thinking not merely as a technical skill, but as a set of cognitive and metacognitive competencies essential for complex problem-solving, decision-making, and the development of critical thinking.

The methodology in these sessions will be active and participatory, combining brief lectures with dynamics designed to activate prior knowledge, analyze practical cases, and foster collective reflection. Innovative robotic devices, such as Sphero Mini and Ozobot, will also be introduced, highlighting their features and educational applications while stimulating student curiosity and interest.

- ### *Second Block: Practical Sessions (Sessions 3–6)*

In this phase, students will engage directly with educational robots, exploring their functionalities and pedagogical applications. A progressive methodology will be applied, beginning with open-ended exploratory activities to familiarize students with the devices, followed by more structured tasks involving basic programming, problem-solving, and peer collaboration.

The methodological approach is based on challenge-based learning, promoting creativity, computational thinking, and teamwork. The challenges are designed to be motivating and aligned with transversal competencies, facilitating meaningful learning and the transfer of knowledge.

- ### *Third Block: Didactic Transfer Sessions (Sessions 7–8)*

The final block focuses on the practical and didactic application of acquired knowledge. Students will design educational proposals integrating robotics into real Early Childhood Education contexts, adapting them to the specific characteristics, interests, and needs of children aged three to five.

These proposals will be shared and discussed in a collective reflection space, where their feasibility, curricular coherence, and potential pedagogical impact will be analyzed. Group discussion will foster constructive criticism and continuous improvement of the proposals, while reinforcing self-assessment skills and consolidating learning.

It is important to note that no pre-test measurement was conducted in this phase. This decision is based on the identification of external factors that could compromise the validity of initial results, such as irregular attendance, differences in time commitment, and overlap with periods of curricular practicum. The focus is thus placed on the quality and reliability of post-intervention data, avoiding potential biases.

Results

The results of the investigation, derived from a rigorous quasi-experimental framework that included a control group and a post-test measurement protocol, provide robust empirical evidence for the positive impact of an educational robotics intervention on fostering computational thinking (CT) competencies in pre-service Early Childhood Education teachers. The analytical approach was carefully tailored to the specific characteristics of the dataset: non-parametric statistical methods, specifically the Mann-Whitney U test, were employed. This methodological choice was necessitated by the ordinal nature of the measurement scales used and the violation of parametric assumptions, such as normality, observed within several of the data distributions. This ensures the validity and reliability of the inferential conclusions drawn from the analysis.

Table 1. Descriptive analysis

Dimension	Group	N	Mean	SD	Skewness	Kurtosis
Creativity	Experimental	63	4,50	,186	,116	-,839
	Control	64	3,03	,252	,126	,480
Algorithmic Thinking	Experimental	63	4,53	,230	,-393	-,29
	Control	64	3,03	,297	,-226	,525
Cooperativity	Experimental	63	4,42	,265	,-415	-,341
	Control	64	3,01	,289	,385	,107
Critical Thinking	Experimental	63	4,50	,221	,127	-,465
	Control	64	2,99	,328	,229	-,133
Problem Solving	Experimental	63	4,48	,212	,20	-,712
	Control	64	3,00	,299	,-265	,150

As presented in Table 1, a comparative analysis of the mean scores reveals that participants in the experimental group consistently and substantially outperformed those in the control group across all five dimensions of computational thinking that were assessed: creativity, algorithmic thinking, cooperativity, critical thinking, and problem-solving. The magnitude of the differences between the two groups was found to be statistically significant in every single dimension, with a high level of confidence ($p < 0.001$). This robust statistical significance, confirmed by the Mann-Whitney U test results detailed in Table 2, strongly indicates that the observed superior performance of the experimental group is attributable to the educational robotics intervention rather than to chance variation.

Table 2. Correlational Mann-Whitney's U

	Creativity	Algorithmic Thinking	Cooperativity	Critical Thinking	Problem Solving
U de Mann-Whitney	,000	,000	1,000	,000	,000
Z	-9,767	-9,778	-9,825	-9,785	-9,771
Sig. asin. (bilateral)	<,001	<,001	<,001	<,001	<,001
a. Correlation control/experimental					

To move beyond the assessment of mere statistical significance and to more precisely quantify the magnitude and practical relevance of the observed intergroup differences, robust non-parametric effect size measures were calculated. Specifically, both Cliff's Delta (δ) and the Vargha and Delaney's A coefficient (VDA) were employed. The resulting values, comprehensively detailed in Table 3, indicate a substantial and consistent effect. The Cliff's Delta value was δ = 0.938, which corresponds to a "very large" effect size according to established benchmarks. Further reinforcing this finding, the VDA coefficient yielded a value of 0.969.

This VDA statistic can be directly interpreted as a probability: it signifies that there is a 96.9% probability that a randomly selected participant from the experimental (intervention) group will achieve a higher score than a randomly selected participant from the control group on the computational thinking measures. This exceptionally high probability, paired with the large Delta value, not only confirms the statistical reliability of the findings but also powerfully underscores the marked and educationally meaningful superiority of the educational robotics intervention in fostering the development of computational thinking competencies among the future educators.

Table 3. Non-parametric Effect Size Statistics for Computational Thinking Dimensions

Dimension	Cliff's Delta (δ)	VDA (A)	Interpretation
Creativity	938	969	Very Large
Algorithmic Thinking	938	969	Very Large
Cooperativity	938	969	Very Large
Critical Thinking	938	969	Very Large
Problem Solving	938	969	Very Large

Upon conducting a thorough analysis of group composition, significant gender differences were identified within the control group on the problem-solving dimension of the computational thinking assessment. Statistical analysis revealed a performance differential that reached the level of significance (p = 0.029), with results indicating an advantage in favor of male students over their female counterparts under the traditional, non-intervention instructional conditions.

In striking contrast, this pattern was not observed within the experimental group following the educational robotics intervention. A detailed analysis of performance data by gender, as presented in Table 4, found no statistically significant differences on the problem-solving dimension or on any other assessed dimension of computational thinking (p > 0.05 in all cases). The convergence of male and female students' performance levels in the experimental condition suggests that the pedagogical framework and hands-on, collaborative activities inherent in the robotics-based intervention exerted an equalizing effect. This outcome indicates that the structured intervention successfully neutralized the gender-based performance gap that was

evident under conventional teaching methodologies, thereby fostering a more equitable learning environment that enabled all participants to achieve comparable levels of competency.

Table 4. Correlational Mann-Whitney's U

Group		Creativity	Algorithmic Thinking	Cooperativity	Critical Thinking	Problem Solving
Experi mental	U de Mann-Whitney	297,500	372,000	379,500	354,000	253,500
	W de Wilcoxon	450,500	525,000	532,500	1435,000	1334,500
	Z	-1,479	-,303	-,188	-,594	-2,185
	Sig. asin. (bilateral)	,139	,762	,851	,553	,029
Contro l	U de Mann-Whitney	465,000	393,500	413,500	437,500	360,500
	W de Wilcoxon	741,000	1254,500	1274,500	1298,500	636,500
	Z	-,093	-1,112	-,843	-,485	-1,578
	Sig. asin. (bilateral)	,926	,266	,399	,628	,115

a. **Grouping Variable: Sex**

In the control group, students with relatives in STEM fields showed significantly superior performance in critical thinking ($p = 0.016$). In contrast, this initial advantage did not persist in the experimental group, with no significant differences associated with family cultural capital found in any dimension of computational thinking ($p > 0.05$, Table 5). This result indicates that the pedagogical intervention acted as a compensatory factor for inequalities associated with socio-familial background.

Table 5. Correlational Mann-Whitney's U

Grupo		Creativity	Algorithmic Thinking	Cooperativity	Critical Thinking	Problem Solving
Experim ental	U de Mann-Whitney	476,500	443,500	449,000	474,500	475,000
	W de Wilcoxon	1004,500	971,500	945,000	970,500	1003,000
	Z	-,274	-,743	-,683	-,306	-,296
	Sig. asin. (bilateral)	,784	,458	,495	,759	,767
Control	U de Mann-Whitney	437,500	421,000	484,500	335,000	498,500
	W de Wilcoxon	1032,500	886,000	1079,500	930,000	1093,500
	Z	-,993	-1,221	-,356	-2,398	-,157
	Sig. asin. (bilateral)	,321	,222	,722	,016	,875

a. Grouping variable: Relatives in STEM

Discussion

The findings of the present study indicate that the implementation of a structured intervention based on educational robotics in the context of initial teacher training produces a significant and multifaceted impact. The results not only confirm substantial improvement in the overall development of computational thinking (CT) among participating students but also reveal the potential of this pedagogical tool to mitigate preexisting disparities associated with gender and family cultural capital in STEM domains.

Firstly, the generalized improvement observed across the dimensions of computational thinking creativity, algorithmic thinking, cooperativity, critical thinking, and problem-solving among the experimental group participants corroborates and extends the existing empirical evidence. This convergence with the literature is observed across various educational stages. In Early Childhood and Primary Education, seminal studies such as those by Caballero-González and García-Valcárcel (2021), Angeli and Georgiou (2023), and Gerosa et al. (2022) document how tangible

interaction with programmable robots catalyzes the development of sequential logic and problem-solving skills in a playful and concrete manner. Similarly, in Secondary Education, research by Díaz-Lauzurica and Moreno-Salinas (2019) and Martín et al. (2024) demonstrates its efficacy in addressing abstract concepts through practical applications. The primary contribution of the present study lies in extrapolating these benefits to the context of initial university-level teacher training a strategic cohort whose preparation presents notable curricular deficiencies in this competency, as highlighted by Ortuño Meseguer and Serrano (2024). Our data reinforce the pressing need, also indicated by emerging research (Yang, 2025; Putra et al., 2025; Sala-Sebastià et al., 2025), to institutionalize CT within teacher education curricula, thereby equipping future educators with the competencies required to transfer these skills to their own classrooms.

Regarding the gender variable, the results are particularly revealing and carry profound socio-educational implications. This study confirms that, in the control condition, the historically documented pattern is replicated (Txabarri & Villamor, 2014; Gallego et al., 2024; Álvarez Arregui et al., 2023), where male students exhibit significantly higher performance in certain dimensions of CT, particularly problem-solving. This finding aligns with the perpetuation of gender stereotypes and the lack of female role models in technical fields. However, the educational intervention using robotics demonstrated remarkable efficacy as an equity strategy, completely eliminating this gap in the experimental group and equalizing performance between genders at a level of excellence. This equalizing effect suggests that the collaborative, playful, and demystifying nature of robotics activities can neutralize self-imposed biases and attitudinal barriers that traditionally limit women's participation and self-efficacy in STEM. The significance of this outcome extends beyond immediate academic performance: by empowering future teachers and providing them with robust digital and computational competencies, they become crucial agents of change. Their role as classroom role models in Early Childhood Education can be decisive in inspiring STEM aspirations among girls, thereby helping to disrupt the cycle of female underrepresentation in these fields (Font et al., 2023; Mas García et al., 2024). Finally, the analysis of family cultural capital sheds light on another vector of inequality. The data confirm the role of the family environment, previously established by Hsieh et al. (2021), as a predictor of critical thinking development within CT in the control group. Students with parents or guardians educated in STEM disciplines began with a discernible advantage. However, the intervention acted as a powerful pedagogical equalizer, to the extent that this initial advantage was completely neutralized in the experimental group. This finding carries substantial social relevance, as it indicates that formal education, when structured through robust and inclusive instructional designs, can at least partially compensate for disadvantages associated with students' socioeconomic and cultural backgrounds. In a socio-labor landscape where STEM competencies are directly correlated with access to high-skilled and better-paid employment, educational robotics emerges not merely as a teaching resource but as a potential educational policy tool aimed at promoting social mobility and ensuring genuine equality of opportunity.

Conclusions

The implementation of a structured intervention based on educational robotics proved to be a highly effective pedagogical strategy for the comprehensive development of computational thinking in pre-service teachers. The experimental group demonstrated significant improvements across all assessed dimensions creativity, algorithmic thinking, cooperativity, critical thinking, and problem-solving validating robotics as a privileged resource for acquiring essential 21st-century cognitive competencies. This finding highlights the need to address curricular

deficiencies identified in teacher training and to systematically and obligatorily integrate such practical experiences into degree programs.

This study provides evidence of the potential of educational robotics to act as an equalizer of the gender gaps traditionally present in STEM disciplines. The intervention eliminated the performance disparity observed in the control group, where male students demonstrated a significant advantage in problem-solving, thus equalizing achievement between genders in the experimental group. Therefore, it can be concluded that robotics, when framed within active and collaborative pedagogy, not only develops technical competencies but also contributes to deconstructing gender stereotypes, empowering future teachers, and generating positive role models that can inspire STEM aspirations among girls.

The results confirm that family cultural capital significantly influences the initial development of computational critical thinking, as observed in the control group. However, the robotics-based intervention was able to compensate for these initial advantages, reducing differences associated with students' socio-familial backgrounds in the experimental group. This suggests that a well-designed educational intervention can function as a mechanism for inclusion and social mobility, mitigating starting disadvantages and promoting equity in the acquisition of key competencies for future professional practice.

Overall, the conclusions extend beyond the experimental context and point to broader implications. Training in educational robotics for Early Childhood Education teachers is not merely a technical or technological matter but a key strategy for educational justice. Equipping future teachers with these competencies involves forming change agents capable of fostering inclusive and equitable computational thinking from the earliest years of schooling, helping to break persistent cycles of inequality and preparing all students, regardless of gender or socio-familial context, to meet the challenges of a digital world.

Limitations and Future Directions

Despite its contributions, this study presents limitations that must be acknowledged. First, the quasi-experimental design with convenience sampling and the absence of a pre-test limit the generalizability of the results and the unequivocal attribution of causality. Future research should employ more robust experimental designs, including random assignment and pre- and post-test measurements. Second, although the intervention was structured, it was implemented within a specific institutional context; therefore, it is recommended to replicate the study in other universities and cultural settings to validate the findings.

Future research could proceed in several directions: (a) conducting longitudinal studies to evaluate the persistence of benefits in the medium and long term; (b) investigating the impact that trained teachers have in their Early Childhood classrooms and on their students' development of computational thinking; (c) analyzing the specific components of the intervention (duration, type of robots, instructional methodology) that are most critical in achieving the observed equity effects; and (d) exploring the combination of robotics with complementary approaches, such as "unplugged computational thinking," to develop even more inclusive and accessible pedagogical frameworks.

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