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Author for correspondence:
Rita Neves Rodrigues
ritanevesrodrigues@hotmail.com
Polytechnic University of Coimbra, Coimbra, Portugal; University of Trás-os-Montes and Alto Douro, Vila Real, Portugal; Research Center for Didactics and Technology in Trainer Training (CIDTFF), University of Aveiro, Aveiro, Portugal

Impact of a Training Program on Developing Computational Thinking in Pre-Service Primary School Teachers: From Theory to Practice

Rita Neves Rodrigues, Cecília Costa, Sónia Brito-Costa, Maryam Abbasi, Fernando Martins

Abstract

Background/purpose. The Computational Thinking ability has become a fundamental skill in the 21st century and has been integrated into educational curricula in various countries. For this curricular integration to be effective, it is essential that teachers are prepared to incorporate the development of this competency into their practices. In this context, this study aims to analyze whether a training program implemented over an extended period, encompassing theoretical, practical, and reflective components, has influenced pre-service teachers' perceptions of the competencies of Creativity, Algorithmic Thinking, Cooperativity, Critical Thinking, and Problem-Solving within Computational Thinking.

Materials/methods. This is a mixed-methods study, using both quantitative and qualitative methods to analyze the perception of the Computational Thinking competence levels of 38 pre-service primary school teachers, who constitute the sample of this study, before and after the implementation of a 9-month training program.

Results. The study results revealed statistically significant differences in all the competencies analyzed from the Pre-Intervention to the Post-Intervention phases. The data collected during the intervention highlight the specific moments within the training program that contributed to the development of each competency.

Conclusion. It is concluded that the training program significantly contributed to changing the pre-service teachers' perceptions of the five Computational Thinking competencies analyzed. This highlights the importance of incorporating training programs into Initial Teacher Training, especially those that integrate theory and practice, fostering the development of essential competencies for the teaching practices of pre-service teachers.

1. Introduction

Computational Thinking has become a fundamental competency in the 21st century, crucial for problem-solving processes across various domains beyond computer science. Originally introduced by Seymour Papert in 1980 and later expanded by Jeannette Wing in 2006, Computational Thinking is defined as the ability to solve complex problems in a methodical and structured manner. Korkmaz et al. (2017) state that the development of Computational Thinking simultaneously involves the development of five key competencies: Creativity, Algorithmic Thinking, Cooperativity, Critical Thinking, and Problem-Solving.

The importance of Computational Thinking has gained increasing recognition in specialized literature, with a significant rise in studies on the topic (Angeli et al., 2016; Peracaula-Bosch et al., 2020). Simultaneously, many countries have integrated the development of this competency into their curricula from the early years of primary education (Macann & Carvalho, 2021; Nordby et al., 2022; Pewkam & Chamrat, 2022).

However, for this curricular integration to be effective, it is essential that teachers are prepared to incorporate the development of this competency into their practices (Kong et al., 2020). Several studies emphasize the need to provide pre-service teachers with the appropriate tools and knowledge to integrate Computational Thinking into their pedagogical practices (Butler & Leahy, 2021; Sun et al., 2023). Nonetheless, the literature highlights a significant gap: inadequate training for pre-service teachers, which leaves them ill-equipped to effectively integrate this competency into their teaching (Angeli & Giannakos, 2019; Haşlaman et al., 2024; Pewkam & Chamrat, 2022).

In this context, a training program was created to develop the pedagogical knowledge of pre-service teachers. The program aimed to help them become proficient in selecting, adapting, and implementing tasks that integrate the development of Computational Thinking dimensions into their teaching practices. Additionally, it sought to promote the learning of mathematical knowledge simultaneously. To assess the development of Computational Thinking in pre-service teachers, it is essential to examine their perception of the five competencies identified by Korkmaz et al. (2017). Accordingly, this study seeks to address the following research question: Did the implemented training program impact pre-service teachers' perception of the five Computational Thinking competencies under analysis?

This study contributes to the body of research on integrating Computational Thinking into Initial Teacher Training by offering valuable insights into the critical features of the implemented training program that successfully influenced pre-service teachers' perceptions of their Computational Thinking competencies.

2. Theoretical Background

2.1. Computational Thinking Competencies

The literature offers varying perspectives on defining Computational Thinking, especially concerning the dimensions that constitute this competency (Angeli, 2022; Grover & Pea, 2013). The dimensions most frequently linked to Computational Thinking include abstraction, generalization, decomposition, algorithmic thinking, and debugging (Grover & Pea, 2013; Voon et al., 2022). In Portugal, the curriculum document for mathematics in Basic Education aligns with dimensions frequently highlighted in the literature. This document defines Computational Thinking as a competency comprising five dimensions: abstraction, decomposition, pattern recognition, algorithmic thinking, and debugging (Ministério da Educação (ME), 2021). In addition to these dimensions, Korkmaz et al. (2017) assert that analyzing the development of Computational Thinking requires evaluating the five competencies linked to it, which are described below:

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- Creativity plays an important role in problem-solving and the development of innovative ideas (Israel-Fishelson & Hershkovitz, 2022), allowing for the formulation of different solutions and providing alternative perspectives on the problems and situations faced in daily life (Korkmaz et al., 2017). Within the scope of Computational Thinking, Creativity can be observed in the ability to formulate various strategies for solving a problem (Doleck et al., 2017; Liu et al., 2023). Implementing tasks that encourage the development of Computational Thinking in the classroom can simultaneously foster Creativity, allowing students to explore innovative approaches and diverse problem-solving strategies (Yadav et al., 2014).

- Algorithmic Thinking is the ability to identify and represent sequences to solve a problem or task, determining step-by-step instructions (Ching & Hsu, 2024; Martínez et al., 2022). Developing Algorithmic Thinking enables individuals to reflect deeply on the steps required to solve a problem, making it a crucial component of Computational Thinking (Korkmaz et al., 2017). Kiss and Arki (2017) observed that traditional teaching methods were inadequate for promoting the development of Algorithmic Thinking, and that tasks specifically designed to develop this competency must be implemented.

- Cooperativity, or cooperative learning, is an approach that aims to enhance learning through small group work (Korkmaz et al., 2017). This approach encourages students to assist one another, oversee each other's work, and engage in discussions to defend their opinions, fostering deep and meaningful learning (Zhou & Tsai, 2023). Cooperative learning also helps develop interpersonal skills such as communication, empathy, and teamwork, which are essential in real-world problem-solving contexts (Doleck et al., 2017; Gasaymeh & AlMohtadi, 2024). In this sense, as highlighted by Korkmaz et al. (2017), the competency of Cooperativity is considered crucial for the development of Computational Thinking.

- Critical Thinking is an essential problem-solving competency, requiring deep analysis and evaluation of information (Jiang & Li, 2021; Wu, Silitonga, et al., 2024). It involves questioning information, identifying inconsistencies, and formulating effective questions to explore alternative solutions and generate new knowledge (Doleck et al. ,2017). Recognizing the shared elements between Computational Thinking and Critical Thinking, studies have shown that interventions aimed at developing Computational Thinking also inherently promote the growth of Critical Thinking (Jiang & Li, 2021; Korkmaz et al., 2017). Developing this competency is crucial for students to become analytical, critical, and aware of their own ideas as well as those of others (Korkmaz et al., 2017).

- Problem-solving is the process of finding solutions to something, whether a task, a challenge, or a specific everyday situation (Jiang & Li, 2021; Wu, Asmara, et al., 2024). Logical and structured problem-solving is regarded as a key competency developed through Computational Thinking (Korkmaz et al., 2017; Wing, 2006).

2.2. Computational Thinking in Initial Teacher Training

Several implementations have been developed to integrate the development of Computational Thinking into Initial Teacher Education, often taking the form of short-term training sessions or workshops (Drot-Delange et al., 2021; Molina-Ayuso et al., 2022; Pewkam & Chamrat, 2022; Sáez-López et al., 2020). This type of training appears misaligned with the specialized literature, which emphasizes that effective professional development should be long-term and incorporate theoretical, practical, and reflective components (Rodrigues, Costa, et al., 2024; Zha et al., 2020).

The literature highlights the importance of the practical aspect in teacher training, as it is essential for pre-service teachers to understand the theoretical concepts of Computational Thinking. However, it is equally important for them to know how to integrate the development of this competency into their teaching practice (Butler & Leahy, 2021; Dong et al., 2024). Interventions

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where pre-service teachers design and implement lesson plans, even with peers acting as students, have proven effective in encouraging collaboration, sharing learning experiences, and reflecting on their proposals (Doleck et al., 2017; Pewkam & Chamrat, 2022).

In this regard, Knie et al. (2022) recommend that training programs aimed at empowering teachers in Computational Thinking should align closely with the teaching practices of their educational level. Similarly, Tankiz and Atman Uslu (2022), in a study analyzing pre-service teachers' Computational Thinking skills and self-efficacy to integrate it into their practices, conclude that lesson planning tasks to promote Computational Thinking should be included in teacher training. The authors further suggest analyzing the lesson plans developed by pre-service teachers during training, as these plans represent a significant challenge for teachers in training.

More specifically, regarding lesson plan development, Drot-Delange et al. (2021) observed that pre-service teachers often struggle with selecting appropriate pedagogical methods and anticipating potential challenges students might face, frequently without reflecting on these decisions. Therefore, training for pre-service teachers should actively involve them in their learning, engaging them in practical tasks, discussions, and peer collaboration to promote reflection on teaching and learning (Kong et al., 2020).

Building on the literature, this study evaluates whether a long-term training program that integrates theoretical, practical, and reflective components, influenced pre-service teachers' perceptions of key Computational Thinking competencies: Creativity, Algorithmic Thinking, Cooperativity, Critical Thinking, and Problem-Solving.

3. Material and Methods

3.1. Study Design

This mixed-methods study (Cohen et al., 2018), combines quantitative and qualitative approaches to assess pre-service teachers' perceptions of their Computational Thinking competency levels. An experimental group of 38 participants was used, and the sample was not random. As detailed in the participants subsection, participants were selected using a convenience sampling approach, consisting of pre-service teachers enrolled in curricular units relevant to this study. Data collection involved administering a questionnaire, capturing photographic and audio recordings during practical sessions (transcribed into dialogues), and analyzing documents produced by participants, including problem-solving solutions, lesson plans, and critical reflections.

3.2. Participants

The sample of this study consisted of 38 participants from a university in mainland Portugal, who participated in the study during the 2023/2024 academic year. The average age of the participants was 23.55 years (SD = 6.785), ranging from 20 to 54 years. Regarding gender, 37 participants identified as female and 1 as male. It is important to note that 19 of the participants were enrolled in the Master's degree in "Preschool Education and Primary School Teaching", 12 participants were enrolled in the Master's degree program in "Primary School Teaching and 2nd Grade School Teaching in Mathematics and Experimental Sciences" and, lastly, 7 participants were enrolled in the Master's degree in "Primary School Teaching and 2nd Grade School Teaching in Portuguese and History and Geography of Portugal". Participants were grouped into pairs or trios during the training program, reflecting the existing group structures defined for the curricular internships required by their master's programs. This structure allowed for the creation of proposals tailored to the context of each internship group.

3.3. Data Collection

The Computational Thinking questionnaire (Korkmaz et al., 2017) in its Portuguese version (Rodrigues, Brito-Costa, et al., 2024) was used in both Pre- and Post-Intervention phases to evaluate pre-service teachers' perceptions of their Computational Thinking competency levels. This questionnaire is divided into 29 items that evaluate five dimensions: Creativity, Algorithmic Thinking, Cooperativity, Critical Thinking, and Problem-Solving, rated on a five-point Likert scale (1 = never, 2 = rarely, 3 = sometimes, 4 = generally, and 5 = always).

To facilitate analysis, responses to negatively worded items in the Problem-Solving dimension (e.g., item Q24: 'I have problems in the demonstration of the solution of a problem in my mind.') were reversed during statistical processing. Thus, the responses were adjusted so that higher values in this dimension reflected higher levels of perceived competence, aligning with the logic of the other dimensions. For example, a response of "1" (never) to an item in this dimension was reversed to "5" (always), a response of "2" (rarely) was reversed to "4" (generally), and so on. This procedure ensures consistency in interpreting the overall results, where higher values in all dimensions indicate more positive perceptions.

Participants completed the questionnaire individually and online through a Google Forms link. In the Pre- and Post-Intervention phases, a sequence of ten tasks (divided into two parts) was administered, aiming to analyze the pre-service teachers' knowledge regarding the dimensions of Computational Thinking and their Didactic Knowledge in Mathematics (Ponte, 2012). Each task was associated with one or more of these dimensions. Part 1 primarily aimed to analyze the dimensions of Computational Thinking, with a special focus on the dimension of Mathematical Knowledge. In this part, the starting point was problem-solving situations that would promote the development of Computational Thinking. Part 2 aimed to analyze the Teacher's Didactic Knowledge in Mathematics, with a primary focus on the dimensions of Knowledge of Students and Learning, Knowledge of the Curriculum, and Knowledge of Teaching Practice. The sequence of tasks was developed by the research team that designed the training program, ensuring consistency and alignment with the tasks implemented throughout the intervention phases. During the intervention (Phases 1 and 2), data collection included audio and video recordings, photographs, and written outputs by pre-service teachers, such as solutions from each session, group projects, and critical reflections.

3.4. Ethical Statement

This study adhered strictly to the ethical principles outlined in the Declaration of Helsinki, prioritizing the protection of participants' rights and well-being. The prior approval was obtained from the Ethics Committee of the Polytechnic University of Coimbra (reference 101_CEIPC/2022, approved on 24 June 2022), ensuring that all procedures complied with ethical regulations. Participants provided informed consent after being fully briefed on the study's purpose, the voluntary nature of their participation, and their right to withdraw at any time without repercussions. Data confidentiality was maintained, and all information was collected and securely stored in compliance with the General Data Protection Regulation (GDPR, Regulation [EU] 2016/679 of the European Parliament and the Council of 27 April). These measures underscore the study's commitment to transparency, integrity, and adherence to the highest ethical and legal standards.

3.5. Pedagogical Intervention Program

The intervention was conducted throughout the 2023/2024 academic year and involved two curricular units: Mathematics and Didactics of Mathematics. These units are part of the master's programs "Primary School Teaching and 2nd Grade School Teaching in Mathematics and

Experimental Sciences" and "Primary School Teaching and 2nd Grade School Teaching in Portuguese and History and Geography of Portugal". The intervention was also carried out in coordination with the Educational Practice curricular unit of each master's program, which is responsible for supervising the internships undertaken by pre-service teachers. The intervention spanned six stages across two semesters: Stages 1–3 in the first semester and Stages 4–6 in the second semester (Figure 1).

The intervention aimed to enhance pre-service teachers' didactic knowledge, enable them to select, adapt, and implement tasks that develop Computational Thinking dimensions while promoting mathematical learning.

The intervention was structured into two phases. Phase 1 aimed to:

1. Provide pre-service teachers with theoretical knowledge on: the mathematical competency of Computational Thinking as defined in the official Portuguese curriculum (ME, 2021); lesson planning structure for the academic year, based on Exploratory Teaching Practices (Canavarro et al., 2012); and the Conceptual Framework of the Didactic Knowledge Model for Mathematics Teachers (Ponte, 2012) (Stage 1).;

2. Enable pre-service teachers to gain practical experience by implementing Primary School tasks that integrate Computational Thinking dimensions while promoting mathematical concept learning, based on Exploratory Teaching Practices (Canavarro et al., 2012) (Stage 2);

3. Encourage pre-service teachers to adapt tasks and plan hypothetical implementation tailored to their internship context (Stage 2).

Throughout Phase 1, pre-service teachers developed intervention plans for their internship contexts to promote Computational Thinking dimensions and mathematical learning. The intervention plan was presented in the curricular unit of Phase 1 and discussed with other pre-service teachers to refine and improve it (Stage 3).

The objectives of Phase 2 were:

1. Implement a part of the intervention plan developed for their internship contexts within the scope of the curricular unit where Phase 2 took place, with colleagues role-playing as students (Stage 4);

2. Execute the refined intervention plan in their internship contexts (Stage 5).;

3. Share the implementation carried out with the other colleagues within the scope of the curricular unit where Phase 2 took place (Stage 6).

To assess the perceived levels of Computational Thinking competence among pre-service teachers, a questionnaire was administered at both the Pre-Intervention phase (September 14, 2023) and the Post-Intervention phase (June 13, 2024). Additionally, task sequences were applied during the Pre- and Post-Intervention phases to assess pre-service teachers' knowledge of Computational

Thinking dimensions and their Didactic Knowledge in Mathematics, as detailed in the "Data Collection" section. The overall structure of the intervention plan is presented in Figure 1.

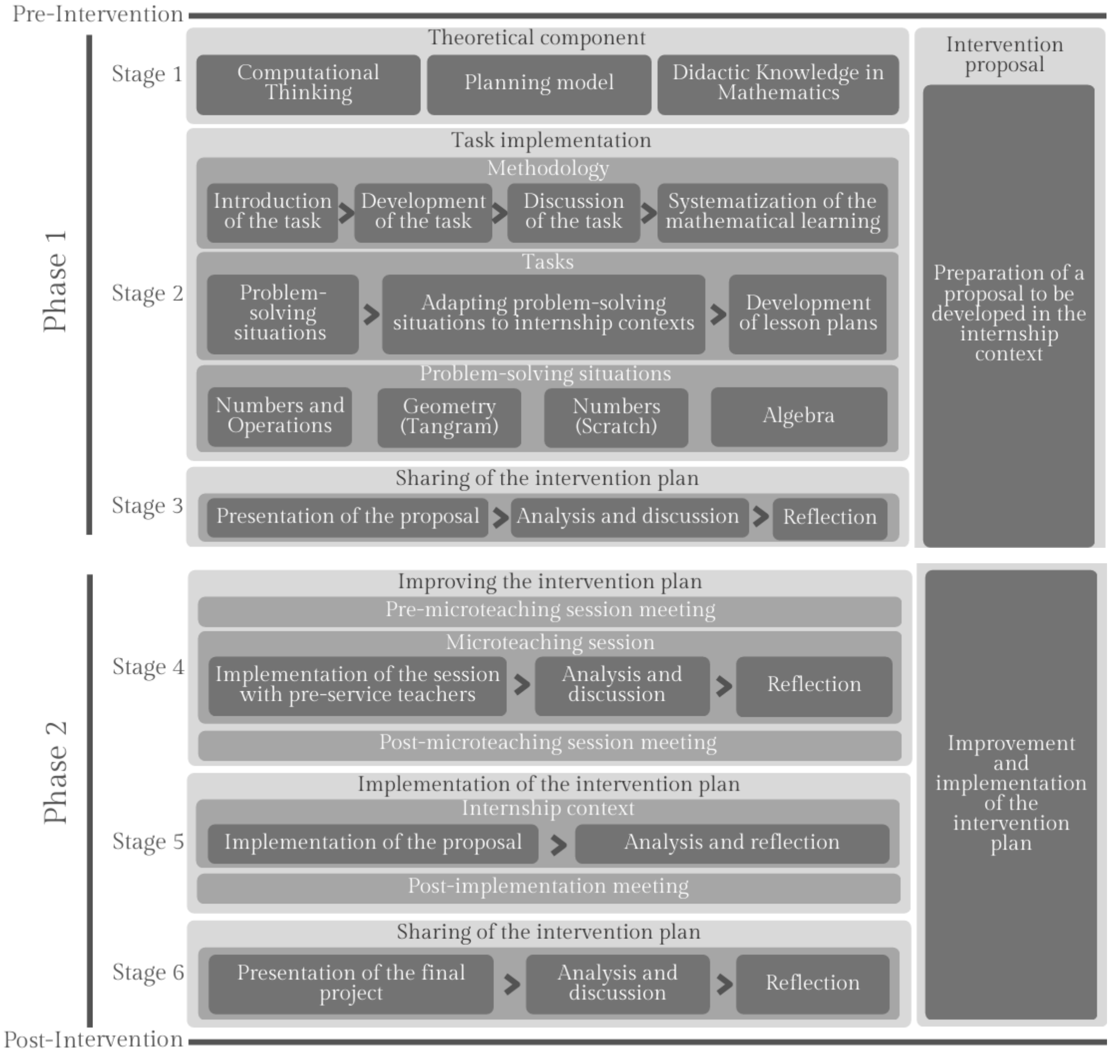

Figure 1. General structure of the intervention plan

Phase 1

Phase 1 of the intervention took place in the first semester, from September 28, 2023, to January 6, 2024. It consisted of three stages, and it was conducted over 13 sessions, each lasting 2 hours.

Stage 1 took place over 3 sessions and focused on enhancing pre-service teachers' understanding of Computational Thinking as a mathematical competency within the Portuguese curriculum. It also aimed to develop their knowledge of the academic year's planning model and the Didactic Knowledge Model for Mathematics Teachers. In the first session, a problem-solving task suitable for Primary School was implemented, containing a sequence of tasks directly related to the development of each dimension of Computational Thinking. In the second session, based on the solved problem, the pre-service teachers developed a lesson plan using the adopted planning model for the session in which they had participated. This approach enabled a deeper exploration of key aspects of the planning model tied to the Portuguese curriculum, including lesson resources, learning objectives related to the mathematical theme and competencies, and suitable assessment methods. The characteristics of the Exploratory Teaching Practices model, which was implemented and represented in the structure of the planning model, were also explored. These include, for example, the 4 phases of the lesson and the distinction between actions aimed at promoting learning and those focused on managing the lesson. The final session of Stage 1 focused on identifying the knowledge a teacher must have to teach, linking the pre-service teachers' conceptions with the dimensions of the model defined by Ponte (2012): Knowledge of Mathematics for Teaching; Knowledge of the Curriculum; Knowledge of Students and their Learning Processes; and Knowledge of Teaching Practice.

Stage 2 was carried out over 8 sessions, during which four problem-solving tasks were implemented. Each problem-solving task was divided into a set of 10 tasks, organized into two parts, with each part conducted in a 2-hour session. In Part 1, the starting point was problem-solving situations aimed at Primary School, taken from or adapted from Canavarro et al. (2022), along with a set of 6 tasks designed to foster the development of Computational Thinking. The main objective of this part, in addition to the dimensions of Computational Thinking, was to develop the dimension of Knowledge of Mathematics for Teaching. In Part 2, the starting point was the resolution of four tasks, culminating in the creation of a lesson plan based on the problem-solving task from Part 1. The goal was to develop the Didactic Knowledge of Mathematics Teachers, with a primary focus on the dimensions of Knowledge of Students and their Learning Processes, Knowledge of the Curriculum, and Knowledge of Teaching Practice. All sessions led by the researcher adhered to the exploratory teaching practices model, enabling pre-service teachers to engage with this teaching method and become familiar with its characteristics and implementation. Each session began with an introduction to the task, during which the researcher clarified its objectives and answered the questions. This was followed by the pre-service teachers working on the task in groups that had been pre-defined for the curricular internship. During the discussion of the task, groups—selected by the researcher based on the resolutions that contained the most elements to explore—shared and discussed their solutions with the other colleagues.

To conclude, each lesson ended with a systematization of mathematical learning, where the researcher reinforced the key concepts addressed during the lesson. The selection of problem-solving tasks accounted for diverse mathematical content, the potential to integrate teaching resources, and the adaptability of proposals for all four years of Primary School. The first problem-solving task was centered around the theme of Numbers, focusing on rectangular arrangements and multiplication. The second task fell under the theme of Geometry and Measurement, based on tasks that involved exploring the Tangram manipulative material. The third task involved concepts related to the principles of the decimal number system, within the theme of Numbers, and was based on tasks to be completed on the Scratch platform. The final task was within the theme of Algebra, focusing on patterns in sequences.

Phase 1 concluded with Stage 3, during which pre-service teachers, guided by the researcher and in coordination with the Educational Practice Curricular Unit, developed an intervention plan. This plan, intended for implementation in their internship contexts, aimed to promote Computational Thinking dimensions while enhancing mathematical concept learning. Stage 3 involved sharing and discussing the developed plan, carried out in two sessions, each lasting two hours. During each session, the pre-service teachers identified the contexts in which they were completing their curricular internship, presented their implementation proposal, and provided the rationale behind their choices. After each presentation, colleagues and the researcher offered feedback to improve the proposed plan.

Phase 2

Phase 2 of the intervention took place in the second semester, from February 15, 2024, to May 23, 2024, and consisted of 3 stages. It was conducted over 13 sessions, each lasting 2 hours.

Stage 4 focused on conducting microteaching sessions, where pre-service teachers implemented parts of the intervention plan from Stage 3, refined using feedback provided during this stage. Before each microteaching session, the researcher met with pre-service teacher groups to assist in session preparation and clarify any doubts about the intervention or suggested improvements. Each microteaching session, conducted by the groups, involved the remaining pre-service teachers role-playing as Primary School students, following instructions and solving the proposed tasks. After each session, a discussion was held where colleagues and the researcher reviewed the proposal, highlighting strengths and weaknesses while offering suggestions for improvement. Following each microteaching session, the researcher met again with the group to reflect on the session and discuss which aspects should be maintained or modified before implementing the plan in the internship contexts.

During Stage 5, the pre-service teacher groups implemented the intervention plan in their internship contexts, incorporating revisions based on the reflections from the end of Stage 4. Following the implementation, the pre-service teachers met with the researcher to reflect on the process.

Phase 2 concluded with Stage 5, which, like Stage 3 of Phase 1, involved sharing and discussing the implemented intervention. This stage was conducted over two sessions, each lasting two hours. In addition to presenting their final implementation proposal, the pre-service teachers shared the results of their intervention and reflected on the application of the exploratory teaching practices model. The primary objective was to develop the dimensions of Computational Thinking while simultaneously enhancing mathematical concept learning in Primary School. At the end of the intervention, the pre-service teachers also wrote individual critical reflections on the entire process undertaken throughout the academic year.

3.6. Data Analysis

Quantitative Data Analysis

The reliability of the data collected, regarding the two applications of the questionnaire (Pre-Intervention and Post-Intervention), was assessed through the internal consistency of the dimensions, evaluated using Cronbach's alpha coefficient based on the following classification: very good ($\alpha \geq 0.9$); good ($0.8 \leq \alpha < 0.9$); reasonable ($0.7 \leq \alpha < 0.8$); weak ($0.6 \leq \alpha < 0.7$); unacceptable ($\alpha < 0.6$) (Pallant, 2020; Pestana & Gageiro, 2014). Statistical analysis was performed using descriptive statistics, with relative and absolute frequency tables employed to describe participants' perceptions regarding the administration of the questionnaire at both the Pre-Intervention and Post-Intervention phases. Perceptions at both phases were characterized using the mean (M) and standard deviation (SD). Positive and negative trends in participants' perceptions were determined by considering levels 1 and 2 as negative and levels 4 and 5 as positive. Level 3 was regarded as a neutral perception.

To ensure consistency in result interpretation, responses in the Problem-Solving dimension, which were negatively phrased (as detailed in Section 3.3: Data Collection), were reversed. This transformation involved recoding responses on the five-point Likert scale, where a '1' was recoded as '5,' a '2' as '4,' and so on. This procedure ensured that higher values across all dimensions reflected more positive perceptions, maintaining consistency in the interpretation of the results. The recoding was essential for ensuring the comparability of the data during statistical analysis, preventing misinterpretations, particularly when comparing the Pre- and Post-Intervention phases. All subsequent analyses were conducted using the transformed data.

To compare participants' perceptions of Computational Thinking competencies before and after the intervention, the paired-sample t-test was used, following the validation of its assumptions (Field, 2018; Marôco, 2021). This test allowed for the evaluation of statistically significant differences between the means of the two measurements (Pre-Intervention and Post-Intervention) and is appropriate for situations where the same samples are assessed at different time points. The

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normality assumption for each dependent variable was assessed using the Kolmogorov-Smirnov test. In cases where the assumption of normality was not met, the central limit theorem was applied (Field, 2018; Marôco, 2021). This theorem ensures that with sufficiently large samples ($n \geq 30$), the sampling distribution of the mean tends to be normal, allowing the use of the t-test even in the absence of normality in the data. Therefore, the normality assumption was assumed to hold (Marôco, 2021; Pallant, 2020; Pestana & Gageiro, 2014). The effect size for the paired-sample t-test was calculated using Cohen's d, and the effect size was classified as follows (Marôco, 2021; Pallant, 2020): small ($d \leq 0.2$), medium ($0.2 < d \leq 0.5$), large ($0.5 < d \leq 0.8$), and very large ($d > 0.8$).

All statistical analysis for a 5% significance level ($p < 0.05$) was performed using the IBM Statistical Package for the Social Sciences (SPSS, version 28) software.

Qualitative Data Analysis

The data collected during the intervention sessions conducted in Stages 1 and 2 of Phase 1 allowed for the construction of a Multimodal Narrative (MN) for each stage, totaling eleven MNs. Each MN, developed following the protocol established by Lopes et al. (2018), provides a chronological, self-contained, and multimodal account of each intervention session, highlighting the most important moments and the dialogues of the various groups involved in the study. The protocol outlines the procedures for data collection, development, and validation of the MNs (Lopes et al., 2018). After their construction, the eleven MNs were validated by independent researchers, who ensured that they adhered to the protocol defined for their structure, compared the multimodal elements collected and provided by the researcher. These researchers ensured the MNs adhered to the protocol's structure, compared the multimodal elements collected and provided by the researcher, and assessed their accuracy, reliability, and readability. Qualitative data analysis was subsequently conducted using an exploratory content analysis approach applied to the MNs and additional data collected throughout all intervention stages, including solutions proposed by the pre-service teachers, group work products, and critical reflections.

The mixed-methods approach in this research aims to provide a deeper understanding of the quantitative results by contextualizing and explaining them through qualitative insights (Cohen et al., 2018; Creswell & Creswell, 2017).

4. Results

To assess the reliability and internal consistency of the scale, Cronbach's alpha coefficient was calculated for both the total scale and each of its dimensions in the two administrations of the questionnaire (Pre-Intervention and Post-Intervention). The scale, consisting of 29 items, showed a total Cronbach's alpha coefficient (DTOTAL) of $\alpha = 0.914$ for the Pre-Intervention and $\alpha = 0.946$ for the Post-Intervention, indicating consistent values across both administrations of the questionnaire. The Cronbach's alpha coefficients for each dimension were as follows: Creativity (DCRI) $\alpha = 0.700$ vs $\alpha = 0.830$; Algorithmic Thinking (DPAL) $\alpha = 0.804$ vs $\alpha = 0.886$; Cooperativity (DCOO) $\alpha = 0.796$ vs $\alpha = 0.880$; Critical Thinking (DPCR) $\alpha = 0.819$ vs $\alpha = 0.834$; Problem-Solving (DRPR) $\alpha = 0.799$ vs $\alpha = 0.863$ (Table 1).

Table 1. Cronbach's alpha coefficients in Pre-Intervention and Post-Intervention

Factors	Items	Cronbach's Alpha (α)	
		Pre-Intervention	Post-Intervention
Creativity(DCRI)	1,2,3,4,5,6,7,8	α = 0.700	α = 0.830
Algorithmic Thinking (DPAL)	9,10,11,12,13,14	α = 0.804	α = 0.886

Cooperativity (DCOO)	15,16,17,18	α = 0.796	α = 0.880
Critical Thinking (DPCR)	19,20,21,22,23	α = 0.819	α = 0.834
Problem-Solving (DRPR)	24,25,26,27,28,29	α = 0.799	α = 0.863
Total Scale (DTotal)	1 to 29	α = 0.914	α = 0.946

In addition to the tabulated Cronbach's alpha coefficients, Figure 2 provides a graphical summary of the growth in participants' perceptions across the five competencies. The radar chart highlights the consistent improvements observed in Creativity, Algorithmic Thinking, Cooperativity, Critical Thinking, and Problem-Solving, underscoring the impact of the intervention program.

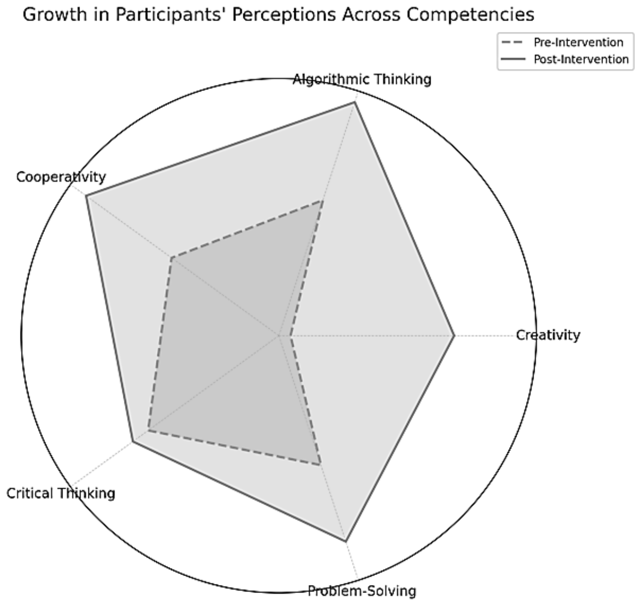

Figure 2. Radar chart illustrating the growth in participants' perceptions across the five competencies between the Pre- and Post-Intervention phases.

In the following five subsections, the results will be presented regarding the descriptive statistics for each dimension of the questionnaire (DCRI, DPAL, DCOO, DPCR, and DRPR), the statistical comparison between the two administrations of the questionnaire (Pre-Intervention and Post-Intervention), and the characterization of the pre-service teachers' perceptions regarding the five dimensions of the questionnaire. Additionally, the qualitative results related to the evidence of the development of the five competencies throughout the intervention will be presented.

4.1. Creativity

The data presented in Table 2 indicate a significant improvement in the participants' perceptions after the intervention. There was an increase in positive responses (values 4 and 5) across all items (Q1 to Q8) compared to the Pre-Intervention responses. After the intervention, there were no responses in the negative range (1 and 2), suggesting an improvement in the participants' perceptions. For all items, the majority of Post-Intervention responses were positive, with a significant increase in responses rated 5 (very positive). For example, items Q5 and Q8 showed an increase in positive responses from 39.4% and 50%, respectively, in the Pre-Intervention phase to 89.5% in the Post-Intervention phase. Furthermore, the overall average of positive responses increased from 63.1% in the Pre-Intervention phase to 91.8% in the Post-Intervention phase.

Table 2. Distribution of relative (%) and absolute frequencies of DCRI

Item	Pre-Intervention (%(n))					Post-Intervention (%(n))				
	Negative		Neutral	Positive		Negative		Neutral	Positive	
	1	2	3	4	5	1	2	3	4	5
Q1	0.0(0)	0.0(0)	13.2(5)	57.9(22)	28.9(11)	0.0(0)	0.0(0)	2.6(1)	34.2(13)	63.2(24)
Q2	0.0(0)	0.0(0)	13.2(5)	52.6(20)	34.2(13)	0.0(0)	0.0(0)	0.0(0)	34.2(13)	65.8(25)
Q3	0.0(0)	0.0(0)	26.3(10)	52.6(20)	21.1(8)	0.0(0)	0.0(0)	2.6(1)	44.7(17)	52.6(20)
Q4	0.0(0)	7.9(3)	34.2(13)	52.6(20)	5.3(2)	0.0(0)	0.0(0)	10.5(4)	52.6(20)	36.8(14)
Q5	0.0(0)	5.3(2)	55.3(21)	36.8(14)	2.6(1)	0.0(0)	0.0(0)	10.5(4)	63.2(24)	26.3(10)
Q6	0.0(0)	5.3(2)	28.9(11)	42.1(16)	23.7(9)	0.0(0)	0.0(0)	13.2(5)	39.5(15)	47.4(18)
Q7	0.0(0)	5.3(2)	50.0(19)	36.8(14)	7.9(3)	0.0(0)	0.0(0)	15.8(6)	50.0(19)	34.2(13)
Q8	0.0(0)	10.5(4)	39.5(15)	42.1(16)	7.9(3)	0.0(0)	0.0(0)	10.5(4)	50.0(19)	39.5(15)
M (%)	0.0%	4.3%	32.6%	46.7%	16.4%	0.0%	0.0%	8.2%	46.1%	45.7%

Table 3 presents the descriptive statistics and the comparison of the results for the Creativity dimension in the Pre- and Post-Intervention phases. A significant increase is observed in the mean value of DCRI after the intervention (M = 35.00) compared to the Pre-Intervention mean value (M = 30.03). This difference is statistically significant, as indicated by the t-value of -7.67, with a p-value of 0.001. The effect size (d = 1.245) is classified as very large, indicating that the intervention had an impact on the participants' perceptions. The increase in the mean score of the Post-Intervention results suggests that the intervention was effective in improving the participants' perceptions of the Creativity dimension, as evidenced by both the statistically significant differences and the large effect size.

Table 3. Descriptive statistics and comparison between the two applications of questionnaire - DCRI (Pre-Intervention and Post-Intervention)

		M	*SD*	*t*	*p*	*d*	Effect size
DCRI	Pre-Intervention	30.03	3.16	-7.67	0.001	1.245	Very large
	Post-Intervention	35.00	3.30				

During the intervention phase, the selection of problem situations to be implemented took into account three main aspects: (i) the diversity of mathematical content addressed; (ii) the possibility of integrating various teaching resources; and (iii) the inclusion of proposals that could be adapted to all four years of Primary School. Throughout the intervention, the pre-service teachers were encouraged to solve the problem situations and, subsequently, adapt them to the specific context of the school year corresponding to their internship. This approach allowed each group to create distinct adaptations and share them with the other pre-service teachers, fostering Creativity through the exploration of different perspectives and solutions, as evidenced by one of the pre-service teachers in the critical reflection she wrote at the end of the training program.

"...the lesson plans of my colleagues allowed me to broaden my perspective on the different implementations that can be carried out with the same theme. During the microteaching sessions conducted by the other groups, I was able to see new ways of introducing a task, as each group chose a different approach to do so."

One of the items in the questionnaire where the most significant improvement in negative perception responses was observed was item Q5: "I trust that I can apply the plan while making it to solve a problem of mine." Throughout the training program, pre-service teachers were given the opportunity to test, refine, and adapt their proposals with the guidance of the researcher and their peers. These hands-on experiences, enriched by the contributions and exchanges of ideas with the research team, provided pre-service teachers with the opportunity to reflect on the lesson plans they developed. This collaborative process not only improved the quality of the proposals, making them more tailored and suited to the realities of their internship contexts, but also helped increase the pre-service teachers' confidence in the plans they created. The relevance of these interactions is highlighted in the following transcript of a dialogue, where the exchange of ideas between group members during the sharing of their planning proposal and the contributions of a colleague in one of the discussions of the task phases can be observed:

Pre-service teacher V: Just to make sure I understand correctly, what you do at the beginning of the lesson is give the answer to what each of those situations is, right?

Pre-service teacher B: We don't exactly give the answer… we guide the students toward the answer… I see what you're saying.

Pre-service teacher V: So, the idea wouldn't be for them to first make a comparison and try to think of the answer, and then, at the end, during the systematization, you would present it?

Pre-service teacher B: … Yes… I understand.

Researcher: That was also a bit of my doubt—using PowerPoint to start the lesson. Since we are working with exploratory teaching, the idea is always for the students to explore first, and only then will they understand what is common among those shapes, what it is...

Pre-service teacher B: But, for example, since we were going to ask them to make diamonds, rectangles, and squares, would they really understand what a diamond is? That a diamond must have four equal sides, that a rectangle has four angles... The rectangle, maybe, but the diamond?

Pre-service teacher N: I think it's about allowing them to explore it, instead of giving it to them. Let them explore it... That's what builds something in them, and they will draw conclusions from what they explore.

4.2. Algorithmic Thinking

The data presented in Table 4 indicate a shift in participants' perceptions between the Pre- and Post-Intervention phases. During the Pre-Intervention phase, positive responses (scoring 4 or 5) constituted 32.9%, whereas neutral responses (scoring 3) were the most frequent, at 52.6%. Following the intervention, positive responses significantly increased to 72.8%, reflecting the intervention's positive impact on participants' perceptions. Individual items show consistent changes. For example, item Q9 saw an increase from 10.5% in the Pre-Intervention to 71.1% in the Post-Intervention for positive responses. Similarly, item Q13 recorded 21.1% positive responses in the Pre-Intervention, which increased to 76.4% in the Post-Intervention. Furthermore, neutral responses decreased substantially from 52.6% in the Pre-Intervention phase to 26.8% in the Post-Intervention phase, while negative perceptions dropped from 14.4% to just 0.4%. These results suggest an improvement in perceptions of the Algorithmic Thinking dimension following the intervention.

Table 4. Distribution of relative (%) and absolute frequencies of DPAL

Item	Pre-Intervention (%(n))					Post-Intervention (%(n))				
	Negative		Neutral	Positive		Negative		Neutral	Positive	
	1	2	3	4	5	1	2	3	4	5
Q9	0.0(0)	13.2(5)	76.3(29)	10.5(4)	0.0(0)	0.0(0)	0.0(0)	28.9(11)	63.2(24)	7.9(3)
Q10	2.6(1)	26.3(10)	44.7(17)	21.1(8)	5.3(2)	0.0(0)	0.0(0)	52.6(20)	34.2(13)	13.2(5)
Q11	0.0(0)	7.9(3)	39.5(15)	47.4(18)	5.3(2)	0.0(0)	0.0(0)	18.4(7)	60.5(23)	21.1(8)
Q12	0.0(0)	5.3(2)	39.5(15)	52.6(20)	2.6(1)	0.0(0)	0.0(0)	15.8(6)	55.3(21)	28.9(11)
Q13	0.0(0)	15.8(6)	63.2(24)	21.1(8)	0.0(0)	0.0(0)	2.6(1)	21.1(8)	55.3(21)	21.1(8)
Q14	0.0(0)	15.8(6)	52.6(20)	23.7(9)	7.9(3)	0.0(0)	0.0(0)	23.7(9)	57.9(22)	18.4(7)
M (%)	0.4%	14.0%	52.6%	29.4%	3.5%	0.0%	0.4%	26.8%	54.4%	18.4%

The results presented in Table 5 indicate a significant change in participants' perceptions after the intervention. An increase in the mean is observed, rising from 19.29 in the Pre-Intervention phase to 23.45 in the Post-Intervention phase. This difference is statistically significant, as indicated by the t-value of -8.25, with a p-value of 0.001, and a Cohen's d of 1.338, which indicates a very large effect size. These data corroborate the trends observed in Table 4, suggesting that the intervention had a substantial positive impact on participants' perceptions of the Algorithmic Thinking dimension. The significant difference in mean values and the very large effect size further highlight the importance of the intervention in altering perceptions.

Table 5. Descriptive statistics and comparison between the two applications of questionnaire - DPAL (Pre-Intervention and Post-Intervention)

		M	SD	t	p	d	Effect size
DPAL	Pre-Intervention	19.29	3.02	-8.25	0.001	1.338	Very large
	Post-Intervention	23.45	3.185				

Regarding the Algorithmic Thinking dimension, it is important to highlight that the tasks given to the pre-service teachers required them to analyze the problem situations sequentially, structuring their actions into clear steps. Figure 3 presents an excerpt from one of the exploration sheets of a group of pre-service teachers, where they describe, step by step, the solution they developed to solve the problem situation.

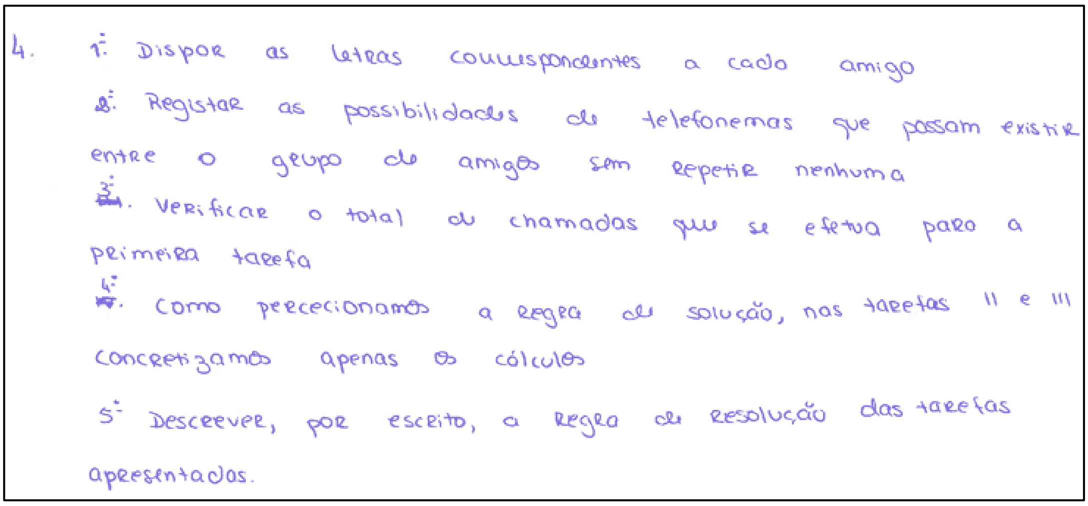
4. 1.º Dispor as letras correspondentes a cada amigo
2.º Registar as possibilidades de telefonemas que possam existir entre o grupo de amigos sem repetir nenhuma
3.º Verificar o total de chamadas que se efetua para a primeira tarefa
4.º Como percecionamos a regra de solução, nas tarefas II e III concretizamos apenas os cálculos
5.º Descrever, por escrito, a regra de resolução das tarefas apresentadas.

Figure 3. Excerpt from one of the pre-service teachers' group exploration sheets. (Translation: 1.º Arrange the letters corresponding to each friend; 2.º Register the possible phone calls between the group of friends without repeating any; 3.º Check the total number of calls made for the first task; 4.º How do we understand the solution rule, in tasks II and III we only do the calculations; 5.º Describe, in writing, the solution rule for the tasks presented.)

Both during the problem-solving and discussion phases, pre-service teachers were asked to verbalize and justify the steps involved in their solutions. This moment, which was present in all the sessions of the training program, fostered the structured and logical thinking necessary for the pre-service teachers to clearly express the solutions they implemented. The following transcription of dialogue highlights the researcher's mediation during the development of the task, which helped the pre-service teachers explain more clearly what they had done to solve the task.

Researcher: ... So, how did you think about solving the addition here? How would you explain it to me?

Pre-service teacher I: First, we explained how we got to sixty-two.

Researcher: And how did you do that? How did you get there?

Pre-service teacher I: We moved two units, then we immediately moved to sixty-two tens, and then we added thirty.

Researcher: Sixty-two tens?

Pre-service teacher J: Sixty tens.

Pre-service teacher I: Sixty tens.

Researcher: Why? Why did you move two units and then...

Pre-service teacher I: Because it's easier to reach the tens in this case.

Researcher: Right, but why did you move two units instead of three or four, for example?

4.3. Cooperativity

The results presented in Table 6 reveal a positive shift in participants' perceptions following the intervention. During the Pre-Intervention phase, positive responses accounted for 85.1%, increasing to 94.7% in the Post-Intervention phase. Although the percentage of positive responses was already high in the Pre-Intervention phase, it is important to note that level 5 responses increased from 44.1% in the Pre-Intervention to 68.4% in the Post-Intervention phase. This trend is reflected in the individual items. For instance, item Q15 experienced an increase in level 5 responses, rising from 34.2% in the Pre-Intervention phase to 63.2% in the Post-Intervention phase. Similarly, Item Q16 showed a substantial improvement a significant change, increasing from 84.2% to 97.4% in terms of positive responses. It is important to highlight that there were no negative perceptions in the Post-Intervention phase, and neutral perceptions decreased from 13.2% in the Pre-Intervention to just 5.3% in the Post-Intervention phase. These findings suggest that the intervention significantly contributed to improving the perception of the Cooperativity dimension.

Table 6. Distribution of relative (%) and absolute frequencies of DCOO

Item	Pre-Intervention (%(n))					Post-Intervention (%(n))				
	Negative		Neutral	Positive		Negative		Neutral	Positive	
	1	2	3	4	5	1	2	3	4	5
Q15	0.0(0)	2.6(1)	18.4(7)	44.7(17)	34.2(13)	0.0(0)	0.0(0)	10.5(4)	26.3(10)	63.2(24)
Q16	0.0(0)	2.6(1)	13.2(5)	55.3(21)	28.9(11)	0.0(0)	0.0(0)	2.6(1)	34.2(13)	63.2(24)
Q17	0.0(0)	0.0(0)	15.8(6)	47.4(18)	36.8(14)	0.0(0)	0.0(0)	7.9(3)	23.7(9)	68.4(26)
Q18	0.0(0)	0.0(0)	5.3(2)	18.4(7)	76.3(29)	0.0(0)	0.0(0)	0.0(0)	21.1(8)	78.9(30)
M (%)	0.0%	1.3%	13.2%	41.4%	44.1%	0.0%	0.0%	5.3%	26.3%	68.4%

The results presented in Table 7 statistically confirm the trends observed. The average perception score increased from 17.13 in the Pre-Intervention phase to 18.53 in the Post-Intervention phase. The t-test showed a statistically significant difference ($t = -3.47$; $p = 0.001$), with a large effect size ($d = 0.563$).

These results demonstrate that the intervention had a significant impact on participants' perceptions, leading to a statistically significant increase in the Cooperativity dimension. The effect size further highlights the effectiveness of the intervention in improving the perception of the Cooperativity competence, as evidenced by both the average scores and the greater percentage of positive responses.

Table 7. Descriptive statistics and comparison between the two applications of questionnaire - DCOO (Pre-Intervention and Post-Intervention)

		M	*SD*	*t*	*p*	*d*	Effect size
DCOO	Pre-Intervention	17.13	2.20	-3.47	0.001	0.563	Large
	Post-Intervention	18.53	1.97				

During the training program, there were several moments of group work, both in solving the problem-solving tasks and in developing lesson plans. These moments provided significant opportunities for sharing ideas, joint reflections, and collaboratively building solutions. The following dialogue transcription highlights a discussion among the members of a group of pre-service teachers, which culminates in them finding the solution to the problem-solving task.

Pre-service teacher P: We understand now! (speaking to the Researcher)

Pre-service teacher R: Yes.

Pre-service teacher P: We've already removed B.

Pre-service teacher Q: We removed B because it is a common diagonal to both triangles. And then...

Pre-service teacher R: It would pass through twice on the...

Pre-service teacher Q: ...it would have to repeat. It would have to pass twice on that path.

Researcher: So... (pre-service teacher Q interrupts)

Pre-service teacher Q: There are only 24 possible paths! Because it's six for each of these letters.

During the microteaching sessions, the pre-service teachers not only collaborated with their group colleagues to implement the tasks, taking on the role of primary school students, but also had the opportunity to comment on the lesson in which they participated, highlighting both the positive and less positive aspects of the proposal and offering suggestions for improvement. This aspect of the training program was emphasized by one of the pre-service teachers in the critical reflection she wrote, as shown in the excerpt presented below:

"Based on the feedback given on my teaching group's performance during the microteaching session, I understood the areas we needed to improve, and we later began to consider this in our internship interventions."

4.4. Critical Thinking

The data presented in Table 8 show the distribution of relative and absolute frequencies for the Critical Thinking dimension before and after the intervention. A significant improvement in participants' perceptions is observed, with an increase in positive responses from 45.2% before the intervention to 77.4% after the intervention. Item Q19 stands out, with positive responses increasing from 15.8% at the Pre-Intervention phase to 68.4% at the Post-Intervention phase. A similar significant increase in positive responses was seen in item Q23, which rose from 45.2% in the Pre-Intervention phase to 76.3% in the Post-Intervention phase.

Table 8. Distribution of relative (%) and absolute frequencies of DPCR

Item	Pre-Intervention (%(n))					Post-Intervention (%(n))				
	Negative		Neutral	Positive		Negative		Neutral	Positive	
	1	2	3	4	5	1	2	3	4	5
Q19	2.6(1)	13.2(5)	68.4(26)	15.8(6)	0.0(0)	0.0(0)	2.6(1)	28.9(11)	57.9(22)	10.5(4)
Q20	2.6(1)	18.4(7)	42.1(16)	26.3(10)	10.5(4)	0.0(0)	2.6(1)	26.3(10)	36.8(14)	34.2(13)
Q21	0.0(0)	0.0(0)	7.9(3)	36.8(14)	55.3(21)	0.0(0)	0.0(0)	7.9(3)	36.8(14)	55.3(21)
Q22	0.0(0)	13.2(5)	36.8(14)	42.1(16)	7.9(3)	0.0(0)	0.0(0)	21.1(8)	42.1(16)	36.8(14)
Q23	0.0(0)	7.9(3)	60.5(23)	31.6(12)	0.0(0)	0.0(0)	0.0(0)	23.7(9)	57.9(22)	18.4(7)
M (%)	1.1%	10.5%	43.2%	30.5%	14.7%	0.0%	1.1%	21.6%	46.3%	31.1%

Table 9 presents the descriptive statistics and the comparison between the two administrations of the questionnaire for the Critical Thinking dimension. A significant increase in the mean score is observed in the Post-Intervention phase (M = 20.37) compared to the Pre-Intervention phase (M = 17.37). Statistical analysis shows a significant difference (t = -6.08, p = 0.001) and a very large effect size (d = 0.987), indicating a substantial improvement in participants' perceptions after the intervention.

Table 9. Descriptive statistics and comparison between the two applications of questionnaire - DPCR (Pre-Intervention and Post-Intervention)

		M	*SD*	*t*	*p*	*d*	Effect size
DPCR	Pre-Intervention	17.37	2.81	-6.08	0.001	0.987	Very large
	Post-Intervention	20.37	2.79				

One of the items where the greatest increase in positive perception responses was observed from the Pre-Intervention to the Post-Intervention phase was item Q23: "I make use of a systematic method while comparing the options at my hand and while reaching a decision." It is worth noting that in the tasks presented to the pre-service teachers, they were asked to analyze the steps they took to solve the problem situations, verifying whether they were correct and if there were alternative solutions. The following dialogue transcription refers to one of the discussion of the task phases, where the pre-service teachers reflected on the importance of analyzing, step by step, what they had developed.

Pre-service teacher S: Our group felt that by writing down the steps, we were becoming more aware of the process we followed. Every time we did something unconsciously, it helped us become more conscious and reflect on all the steps.

Researcher: Ok. Does this group want to add anything? (pre-service teacher J raised her hand to speak)

Pre-service teacher J: I think it helps us set our goals and verify if our answers are correct in the end, or if we meet the goals we set.

During the sharing and discussion of the lesson plans developed in the third phase of the exploratory teaching practices model, the different groups were asked to reflect both on the proposals shared and on their own. The following dialogue transcript shows the exchange between two groups of pre-service teachers, which resulted in a critical reflection on the proposal by the group that developed it.

Researcher: Group 5, would you like to comment on this introduction? Do you have any questions or anything you did differently?

Pre-service teacher K: The only difference we have is that instead of pawns, we use the SuperDoc robot.

Researcher: Okay. So, you did something similar, but used the robot instead of Scratch. Yes, go ahead, pre-service teacher S.

Pre-service teacher S: I think it's more a matter of... For example, I think we should use verbs in the promotion of mathematical learning and classroom management, rather than "distribution," since distribution implies the act of distributing.

Pre-service teacher R: Actually, that was our fault.

4.5. Problem-Solving

Before presenting the statistical results for the Problem-Solving dimension, it is important to note that the responses to the items in this dimension were reversed prior to analysis. This procedure was implemented to ensure that higher values across all dimensions would reflect more positive perceptions, thereby maintaining consistency in data interpretation.

The results presented in Table 10 show a significant improvement in participants' perceptions after the intervention. In item Q24, neutral responses decreased from 63.2% to 36.8%, while positive responses increased from 23.7% to 60.5%. Similarly, in item Q26, neutral responses dropped from

60.5% to 13.2%, and positive responses increased from 31.5% to 84.2%. The overall averages reflect this trend, with neutral responses decreasing from 42.5% to 21.1% and positive responses rising from 46.9% to 76.3%. These data suggest that the intervention was effective in improving participants' perceptions of the Problem-Solving dimension.

Table 10. Distribution of relative (%) and absolute frequencies of DRPR

Item	Pre-Intervention (%(n))					Post-Intervention (%(n))				
	Negative		Neutral	Positive		Negative		Neutral	Positive	
	1	2	3	4	5	1	2	3	4	5
Q24	0.0(0)	13.2(5)	63.2(24)	23.7(9)	0.0(0)	0.0(0)	2.6(1)	36.8(14)	57.9(22)	2.6(1)
Q25	0.0(0)	15.8(6)	52.6(20)	28.9(11)	2.6(1)	0.0(0)	7.9(3)	34.2(13)	34.2(13)	23.7(9)
Q26	0.0(0)	7.9(3)	60.5(23)	28.9(11)	2.6(1)	0.0(0)	2.6(1)	13.2(5)	68.4(26)	15.8(6)
Q27	0.0(0)	18.4(7)	50.0(19)	28.9(11)	2.6(1)	0.0(0)	2.6(1)	31.6(12)	52.6(20)	13.2(5)
Q28	0.0(0)	7.9(3)	23.7(9)	55.3(21)	13.2(5)	0.0(0)	0.0(0)	7.9(3)	50.0(19)	42.1(16)
Q29	0.0(0)	0.0(0)	5.3(2)	39.5(15)	55.3(21)	0.0(0)	0.0(0)	2.6(1)	21.1(8)	76.3(29)
M (%)	0.0%	10.5%	42.5%	34.2%	12.7%	0.0%	2.6%	21.1%	47.4%	28.9%

In the Pre-Intervention phase, the average score was 20.95, while in the Post-Intervention phase, the average increased to 24.16, indicating an improvement in the perception of Problem-Solving competence after the intervention. The results of the paired Student's t-test revealed a significant difference between the two evaluation points (t = -8.07, p = 0.001), with a very large effect size (d = 1.310), indicating that participants' perceptions changed substantially after the intervention. These results suggest that the intervention had a significant positive impact, leading to an improvement in participants' perceptions of this competence.

Table 11. Descriptive statistics and comparison between the two applications of questionnaire - DRPR (Pre-Intervention and Post-Intervention)

		M	*SD*	*t*	*p*	*d*	Effect size
DRPR	Pre-Intervention	20.95	2.93	-8.07	0.001	1.310	Very large
	Post-Intervention	24.16	3.11				

The sessions of Stage 2 of the training program were designed based on solving problem situations suitable for Primary School, incorporating mathematical content and dimensions of Computational Thinking. These tasks required the pre-service teachers to develop their problem-solving skills by identifying strategies to solve the problems and integrating various types of knowledge, both mathematical and didactic. Figure 4 shows the solution of a group of pre-service teachers, where they presented several possible approaches to solving the given problem.

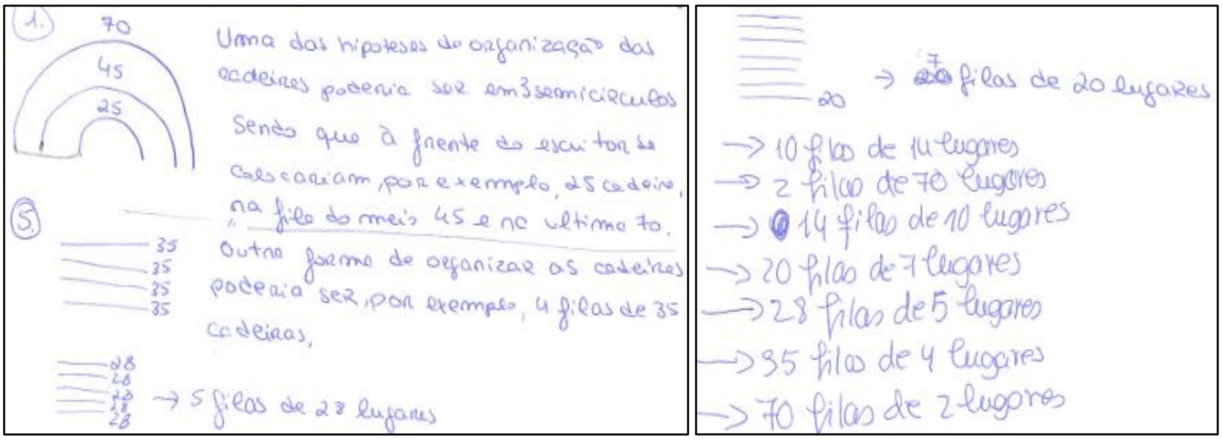

Figure 4. Excerpt from the exploration sheet of one of the pre-service teachers' groups. (Translation: Left image: One way of arranging the chairs could be in 3 semicircles, with 25 chairs in front of the writer, 45 in the middle row and 70 in the last row; Another way of arranging the chairs could be, for example, 4 rows of 35 chairs; 5 rows of 28 seats. Right image: 7 rows of 20 seats; 10 rows of 14 seats; 14 rows of 10 seats; 20 rows of 7 seats; 28 rows of 5 seats; 35 rows of 4 seats; 70 rows of 2 seats)

During the adaptation of problem-solving situations to their internship contexts, the pre-service teachers needed to find strategies to tailor the situations to the realities of their classrooms. The following dialogue transcript shows the discussion between the researcher and a group of pre-service teachers, highlighting the development of different strategies to adjust the situation to the teaching level and meet the students' needs.

Researcher: Thinking about everything they would need to do in Scratch to perform that addition—meaning, the question of understanding how they would program to get to the ten and then to the three units—I'm not sure to what extent this resource might not...

Pre-service teacher S: That's exactly what I was going to say. It could be BaseBlocks, or it could be in Hypatiamat, which has an app there for representing with multi-base blocks. So, I would use this...

Pre-service teacher H: So, work with the ten and the units in another...

Pre-service teacher S: Yes, for example, this lesson plan would be excellent in one of those applications. In Hypatiamat, there's one specifically for representation.

5. Discussion

This study aimed to analyze the impact of an intervention designed to develop pre-service teachers' pedagogical knowledge, based on their perceptions of the levels of Computational Thinking competencies. The goal was to help them become proficient in selecting, adapting, and implementing tasks that integrate the development of Computational Thinking dimensions into their practices, while simultaneously promoting the learning of mathematical knowledge. Therefore, this section will discuss how the main characteristics of this training program align with the recommendations from the relevant literature and how they may have influenced the observed changes in the perception of the levels of the five Computational Thinking competencies among pre-service teachers.

During Phase 1 of the training program, the model of exploratory teaching practices was implemented, starting with pre-service teachers solving problem-solving tasks in small groups. The proposed solutions were then discussed and systematized in a large group. Next, the pre-service teachers adapted the problem-solving tasks to their internship contexts by creating a hypothetical lesson plan, which was later discussed in the large group during the third phase of the lesson. After the implementation of the training program, an improvement in the perception of the Creativity competency was observed. As noted by Israel-Fishelson and Hershkovitz (2022), this competency is developed when solving problems and formulating different solutions. Therefore, the change in perception can be attributed to the fact that pre-service teachers were asked to find multiple ways to solve the presented problems (Liu et al., 2023). They were also asked to adapt the tasks to their internship contexts, leading to the emergence of various strategies for solving them, which highlighted the development of the Creativity dimension (Doleck et al., 2017).

The choice of the exploratory teaching practices model, in which pre-service teachers completed all the proposed tasks in small groups, helps to explain the observed change in the Cooperativity competency (Gasaymeh & AlMohtadi, 2024). This competency is developed when students work in small groups, giving them the opportunity to assist one another, discuss, and defend their ideas, as stated by Zhou and Tsai (2023). The third phase of the exploratory teaching practices model, implemented in the training program, also helps to explain the improvement observed in the perception of the Critical Thinking competency. During the sharing and discussion of tasks, pre-service teachers analyzed the solutions presented by their peers, questioned, and critiqued the proposals, which fostered the development of Critical Thinking, as noted by Jiang and Li (2021). As for the Algorithmic Thinking and Problem-Solving competencies, where improvements in the pre-service teachers' perceptions were also observed, the changes can be attributed to the selection of the problem-solving tasks implemented in the training program. Algorithmic Thinking is developed when identifying and representing sequences to solve a task, steps that were required from the pre-service teachers when solving problem situations, thus aligning with Martínez et al. (2022) regarding the development of this competency. The distinctive feature of beginning the sessions with the resolution of problem situations meant that the pre-service teachers needed to find solutions in a logical and structured way, which, as noted by Korkmaz et al. (2017), explains the improvements observed in the perception of the Problem-Solving competency.

In Phase 2 of the training program, microteaching sessions were conducted with the goal of improving the intervention plan that had been initiated in Phase 1 of the study. Phase 2 culminated with the implementation of the plan in their teaching contexts. The implementation of the microteaching sessions, in which the pre-service teachers initially acted as students and later had the opportunity to comment on the session they had participated in, helps explain the change in the perception of Cooperativity competency. As noted by Doleck et al. (2017), the participation of pre-service teachers in the role of teachers, with their peers acting as students, allows them to feel more engaged, not only with the members of their own group but also with other members of the class. This culminates in the development of their Cooperativity skills. The change in the pre-service teachers' perception of the Creativity competency is also explained by the implementation of the microteaching sessions, as it gave the participants the opportunity to observe different proposals and viewpoints for implementing the plan they were to develop (Israel-Fishelson & Hershkovitz, 2022).

The improvement in the perception of Algorithmic Thinking, similar to what occurred in Phase 1 of the training program, can be explained by the fact that the pre-service teachers needed to structure their proposals step by step in order to reflect in detail on the stages of the plan and, subsequently, share them with the other colleagues and the researcher (Ching & Hsu, 2024). In this regard, the improvements observed in the perception of Critical Thinking can also be justified by the discussions that took place regarding the plans proposed by the pre-service teachers (Wu, Silitonga, et al., 2024). In line with what Jiang and Li (2021) observed, the development of Critical Thinking was evident in the pre-service teachers, as they demonstrated the ability to analyze proposals, identify less positive aspects, and formulate relevant questions about the shared proposals. Furthermore, by showing that they were able to reformulate the plans they had developed and find alternative solutions based on the feedback they received, the pre-service teachers demonstrated the development of their Problem-Solving competency (Korkmaz et al., 2017; Wu, Asmara, et al., 2024).

6. Conclusion

This study highlights the significant impact of a carefully designed training program on pre-service teachers' perceptions of five key Computational Thinking competencies: Creativity, Cooperativity, Critical Thinking, Algorithmic Thinking, and Problem-Solving. By integrating theoretical, practical, and reflective components over an extended period, the program promoted a deeper understanding of these competencies and their practical application in educational contexts.

The improvement in Creativity perceptions was attributed to tasks that encouraged pre-service teachers to explore diverse strategies for problem-solving and lesson adaptation. Cooperativity was enhanced through collaborative group work and microteaching sessions, fostering peer interaction and collective engagement. The focus on sharing and critically discussing proposed solutions was instrumental in developing Critical Thinking, enabling participants to analyze, evaluate, and refine their approaches. Algorithmic Thinking was strengthened by requiring participants to structure task steps logically and sequentially, both in problem-solving and in planning interventions. Finally, the iterative refinement of intervention plans based on feedback contributed significantly to the enhanced perception of Problem-Solving skills.

This study underscores the importance of integrating long-term training programs into Initial Teacher Training, emphasizing the connection between theory and practice. Such programs are vital for equipping pre-service teachers with the competencies necessary for effective teaching in the 21st-century educational landscape.

7. Implications and Suggestions

This study is considered to have implications for research on Computational Thinking, as it presents a training program implemented over an extended period, integrating theoretical, practical, and reflective knowledge. By addressing one of the major limitations identified in the specialized literature regarding to the short duration of the programs developed, the program presented here was implemented over two semesters. This approach allowed pre-service teachers not only to understand the theoretical concepts related to Computational Thinking but also to engage in opportunities to develop implementation proposals, implement them with their colleagues, and later with their student groups. Furthermore, the continuous support from the research team and the moments of reflection on each developed task facilitated the identification of key difficulties and areas for improvement, leading to the constant evolution of the proposals throughout the program.

Thus, some practical implications are suggested for teacher training institutions. It is essential that initial teacher training programs include specific interventions that integrate theory and practice, as demonstrated in Phase 1 of this study, following the exploratory teaching practices model. It is also recommended to implement sessions where pre-service teachers can implement didactic proposals and receive feedback on their performance, similar to the microteaching sessions conducted in Phase 2 of this study. This methodology proved effective not only in developing Computational Thinking skills but also in encouraging reflection on the implemented practices and, consequently, in improving the quality of the proposed solutions.

The sample of this study is predominantly composed of female participants from a single university in Portugal. However, it is important to note that this distribution reflects the reality of Initial Teacher Training programs in Portugal. Nevertheless, it is recommended that future studies replicate this research with a more diverse sample.

Declarations

Author Contributions. RNR, CC, SB-C, MA & FM: resources, visualization, writing – review & editing; RNR: conceptualization, data curation, formal analysis, funding acquisition, investigation,

methodology, software, validation, writing – original draft; CC: conceptualization, data curation, supervision, validation; SB-C: conceptualization, formal analysis, funding acquisition, methodology, software, supervision, writing – original draft; MA: writing – review & editing original draft; FM: conceptualization, data curation, formal analysis, funding acquisition, methodology, project administration, software, supervision, validation. All authors have read and approved the final version of the article.
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About the Contributor(s)

Rita Neves Rodrigues is a PhD student in Science and Technology Education Research of the University of Trás-os-Montes and Alto Douro, Portugal and an invited lecturer at the Polytechnic University of Coimbra. PhD Research Fellow at the Foundation for Science and Technology, researcher at the research Centre Didactics and Technology in Education of Trainers at the University of Aveiro. Research interests include Mathematical Education, focusing on developing the didactic knowledge of pre-service teachers so that they can integrate the dimensions of Computational Thinking into their practices, simultaneously promoting learning of mathematical knowledge.
Email: ritanevesrodrigues@hotmail.com
ORCID: https://orcid.org/0000-0001-8072-8453

Cecília Costa is an Associate Professor at the School of Science and Technology of the University of Trás-os-Montes e Alto Douro, Portugal. With a PhD in Mathematics and Habilitation in Didactics of Science and Technology, she is the director of the doctoral course in Science and Technology Didactics, and she teaches Didactics of Mathematics in several teacher training courses and a researcher at the research Centre Didactics and Technology in Education of Trainers at the University of Aveiro (UIDB/00194/2020). Her main research areas are Sciences and Technological Education (STEM) Research, in particular: teaching practices and teacher mediation of student learning, teacher education and professional development, artefacts as epistemic tools to enhance STEM learning, and Instrumental Orchestration.

Email: mcosta@utad.pt
ORCID: https://orcid.org/0000-0002-9962-562X

Sónia Brito Costa is a lecturer and researcher at the Polytechnic University of Coimbra. She holds a Bachelor's, Master's, PhD, and Post-Doctorate in Psychology. She is also certified in Cognitive Behavioral Psychotherapy (APTC), Legal Medicine and Forensic Sciences, Health Ethics, Gender Equality, and Human Trafficking Prevention and Victim Support. Recognized as a Specialist in Clinical and Health Psychology and an Advanced Specialist in Justice Psychology by the Portuguese Psychologists' Order, she is additionally a certified trainer (CNQF). She also coordinates the Coimbra Branch of the Centre for Research and Innovation in Education (INED). She has authored over 80 publications and contributed extensively to international conferences. She acts as Expert Evaluator at the European Commission, and she is also reviewer and editor in various editorial boards, dedicated to advancing research in psychology.
Email: sonya.b.costa@gmail.com
ORCID: https://orcid.org/0000-0002-7074-887X

Maryam Abbasi is a researcher specializing in Artificial Intelligence (AI) and Machine Learning, with a strong academic background that includes a PhD in Informatics Engineering, a Master's degree, and a Bachelor's degree in Computer Science. She is affiliated with the Institute of Applied Research (i2A) at the Polytechnic Institute of Coimbra (IPC), the Centre for Natural Resources, Environment and Society (CERNAS), and the Laboratory of Artificial Neural Networks (LARN) at the Center for Informatics and Systems of the University of Coimbra (CISUC). Her research focuses on advanced data science and pattern recognition techniques in AI and machine learning to address complex biological problems. She develops innovative algorithms that leverage these methods to model challenges and provide meaningful insights. Her interdisciplinary expertise bridges computational modeling and practical applications, contributing to advancements in both AI methodologies and their implementation in diverse domains.
Email: maryam.abbasi@ipc.pt
ORCID: https://orcid.org/0000-0002-9011-0734

Fernando Martins is a Full Professor at the Polytechnic University of Coimbra - Coimbra Education School, Portugal. With Aggregate Degree in Child Studies and a PhD in Mathematics, he teaches Mathematics and Didactics of Mathematics subjects in Basic Education degrees and Master's in Training for Educators and Teachers. Researcher at the inED - Centre for Research and Innovation in Education (UIDB/05198/2020, and DOI identifier https://doi.org/10.54499/UIDB/05198/2020), Instituto de Telecomunicações (UIDB/50008/2020, and DOI identifier https://doi.org/10.54499/UIDB/50008/2020) and Research Group in Training, Education, and Intervention. Research interests include mathematical knowledge for teaching, mathematical methods applied to sports sciences problems and engineering, social network analysis, elementary mathematics, computational thinking, educational robotics, and STEAM education.
Email: fmlmartins@esec.pt
ORCID: https://orcid.org/0000-0002-1812-2300