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Evaluating pre-service primary school teachers' didactic knowledge in mathematics through the planning of exploratory teaching practices integrating computational thinking

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Lesson planning is a complex and central professional practice in teacher education, requiring the integrated mobilization of different types of didactic knowledge in mathematics. The recent integration of Computational Thinking into the Portuguese Mathematics curriculum reinforces the need to prepare pre-service primary school teachers to design teaching practices that promote the development of this mathematical ability. This study aims to evaluate the didactic knowledge in mathematics of pre-service teachers at three moments (Pre-Intervention, Post-Intervention I, and Post-Intervention II) throughout a training program, through the planning of Exploratory Teaching Practices integrating tasks designed to promote the development of the Computational Thinking dimensions of abstraction, decomposition, algorithm, debugging, and pattern recognition. Nineteen female Pre-Service Primary School Teachers, aged between 20 and 54 years ($M = 24.47$; $SD = 9.576$), participated in the study, enrolled in an Initial Teacher Training during the 2023/2024 academic year at a Portuguese higher education institution. Following a mixed methods design, the Levels of Suitability of the lesson plans and the Global Performance of the pre-service teachers were analyzed across the three moments. The results of the study show statistically significant differences both in the Levels of Suitability of the lesson plans for Exploratory Teaching Practices integrating Computational Thinking and in the Global Performance of the pre-service primary school teachers across the three moments. In conclusion, the present study provides evidence of how the didactic knowledge in mathematics of pre-service teachers can be evaluated through the planning of Exploratory Teaching Practices with the integration of Computational Thinking.

KEYWORDS
computational thinking, didactic knowledge in mathematics, exploratory teaching practices, initial teacher training in primary school, lesson planning

1 Introduction

Initial Teacher Training is a complex process that integrates a set of experiences and learnings essential to the development of pre-service teachers' didactic knowledge (Duarte et al., 2024). For students to learn meaningfully, it is essential that the teacher integrates content knowledge of the discipline with other types of knowledge that guide their practice (Giacomelli and Lopes, 2020). The pre-service teacher must articulate content knowledge with curriculum guidelines, students' learning processes, and classroom teaching practices to be capable of designing a high-quality and purposeful lesson plan (Beckmann and Ehmke, 2023).

Lesson planning is a demanding professional practice and is recognized by several authors as one of the most important—but also one of the most challenging—tasks for pre-service teachers (Beckmann and Ehmke, 2023; Conceição et al., 2022; Tankiz and Atman Uslu, 2023). During periods of curricular change, lesson planning becomes even more complex, especially when essential teaching and learning resources, such as educational curricula, are being restructured and require adaptation by teachers (Pepin et al., 2025). This context reinforces the need to promote teachers' professional autonomy, recognizing their role as critical and reflective agents in the construction of planned, contextualized, and pedagogically aligned practices with the specificities of school realities (Alarcão, 2020; Fonseca and Ponte, 2025; Nóvoa, 2021).

In 2021, the national mathematics curriculum for basic education in Portugal was updated, coming into effect in the 2022/2023 academic year [Ministério da Educação (ME), 2021]. This document states that teachers must include in their lesson planning a set of mathematical competencies to be developed in an integrated way within the approach to mathematical topics. It also introduces a particularly relevant change: the inclusion, for the first time, of Computational Thinking as a competency to be developed in mathematics education—adding further complexity to a lesson planning process that is already challenging for pre-service teachers (Conceição et al., 2022). Among the methodological guidelines for mathematics teaching, particular emphasis is placed on providing students with time and space to explore mathematical tasks, discuss their solution strategies, and collectively systematize their learning (Freitas et al., 2025a; ME, 2021). Collaborative working methods are also valued, where students can interact with one another under the teacher's supervision, fostering autonomy, mathematical communication, and reasoning. These guidelines align with the reference framework for Exploratory Teaching Practices in mathematics, as defined in Canavarro et al. (2012) and Canavarro and Reis, 2018. Such recommendations call for a reconfiguration of planning practices by both teachers and pre-Service teachers, ensuring effective articulation between the content of various topics and the competencies to be developed, while applying the proposed methodological guidelines (Pepin et al., 2025; Rodrigues et al., 2024).

It is essential that Initial Teacher Training enables pre-service teachers to plan teaching practices that respond to these guidelines (Alrwaished, 2024; Tadeu et al., 2025), in particular, it is necessary to provide specific training that allows them to develop the didactic knowledge to integrate Computational Thinking into their planning in an intentional and reasoned way (Tripon, 2022). Within this context, and as part of a study aimed at developing the Didactic Knowledge in Mathematics (DKM) of Pre-Service Primary School Teachers (PSPST) required to integrate Computational Thinking into their teaching practices, in accordance with the guidelines established by the Portuguese Mathematics curriculum (ME, 2021), a training program was designed and implemented at a Portuguese higher education institution in the 2023/2024 academic year. This training program was developed with PSPST, in the context of master's degree curricular units in teaching and structured in such a way as to promote the articulation between theory, practice and reflection in the planning of mathematics lessons integrating the development of the five Computational Thinking dimensions defined in the Portuguese curriculum: abstraction, decomposition, pattern recognition, algorithmic thinking, and debugging. In this context, the following research question was formulated for this study: did the training program influence the development of the didactic knowledge in mathematics required for Pre-Service Primary School Teachers to plan Exploratory Teaching Practices that integrate the development of Computational Thinking? This study aims to evaluate the Didactic Knowledge in Mathematics of the Pre-Service Primary School Teacher through the planning of Exploratory Teaching Practices that integrate Computational Thinking, developed in three moments throughout the training program. Based on the literature (Duarte et al., 2024; Zaragoza et al., 2023, 2024), it is understood that PSPSTs who demonstrate a higher Level of Suitability and Global Performance in the planning of teaching practices show greater DKM, so the evolution of the development of the DKM of the PSPST is analyzed based on the assessment of the adequacy of the planning of Exploratory Teaching Practices that integrate Computational Thinking. Thus, the following hypotheses were formulated:

H1. There are statistically significant differences in the Levels of Suitability of the Exploratory Teaching Practices plans that integrate Computational Thinking carried out by pre-service primary school teachers between Pre-Intervention, Post-Intervention I and Post-Intervention II;

H2. There are statistically significant differences in the Global Performance of pre-service primary school teachers when planning Exploratory Teaching Practices that integrate Computational Thinking between Pre-Intervention, Post-Intervention I and Post-Intervention II.

The main contribution of this study is an approach to evaluating the Didactic Knowledge in Mathematics of the Pre-Service Primary School Teachers through planning Exploratory Teaching Practices that integrate Computational Thinking.

2 Literature review

The present study examines the Didactic Knowledge in Mathematics of Pre-Service Primary School Teachers as evidenced in the planning of Exploratory Teaching Practices integrating Computational Thinking. Therefore, the literature review first presents the curricular framework that justifies the integration of Computational Thinking in mathematics education, followed by the theoretical framework underpinning Didactic Knowledge in Mathematics and, finally, the characteristics of Exploratory Teaching Practices that guided the planning analysed in this study.

2.1 Computational thinking

Recent curricular reforms in mathematics education have emphasized the integration of Computational Thinking as an ability to be developed by students. The Joint Report of the Council of the European Union and European Commission (Council of the European Union and European Commission, 2015) highlighted the importance of adopting innovative approaches in teaching, with a focus on developing digital and social skills in line with the demands of society. According to Trocado et al. (2022), these guidelines may have been the starting point for the introduction of Computational Thinking into the curricula of several countries, aimed at developing digital skills and adopting pedagogical practices centered on problem-solving. In some countries Computational Thinking has been included in the general curriculum (Santos et al., 2025), in Portugal it appears as an integral competence of the official Mathematics curriculum (ME, 2021) from primary to secondary education (approximately 6–18 years of age) and involves the development of a set of practices that are indispensable in mathematical activity and provide students with tools that allow them to solve problems (ME, 2021).

The effective integration of Computational Thinking into mathematics teaching requires teachers and pre-service teachers to be aware of how it is defined and of the indications for operationalization defined in the official educational curriculum (Amante et al., 2023). The Portuguese curriculum (ME, 2021) resents a structured definition of Computational Thinking and defines five dimensions to be developed in an integrated way: abstraction, decomposition, algorithm, debugging and pattern recognition. These definitions are in line with the literature (Angeli et al., 2024; Machuqueiro and Piedade, 2024; Santos et al., 2025; Wing, 2006). The development of Abstraction involves situations in which students must focus on the essential aspects of tasks in order to simplify their solutions (Candeias et al., 2025). In the development of Decomposition, it is necessary to create opportunities for students to break down a problem into simpler parts in order to make solving it more accessible (Chaabi et al., 2025). To develop the Algorithm dimension, situations are used in which students need to structure the necessary steps to solve a task in a sequential manner (Yun and Crippen, 2025). The development of Debugging involves situations in which students must try to identify inaccuracies, errors or steps to be revised, with the aim of optimizing the resolution proposals (Macann and Hartnett, 2025). In order to develop the Pattern Recognition dimension, it is essential to encourage students to identify regularities and similarities in the processes of solving tasks, allowing them to use previously developed and understood strategies in new tasks (Palop et al., 2025). In this sense, the Computational Thinking dimensions (Macann and Hartnett, 2025; ME, 2021; Palop et al., 2025) are the reference framework for the practices to be developed in the classroom and are therefore fundamental for guiding the planning of teaching practices that promote the development of Computational Thinking integrated with mathematical topics.

However, recent literature shows that significant gaps in initial teacher training remain regarding Computational Thinking. Espinal et al., 2024 identify that many programs prioritize conceptual understanding but offer few opportunities for Pre-Service Primary School Teachers to learn how to design, plan, and evaluate tasks that foster the development of Computational Thinking. Tariq et al., 2025 reinforce this perspective by noting an insufficient focus on the integration of Computational Thinking within higher education, precisely where initial teacher training takes place. Complementarily, Tadeu et al., 2025 highlights the scarcity of clearly identified and implemented methods that effectively enhance Pre-Service Primary School Teachers' skills in Computational Thinking. Taken together, these gaps underline the need to investigate training approaches that support the development of didactic knowledge and the ability to plan teaching practices that integrate Computational Thinking in an intentional and appropriate way.

2.2 Didactic knowledge in mathematics of the pre-service teacher

Teachers' Didactic Knowledge in Mathematics (DKM) is a central element of professional practice, integrating specific knowledge about content, students, the curriculum and teaching practices (Duarte et al., 2024; Ponte, 2012). This knowledge, which is essential for effective teaching practice, is evident in lesson planning, a demanding task that requires the articulated mobilization of these different types of knowledge (Beckmann and Ehmke, 2023; Rodrigues and Ponte, 2020; Serrazina, 2017). In the context of Initial Teacher Training, planning is a particular challenge, given that the DKM of the pre-service teachers is still under development (Duarte et al., 2024). However, this knowledge is central to planning a math lesson. Thus, it is necessary to have a thorough understanding of the concepts to be taught, to interpret the curriculum guidelines rigorously, to know the students, their difficulties and the most appropriate strategies for the group (Cardoso et al., 2025; Noviyanti et al., 2025).

One framework that helps understand the different types of knowledge that make up the didactic knowledge of teachers who teach mathematics is Ponte's (Ponte, 2012) which includes the following components: Knowledge of Mathematics for Teaching (KMT), Knowledge of the Curriculum (KC), Knowledge of Students and their Learning Processes (KSLP) and Knowledge of Teaching Practice (KTP). KMT refers to the in-depth understanding of mathematical concepts, their connections and representations and their applicability in school contexts (Ponte, 2012; Serrazina, 2017). It is known that pre-service teachers have gaps in this type of knowledge, which leads to difficulties in planning lessons and defining concrete actions aligned with the tasks to be implemented (Bezerra and Quaresma, 2023; Vieira et al., 2022). Pre-service teachers need to have developed this component in order to be able to define learning objectives and pedagogical actions aligned with the mathematical content or specific mathematical skills to be developed (Kurt and

Çakıroğlu 2025; Zaragoza et al., 2023). KC is related to the domain of curricular guidelines, both for defining learning objectives and the pedagogical sequence to achieve them, and for selecting and using relevant resources for learning (Duarte et al., 2024). Njiku, 2025 found that pre-service teachers have difficulty mobilizing specific resources that are properly aligned with the content to be covered, thus compromising teaching effectiveness. In order to plan a lesson effectively, pre-service teachers need to mobilize knowledge that allows them to articulate the curriculum guidelines with the content of the tasks to be developed, as well as being able to select and integrate appropriate teaching resources that promote learning (Martin and Jamieson-Proctor, 2022; Rodrigues and Ponte, 2020). For pre-service teachers to develop the knowledge necessary to adequately define learning objectives and coherently integrate teaching resources, it is essential that they receive feedback on their pedagogical decisions (Karalar and Aslan Altan, 2018). In this context, the implementation of micro-teaching sessions can be an effective strategy, as it allows pre-service teachers to experiment, reflect and adjust their planning and practice based on the recommendations they receive from both colleagues and trainers (Täschner et al., 2025). KSLP is defined as the teacher's knowledge of the students, their interests, characteristics, difficulties and ways of learning (Fonseca and Ponte, 2025). Given pre-service teachers' limited teaching experience, it is common to observe gaps in this type of knowledge (Cardoso et al., 2025). Hourigan and Leavy (Hourigan and Leavy, 2019) state that for pre-service teachers to develop knowledge, contact with students is not enough; it is essential that they observe, reflect and have the opportunity to adapt and refine the lesson based on the evidence gathered during practice. In the context of lesson planning, the KSLP is essential for pre-service teachers to anticipate learning difficulties, define strategies to overcome them and promote approaches that encourage students to develop and share different types of reasoning when solving tasks (Copur-Gencturk and Li, 2023; Martins et al., 2024). In addition to the three components of knowledge mentioned above, KTP is the core of the teacher's DKM and relates to all the essential points of lesson planning (Ponte, 2012). This type of knowledge occupies a central place in lesson planning, as it is essential for defining the structure of the lesson, time management and the definition of forms of assessment and feedback, reflecting an integrated and operational vision of the didactic knowledge needed to effectively conduct teaching practice (Rodrigues and Ponte, 2020). With regard to KTP, it should be noted that pre-service teachers tend to have difficulties in planning lessons in a coherent way, namely in articulating learning objectives, strategies for achieving them and ways of evaluating (Beckmann and Ehmke, 2023).

In this framework, knowledge should not be seen in a fragmented way, but as an articulated whole, aimed at promoting meaningful mathematical learning (Silva and Ponte, 2025). Despite the centrality of planning in teaching practice, pre-service teachers' planning skills remain under-researched, especially with regard to how they mobilize knowledge in lesson planning (Beckmann and Ehmke, 2023; Zaragoza et al., 2023). Although research on professional knowledge focuses on classroom observation, lesson planning offers a privileged context for analyzing pedagogical decisions and the knowledge mobilized (Zaragoza et al., 2024). Duarte et al. also identify, in the field of research into teacher training, the scarcity of studies that specifically explore the development of didactic knowledge in the context of Exploratory Teaching Practices, highlighting this as a relevant gap to be investigated. It is therefore important to investigate how Exploratory Teaching Practice plans can be analyzed to evaluate DKM.

2.3 Exploratory teaching practices

Exploratory Teaching Practices are an approach focused on the active construction of knowledge by students, through the resolution of challenging tasks that promote exploration, questioning, argumentation and reflection (Canavarro et al., 2012; Freitas et al., 2024). A lesson planned according to Exploratory Teaching Practices is generally organized into four phases: Task introduction phase, Task development phase, Task discussion phase and Mathematical learning systematization, allowing for meaningful and progressive learning (Canavarro et al., 2012; Rodrigues et al., 2025). The development of the whole lesson is intrinsically linked to the tasks presented to the students. These tasks often take the form of problems or investigations, requiring students to work collaboratively, mobilize prior knowledge and develop different strategies for solving them (Azevedo, 2020; Ferreira and Ponte, 2017). The teacher's role in these practices is that of mediator and facilitator: observing, listening, relaying ideas, asking intentional guiding questions and managing discussions in order to promote students' mathematical thinking (Freitas et al., 2025b; Oliveira et al., 2013).

Several studies have highlighted the potential of Exploratory Teaching Practices to promote essential mathematical skills and student learning success (Freitas et al., 2025a; Silva et al., 2024). However, it is important to understand how this approach challenges pre-service teachers, particularly in terms of their ability to plan lessons that require in-depth DKM and intentional management of each phase of the lesson (Martins et al., 2021). Planning a lesson centered on Exploratory Teaching Practices requires more than selecting content or tasks, it involves anticipating students' contributions, setting clear objectives, anticipating difficulties and being able to structure the discussion productively (Duarte et al., 2024; Ferreira and Ponte, 2017). Recent studies show that, when planning these practices, the main difficulties identified by pre-service teachers relate to formulating learning objectives, selecting and adapting suitable tasks, as well as predicting students' work and possible unforeseen events that may arise during the lesson (Duarte et al., 2024; Quaresma et al., 2024). Täschner et al., 2025 argue that one of the ways to improve pre-service teachers' self-efficacy and, consequently, their performance, is through experiences in which they have the opportunity to observe teaching models and good practices from other professionals. Thus, considering the importance of training pre-service teachers to implement Exploratory Teaching Practices with their students, it is pertinent that this approach is also integrated into Initial Teacher Training programs (Henriques and Martins, 2022).

3 Methodology

3.1 Study design

This study adopted a convergent mixed methods design, as defined by Cohen et al. (Cohen et al., 2018), integrating quantitative and qualitative approaches in a complementary way. The quantitative component aimed to compare the Levels of Suitability and Global Performance of Pre-Service Primary School Teachers (PSPST) at three different moments: before the intervention (Pre-Intervention—M1), after the first phase of the intervention (Post-Intervention I—M2) and after the second phase (Post-Intervention II—M3). At the same time, the qualitative component involved an inductive and exploratory content analysis of the lesson plans produced by the PSPSTs during the same three data collection moments, allowing the identification and interpretation of evidence related to the development of Didactic Knowledge in Mathematics. The quantitative and qualitative data were analyzed independently and subsequently integrated during the interpretation of the results through data triangulation, providing a more comprehensive understanding of the effects of the training program on the development of the PSPSTs' Didactic Knowledge in Mathematics (Cohen et al., 2018; Creswell and Creswell, 2017).

3.2 Participants

Nineteen female PSPSTs took part in this study, aged between 20 and 54 (M = 24.47; SD = 9.576), all enrolled in the 2023/2024 academic year at a Portuguese higher education institution. Among the participants, twelve were attending the Master's degree program in "Primary School Teaching [Grades 1–4; approximately 6–10 years old] and 2nd Grade School Teaching [Grades 5–6; approximately 10–12 years old] in Mathematics and Experimental Sciences", and seven the Master's degree in "Primary School Teaching and 2nd Grade School Teaching in Portuguese and History and Geography of Portugal". During that academic year, as part of their master's degree, the PSPSTs completed a year-long curricular internship in a Primary School, spanning both semesters of the academic year, organized in groups of two or three. These groups were maintained throughout the training program to ensure continuity between the teaching practice and the development of the proposals, allowing for more effective adaptation to the specificities of the school contexts involved.

The sample was selected using a non-probabilistic convenience sampling strategy. All PSPSTs enrolled in the above-mentioned master's programs who voluntarily expressed an interest in participating were included in the study. PSPSTs who did not give their consent to participate, who were absent from the most important practical sessions of the training program, or who did not complete tasks essential to the development of the intervention, such as drawing up lesson plans or solving the proposed tasks, were excluded from the study. It should be noted that the participants had a bachelor's degree in basic education, which is the compulsory qualification for access to Initial Teacher Training master's degrees. This course includes curricular units on elementary mathematics and the didactics of elementary mathematics for the first years of school, providing knowledge of the Portuguese mathematics curriculum and elementary notions of planning.

3.3 Ethical statement

The Declaration of Helsinki's ethical guidelines were closely followed in this study, which placed a high priority on safeguarding the rights and welfare of participants. The Polytechnic University of Coimbra's Ethics Committee granted prior clearance (reference 101_CEIPC/2022, issued on June 24, 2022), guaranteeing that all procedures adhered to ethical standards. After receiving a thorough explanation of the study's objectives, the voluntary nature of their involvement, and their freedom to discontinue participation at any moment without facing consequences, participants gave their informed consent.

3.4 Instruments

To evaluate the development of the PSPSTs' Didactic Knowledge in Mathematics (Ponte, 2012; Rodrigues and Ponte, 2020), tasks were applied at three moments (see Figure 1): Pre-Intervention (M1), Post-Intervention I (M2, between Phase 1 and Phase 2) and Post-Intervention II (M3). The focus of the tasks analyzed in this study (Part II) was the development of Exploratory Teaching Practice plans that integrated Computational Thinking and allowed for a comparative analysis of the Level of Suitability of the solutions presented and the Global Performance of the PSPSTs in the construction of these plans.

The tasks applied are structured in two parts (Table 1): Part 1 consisting of six tasks and Part 2 of four and are based on the Framework of the Didactic Knowledge of Teachers who Teach Mathematics (Ponte, 2012; Rodrigues and Ponte, 2020).

In Part 1, the Pre-Service Primary School Teachers, at each of the three moments (M1, M2 and M3), first solved a problem-solving situation (see Table 2) and then completed five additional tasks designed to promote the different dimensions of Computational Thinking (see Table 1). The three problem-solving situations presented in Table 2, adapted from Canavarro et al., 2022, addressed objectives within the same mathematical topic [Numbers (ME, 2021)], while ensuring the diversity of mathematical concepts addressed at each moment. Subsequently, the PSPST completed Part 2, which consisted of developing an Exploratory Teaching Practices plan by adapting the tasks completed in Part 1. Since the aim of Part 2 was to plan an Exploratory Teaching Practice integrating Computational Thinking, the present article focuses exclusively on the analysis of this part at each of the three moments (M1, M2 and M3), in order to evaluate the Pre-Service Primary School Teachers' Didactic Knowledge in Mathematics through the lesson plans they developed.

Table 3 shows the purposes of the Part 2 tasks carried out by the PSPSTs.

The tasks were developed by the research team and validated by five external researchers with relevant experience in the field of

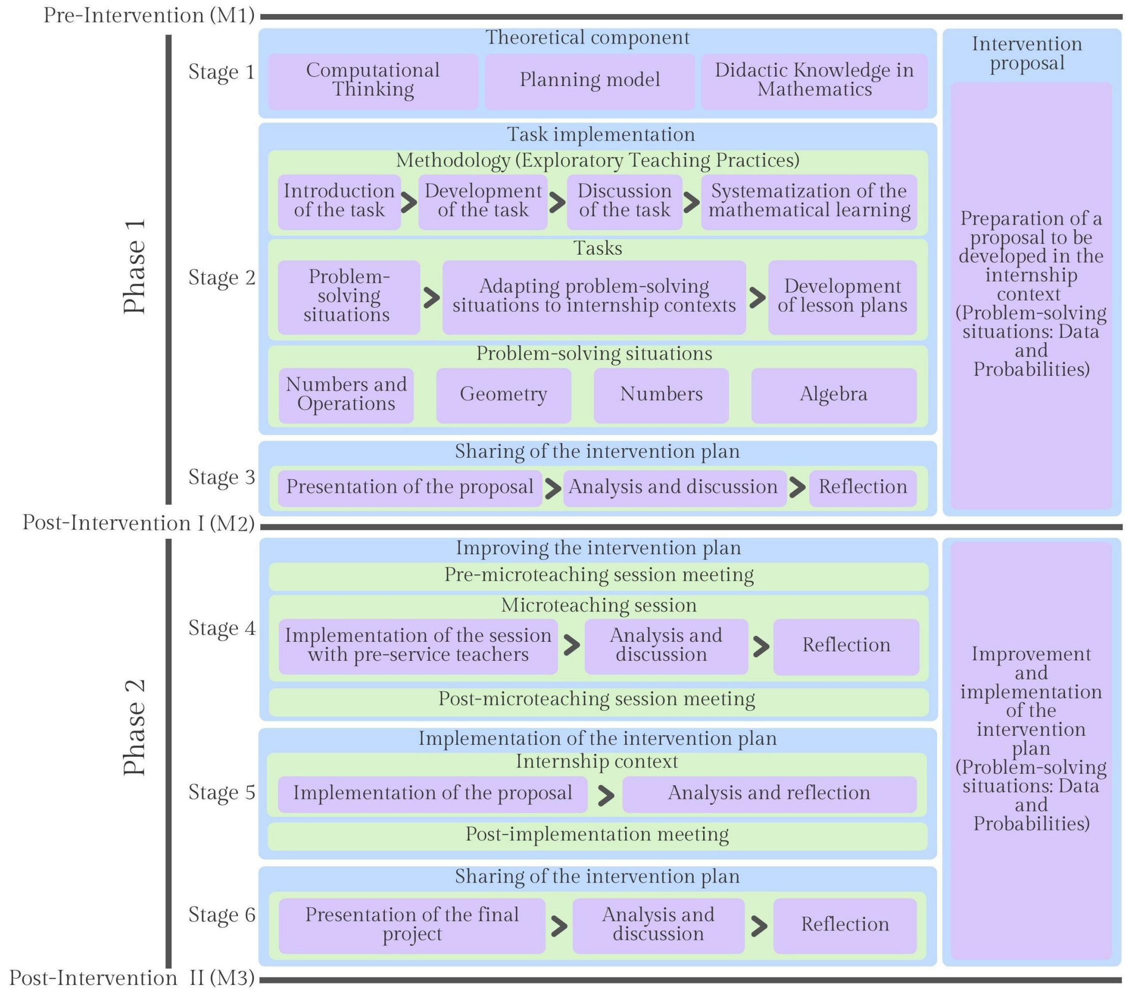


FIGURE 1
General structure of the training program. (Source: Authors own elaboration).

Mathematics Education. These experts work directly in Initial Teacher Training, both in national and international contexts, and have recognized experience in the development of didactic Knowledge in mathematics and the didactics of mathematics, including in the specific field of the development of Computational Thinking.

3.5 Pedagogical intervention program

Below is a summary of the training program implemented, the general structure of which is shown in Figure 1 (Rodrigues et al., 2025) and which shares similar characteristics with the programs implemented by Piedade et al., 2018, Silva et al., 2024 and Tadeu et al., 2025.

The main purpose of the training program was to promote the development of the PSPSTs' Didactic Knowledge in Mathematics (DKM), with a focus on the integration of Computational Thinking, and it took place over the course of the 2023/2024 academic year. The intervention was organized into two phases, with three stages each, spread over two semesters. In stage 1 of Phase 1, the PSPSTs deepened their knowledge of Computational Thinking, the lesson planning template and Exploratory Teaching Practices. In stage 2, experimented with solving tasks integrating Computational Thinking and mathematical topics, and then developed lesson plans that included these tasks, following the model presented in Table 1 (see Section 2.4. Instruments). In stage 3, they developed and shared with the other participants an intervention plan to be applied in the internship context, following the same template. Each group also prepared a written assignment describing the design and planning of the intervention plan. This written assignment included a reflective conclusion in which the participants summarized the main learning outcomes and reflected on the development of the intervention plan. In Phase 2, the participants carried out micro-teaching sessions (Step 4), implemented their intervention plans in their internship contexts (Step 5), and shared/reflected on these implementations with their colleagues and the researcher (Step 6). In Stage 6, each group also prepared a second written assignment describing the implementation of the intervention plan, which concluded with a reflective section discussing the main learning outcomes achieved during Phase 2. In addition, individual critical reflections were collected from the PSPSTs at the end of Phase 1 (M2) and again at

TABLE 1 General Structure of the tasks applied at Pre-intervention (M1), post-intervention I (M2) and post-intervention II (M3).

<table>
<tr><th colspan="6">General structure of the tasks</th></tr>
<tr><th colspan="6">Problem situation</th></tr>
<tr><td colspan="6">Part I
1. Solve the problem step by step using appropriate mathematical language. Explain your reasoning at each step of the solution using diagrams, drawings, or words, and provide a contextualized response to the problem situation.
2. Indicate all the elements of the problem situation that you considered essential to solving the task. (Abstraction)
3. For each element you indicated in Task 2, describe what you must do to fulfil it. (Decomposition)
4. Indicate the sequence of steps you need to follow to solve the problem situation. (Algorithm)
5. Could there be more solutions? Check that the solutions you have found follow all the steps in the sequence you indicated in Task 3. Justify your answer. (Debugging)
6. What characteristics do the solutions you found for the problem situation have in common? (Pattern Recognition)</td></tr>
<tr><td colspan="6">Part II
Draft a lesson plan (using the lesson planning model) of a session implementing your teaching practice, within the context of your practicum class, where you integrate the given problem situation. To do this, complete the following tasks.
1. Indicate the mathematical knowledge that students need to have to solve the problem situation.
2. Define the learning objectives related to the mathematical knowledge and skills to be achieved.
3. Indicate the necessary resources and the expected duration and describe the assessment to be adopted for the intended session.
4. Describe the development of the lesson using Exploratory Teaching (Canavarro et al., 2012).</td></tr>
<tr><th colspan="6">Lesson Planning Model</th></tr>
<tr><td colspan="4">School year</td><td>Subject area</td><td>Duration</td></tr>
<tr><td colspan="4">Prior knowledge</td><td colspan="2">Resources</td></tr>
<tr><td colspan="2">Theme</td><td>Topic</td><td>Subtopic</td><td>Learning objective</td><td>Competence Areas of the Student Profile</td></tr>
<tr><td>Maths theme</td><td></td><td></td><td></td><td></td><td rowspan="2"></td></tr>
<tr><td colspan="2">Mathematical skills</td><td></td><td></td><td></td></tr>
<tr><th colspan="6">Class assessment</th></tr>
<tr><td>Lesson phase (Time)</td><td colspan="5">Description of lesson development</td></tr>
<tr><td rowspan="2">Task introduction phase (__ minutes)</td><td colspan="5">Lesson development</td></tr>
<tr><td colspan="3">Promoting mathematical learning</td><td colspan="2">Classroom management</td></tr>
<tr><td rowspan="2">Task development phase (__ minutes)</td><td colspan="5">Lesson development</td></tr>
<tr><td colspan="3">Promoting mathematical learning</td><td colspan="2">Classroom management</td></tr>
<tr><td rowspan="2">Task discussion phase (__minutes)</td><td colspan="5">Lesson development</td></tr>
<tr><td colspan="3">Promoting mathematical learning</td><td colspan="2">Classroom management</td></tr>
<tr><td rowspan="2">Mathematical learning systematization phase (__minutes)</td><td colspan="5">Lesson development</td></tr>
<tr><td colspan="3">Promoting mathematical learning</td><td colspan="2">Classroom management</td></tr>
</table>

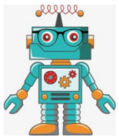
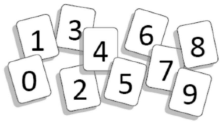
the end of Phase 2 (M3), providing qualitative evidence of their learning throughout the training program.

3.6 Data collection

The qualitative data was collected through the tasks carried out individually in the three moments.

The quantitative data was obtained by analyzing the lesson plans using the criteria (see Table 4), which were subdivided into 11 categories, directly linked to the components of the Framework of the Didactic Knowledge of Teachers who Teach Mathematics (Ponte, 2012; Rodrigues and Ponte, 2020): Knowledge of Mathematics for Teaching (KMT); Knowledge of the Curriculum (KC); Knowledge of Students and their Learning Processes (KSLP); and Knowledge of Teaching Practice (KTP). The set of descriptors was validated by the same researchers who validated the tasks (see subsection Instruments). For each descriptor, one of four levels of suitability was assigned, considering the extent to which the evidence presented in the lesson plans met the specific characteristics defined for that descriptor. The suitability descriptors were applied using the following four levels: 1—Totally unsuitable; 2—Partially unsuitable; 3—Partially suitable; and 4—Totally suitable. Level 1 of Suitability was assigned when it was not possible to identify the descriptor under analysis in the lesson plan or when it appeared in a totally unsuitable form, revealing a lack of pedagogical intent or incoherence in the proposal presented. Level 2 of Suitability was awarded when the descriptor under analysis could be identified in the lesson plan, but with significant flaws. Level 3 of Suitability was awarded when it was possible to identify the development of the descriptor in a reasonable way, although with some limitations that partially compromised the clarity of the proposal, making it incomplete.

TABLE 2 Problem-solving situations presented in the Pre-intervention (M1), post-intervention I (M2) and post-intervention II (M3) tasks.

Moments when the tasks were applied	Problem-solving situations
Pre-Intervention (M1)	How many numbers can the Numi robot write?  Numi is a robot who only writes numbers. You're going to help Numi write numbers: using the digits 1-2-5 1. How many two-digit numbers can Numi write?
Post-Intervention I (M2)	Four numbers  I. Using the digits on the cards, write down four different numbers, considering the following conditions: • All numbers must have four digits; • You cannot repeat digits in the same number; • All numbers must start with the same digit; • At least three numbers must be even. II. In each of the numbers written above, choose two of the digits you used and write down the value they represent in each of those numbers. III. Sort the numbers in ascending order.
Post-Intervention II (M3)	Deci the Robot 8 3 6 , I. Use these cards to find different numbers. (Please note: you can swap the cards around, but you must always use all four to make up a number). II. How many different numbers can you write down? Present them.

Level 4 of Suitability was awarded when it was possible to identify the descriptor clearly, coherently and effectively.

The development of KMT was evaluated based on the Level of Suitability of the plans in terms of the integration of Computational Thinking, considering its articulation with the objectives and mathematical content and the way in which its development was promoted throughout the lesson. The evaluation of KC was based on the lesson plans' Level of Suitability regarding the alignment and pedagogical sequence of the content and the way in which teaching resources were selected and integrated into the development of the lesson. The KSLP was evaluated based on the Level of Suitability of the methodological strategies defined and the ability to establish connections between the content and the students' reality, promoting active and inclusive learning. The KTP was evaluated based on the Level of Suitability of the lesson plans in terms of organizing the different phases of the class, managing the time available, anticipating possible unforeseen events and defining evaluation and feedback strategies, which are essential elements for effective teaching.

After applying the Levels of Suitability of the lesson plans considering each descriptor, the global Levels of Suitability per category were obtained by taking the median of the levels of the descriptors that make up each category. The Global Performance value of the PSPST was obtained using the criteria in Table 5, which shows the distribution of the percentage values attributed to each category and each level within the categories, considering the number of descriptors that make it up. The three tasks were analyzed according to the same analysis criteria, with the distribution of percentage values per category and per level being the same for the three moments (M1, M2 and M3). We also organized the Global Performance values into four classes: [0; 25[, [25; 50[, [50; 75[and [75; 100].

3.7 Data analysis

3.7.1 Analysis of qualitative data

An exploratory content analysis was carried out on the qualitative data collected at the three moments when the tasks were applied (Pre-Intervention—M1, Post-Intervention I—M2 and Post-Intervention II—M3). This analysis made it possible to observe and identify evidence of the evolution of the participants' knowledge and the difficulties they encountered when drawing up lesson plans. In addition to the lesson plans produced at the three moments, the analysis also included the

TABLE 3 Tasks and purposes of part 2.

Tasks	Purposes
Part 2	
Assuming you want to implement a session in your teaching practice, within the context of your practicum class, where you integrate the given problem situation, solve the tasks.	
1. Indicate the mathematical knowledge that students need to have to solve the problem situation.	The pre-service teacher is asked to mention the mathematical knowledge involved in the mathematical situation. This task allows us to analyse the pre-service teacher's knowledge related to the component of Knowledge of Mathematics for Teaching, Knowledge of Students and their Learning Processes and Knowledge of the Curriculum, as we want to find out whether the pre-service teacher uses appropriate mathematical terminology (Knowledge of Mathematics for Teaching) and identifies the mathematical knowledge (Knowledge of the Curriculum) that pre-service teachers would need to have in order to solve the problem situation (Knowledge of Students and their Learning Processes).
2. Define the learning objectives related to the mathematical knowledge and skills to be achieved.	The pre-service teacher is asked to mention the learning objectives related to mathematical knowledge and skills for the school year in question. This task makes it possible to analyse the pre-service teacher's knowledge related to the component of Knowledge of Mathematics for Teaching and Knowledge of the Curriculum, since the aim is to analyse whether the pre-service teacher identifies the learning objectives that can be achieved by solving the problem situation, within the framework of the curriculum (Knowledge of the Curriculum), using appropriate mathematical terminology (Knowledge of Mathematics for Teaching).
3. Indicate the necessary resources and the expected duration and describe the assessment to be adopted for the intended session.	The aim is for the pre-service teacher to describe the resources needed to integrate this problem situation into their practice, as well as how long they would anticipate implementing it and how they would assess the students. This task makes it possible to analyse the pre-service teacher's knowledge in relation to the Knowledge of Teaching Practice component, since the aim is to find out whether the pre-service teacher identifies the resources that could favour learning the knowledge involved in the problem situation, whether they can predict the duration of the planned implementation and whether they are able to define a form of assessment that suits the implementation.
4. Describe the development of the lesson using Exploratory Teaching (Canavarro et al., 2012).	The aim is for the pre-service teacher to draw up an outline of a session plan, as a pre-service teacher, to integrate this problem situation into their future educational practice, describing how it could be presented in the classroom. This task allows us to analyse the pre-service teacher's knowledge related to the component of Knowledge of Mathematics for Teaching, Knowledge of Students and their Learning Processes, Knowledge of the Curriculum and Knowledge of Teaching Practice. Regarding Knowledge of Mathematics for Teaching, the aim is to analyse whether the pre-service teacher uses appropriate mathematical terminology when describing their proposal. For the Knowledge of Students and their Learning Processes component, the aim is to find out whether the pre-service teacher chooses strategies that favour learning the knowledge they want to develop and whether they identify the roles the pre-service teacher should play. For the Knowledge of the Curriculum component, the aim is to analyse whether the pre-service teacher can define tasks within the framework of the curriculum of the school year in which the intervention is to take place. The Knowledge of Teaching Practice component aims to analyse whether pre-service teachers can define their role as a pre-service teacher and whether they choose strategies and methodologies appropriate to the planning they intend to develop.

individual critical reflections written by the PSPSTs after Phase 1 (M2) and Phase 2 (M3) of the training program, as well as the reflective conclusions included in the written group assignments produced at the end of Phases 1 and 2. These qualitative sources were used to complement and support the interpretation of the quantitative findings regarding the evolution of the PSPSTs' Didactic Knowledge in Mathematics.

3.7.2 Analysis of quantitative data

The statistical analysis was carried out using descriptive statistics, using relative and absolute frequency tables to describe and analyze the Levels of Suitability per descriptor of the planning carried out by the PSPSTs at the three moments. The Global Levels of Suitability by category and Global Performance were characterized using the mean (M) and standard deviation (SD). In each analysis criterion, evaluations with levels 1 and 2 were classified as inadequate and evaluations with levels 3 and 4 as adequate. In relation to the Global Performance of the PSPST, the intervals [0; 25[and [25; 50[were considered negative while the intervals [50; 75[and [75; 100] were considered positive (Freitas et al., 2024). As the literature mentions (Duarte et al., 2024; Zaragoza et al., 2023, 2024), the Level of Suitability of the teaching practices planned by PSPSTs is directly related to the development of their Didactic Knowledge in Mathematics (DKM). Thus, it is understood that higher Levels of Suitability in lesson plans correspond to greater evidence of mobilization of DKM by PSPSTs. On the other hand, lower Levels of Suitability, such as level 1 ("Totally Unsuitable"), correspond to a lack of evidence of the mobilization of knowledge relating to the category under analysis, as defined by the respective descriptor.

A one-way repeated measures ANOVA test was used to compare the Global Levels of Suitability by Category of analysis of the plans made and the Global Performance of the PSPST between the three moments (Pre-Intervention—M1, Post-Intervention I—M2 and Post-Intervention II—M3), after

TABLE 4 Analysis criteria for lesson planning and coding.

Framework component	Categories Descriptors (code)
Knowledge of Mathematics for Teaching	**Computational Thinking**
	Promotion of situations for identifying the essential elements of a problem (abstraction) (d1)
	Promotion of situations for breaking down a problem into simpler parts to facilitate its resolution (decomposition) (d2)
	Promotion of situations for creating a logical sequence to solve the problem (algorithm) (d3)
	Promotion of situations for analyzing the resolution process, identifying errors, and proposing improvements (debugging) (d4)
	Promotion of situations for identifying and applying patterns in similar situations (pattern recognition) (d5)
Knowledge of the Curriculum	**Curricular Alignment**
	Level of alignment between the proposed objectives and contents and the official curriculum (d6)
	Coherence in the pedagogical and curricular sequencing of the contents (d7)
	Use and Integration of Resources
	Quality and relevance of the selected resources (d8)
	Integration of the resources into the learning process (d9)
Knowledge of Students and their Learning Processes	**Methodological Strategies**
	Diversity and appropriateness of teaching strategies (d10)
	Active promotion of participation and critical thinking (d11)
	Connection with Students' Reality
	Relevance of content in relation to students' context (d12)
	Valuing students' diversity and experiences (d13)
	Creativity and Innovation
	Originality and creativity in the approach to content (d14)
	Encouragement of exploring different problem-solving strategies (d15)
Knowledge of Teaching Practice	**Clarity and Overall Coherence**
	Structure and organization of the lesson plan (d16)
	Interconnection between learning objectives, content, and tasks (d17)
	Lesson Structure
	Clarity in the definition of lesson phases (Introduction, Development, Discussion and Systematization) (d18)
	Adequate time distribution across the different lesson phases (d19)
	Flexibility and Management of Unexpected Events
	Ability to anticipate and address unforeseen situations expressed in the plan (d20)
	Adaptation of strategies to unexpected situations expressed in the plan (d21)
	Systematization and Reflection
	Deepening of knowledge (d22)
	Encouragement of reflection on learning processes (d23)
	Evaluation and Feedback
	Clarity and quality of assessment methods (formative and summative) (d24)
	Relevance and quality of the feedback intended for students (d25)

validating its assumptions (Marôco, 2021; Pallant, 2020). The normality assumption for each dependent variable was evaluated using the Shapiro–Wilk test (Marôco, 2021; Pallant, 2020). In cases where normality was not found, the symmetry analysis was carried out using the following condition (Pestana and Gageiro, 2014; Tabachnick and Fidell, 2021):

$$\left|\frac{\textit{skewness coefficient}}{\textit{standard error of the skewness coefficient}}\right| \leq 1.96$$

The assumption of sphericity was evaluated using Mauchly's test

TABLE 5 Percentage values assigned to each level of the descriptors by category.

Categories	Total percentage value	Number of descriptors	Percentage distribution by levels			
			1	2	3	4
Computational Thinking	25%	5	0%	1%	3.5%	5%
Curricular Alignment	7.5%	2	0%	0.75%	2.6%	3.75%
Use and Integration of Resources	7.5%	2	0%	0.75%	2.6%	3.75%
Methodological Strategies	7.5%	2	0%	0.75%	2.6%	3.75%
Connection with Students' Reality	7.5%	2	0%	0.75%	2.6%	3.75%
Creativity and Innovation	7.5%	2	0%	0.75%	2.6%	3.75%
Clarity and Overall Coherence	7.5%	2	0%	0.75%	2.6%	3.75%
Lesson Structure	7.5%	2	0%	0.75%	2.6%	3.75%
Flexibility and Management of Unexpected Events	7.5%	2	0%	0.75%	2.6%	3.75%
Systematization and Reflection	7.5%	2	0%	0.75%	2.6%	3.75%
Evaluation and Feedback	7.5%	2	0%	0.75%	2.6%	3.75%

(Pallant, 2020; Tabachnick and Fidell, 2021). If sphericity cannot be assumed, the degrees of freedom obtained by the Greenhouse-Geisser criterion should be considered for the F-statistic of the one-way repeated measures ANOVA table (Tabachnick and Fidell, 2021). The multiple comparisons of means were performed using the Bonferroni *post-hoc* test (Field, 2018; Pallant, 2020).

The effect size (ES) was presented as for the one-way repeated measures ANOVA test and interpreted using the following criteria: no effect ($ES < 0.04$), minimum effect ($0.04 \leq ES < 0.25$), moderate effect ($0.25 \leq ES < 0.64$), and strong effect ($ES \geq 0.64$) (Ferguson, 2009). Apart from ES, the power (π) of the corresponding test is also presented (Pallant, 2020).

IBM SPSS statistics software (version 28, IBM USA) was used to perform the statistical analysis, for a significant level of 5%.

4 Results

The results of the study are presented in five subsections. The first four subsections present the analysis of the Levels of Suitability in relation to the components defined in the Framework of the Didactic Knowledge in Mathematics considered: Knowledge of Mathematics for Teaching (KMT), Knowledge of the Curriculum (KC), Knowledge of Students and their Learning Processes (KSLP) and Knowledge of Teaching Practice (KTP). The fifth subsection presents the analysis of the Global Performance of the PSPSTs at the three moments analyzed. English translations of all excerpts presented in the figures are available in the Supplementary Material S1.

4.1 Knowledge of mathematics for teaching (KMT)

Table 6 shows the distribution of the absolute and relative frequencies (%) of the Levels of Suitability that were determined in relation to the category that makes up the KMT, at the three moments when the tasks were applied.

Regarding the Computational Thinking category, the data presented in Table 6 shows that, in M1, all the resolutions, in all the descriptors (d1 to d5), were classified as inadequate, with 100% of the answers in Level 1 of Suitability. These results indicate that the PSPSTs showed no evidence of KMT mobilization. After the implementation of the first phase of the training program (M2), there was a trend towards improvement in all five descriptors, especially the improvement shown by the PSPSTs in integrating situations into their lesson plans in which students are asked to identify the essential elements of a problem (d1). This descriptor showed a reduction in inadequate resolutions (from 100% to 36.8%) and an increase in resolutions classified as adequate (63.1%). This trend of improvement can also be seen in M3, where all the descriptors show percentages of more than 84% in terms of resolutions classified as adequate (levels 3 and 4), with descriptors 2, 3 and 4 standing out with 84.2% of the resolutions evaluated at Level 4 of Suitability.

The data presented in Table 7, concerning the descriptive statistics and comparison of the KMT Levels of Suitability, reveal a consistent and statistically significant evolution in the Computational Thinking category over the three moments.

Table 7 shows a significant increase in the mean Levels of Suitability from 1.00 in M1, to 2.84 in M2, and reaching 3.92 in M3. This evolution was confirmed by a highly significant one-way repeated measures ANOVA ($F = 123.869$; $p = 0.001$), with a strong effect size (= 0.873). The results suggest that, over the course of the training program, the PSPSTs have become progressively more prepared to integrate learning objectives and evidence of the promotion of situations that enable the development of Computational Thinking in their students into their lesson plans. This evolution translates into a greater awareness and use of approaches that encourage, for example, the identification of essential elements of a problem, the division of a problem into small parts and the creation of a sequence of steps that allow that problem to be solved.

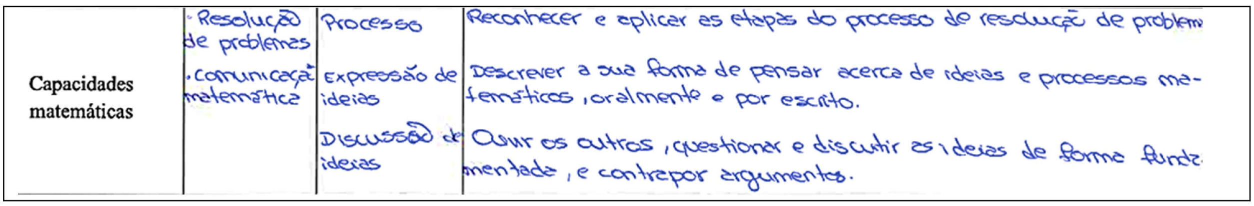
TABLE 6 Distribution of relative (%) and absolute frequencies of the KMT levels of suitability.

Category	Descriptors	M1 [%(n)]				M2 [%(n)]				M3 [%(n)]			
		Inadequate		Adequate		Inadequate		Adequate		Inadequate		Adequate	
		1	2	3	4	1	2	3	4	1	2	3	4
Computational Thinking	d1	100.0 (19)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	36.8 (7)	26.3 (5)	36.8 (7)	10.5 (2)	5.3 (1)	5.3 (1)	78.9 (15)
	d2	100.0 (19)	0.0 (0)	0.0 (0)	0.0 (0)	10.5 (2)	36.8 (7)	15.8 (3)	36.8 (7)	5.3 (1)	5.3 (1)	5.3 (1)	84.2 (16)
	d3	100.0 (19)	0.0 (0)	0.0 (0)	0.0 (0)	21.1 (4)	26.3 (5)	15.8 (3)	36.8 (7)	5.3 (1)	5.3 (1)	5.3 (1)	84.2 (16)
	d4	100.0 (19)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	36.8 (7)	26.3 (5)	36.8 (7)	5.3 (1)	5.3 (1)	5.3 (1)	84.2 (16)
	d5	100.0 (19)	0.0 (0)	0.0 (0)	0.0 (0)	5.3 (1)	42.1 (8)	15.8 (3)	36.8 (7)	5.3 (1)	5.3 (1)	10.5 (2)	78.9 (15)

TABLE 7 Descriptive statistics and comparison of the KMT levels of suitability between pre-intervention (M1), post-intervention I (M2) and post-intervention II (M3).

Category	M1	M2	M3	F	p	η_p^2	ES	π
Computational Thinking	$1.00 \pm 0.00^{a,b}$	$2.84 \pm 1.01^{a,c}$	$3.92 \pm 0.15^{b,c}$	123.869	0.001	0.873	Strong effect	1.000

One-way repeated measures ANOVA: significantly different at $p < 0.05$ for the following comparisons [a]Pre-Intervention vs. Post-Intervention I; [b]Pre-Intervention vs. Post-Intervention II; & [c]Post-Intervention I vs. Post-Intervention II.



Capacidades matemáticas	· Resolução de problemas	Processo	Reconhecer e aplicar as etapas do processo de resolução de problem
	· Comunicação matemática	Expressão de ideias	Descrever a sua forma de pensar acerca de ideias e processos matemáticos, oralmente e por escrito.
		Discussão de ideias	Ouvir os outros, questionar e discutir as ideias de forma fundamentada, e contrapor argumentos.

FIGURE 2
Excerpt from pre-service primary school teacher L's resolution (Pre-intervention—M1). (Source: Authors own elaboration).

The changes observed in the KMT are also confirmed by the qualitative evidence identified in the lesson plans prepared by the PSPSTs at the three moments. Figure 2 shows the excerpt from the resolution made by PSPST L in M1, regarding the definition of the mathematical skills he wanted to develop in the students through the given problem-solving situations.

The excerpt presented (Figure 2) shows that, although the problem-solving situations included five tasks directly related to the dimensions of Computational Thinking, PSPST L did not integrate the development of this skill into the lesson plan. For this reason, his resolution was classified as Level of Suitability 1.

Figure 3 shows two excerpts from PSPST L's resolution in M2, the same field of lesson plan illustrated in Figure 2 and then the actions defined to promote mathematical learning during the discussion phase of the lesson.

In M2, PSPST L identifies Computational Thinking as the mathematical skill to be developed, describing the five dimensions mentioned in the curriculum. However, in the actions to promote mathematical learning, it only presents a guiding question for three of these dimensions. For this reason, its resolution was classified as Level of Suitability 3.

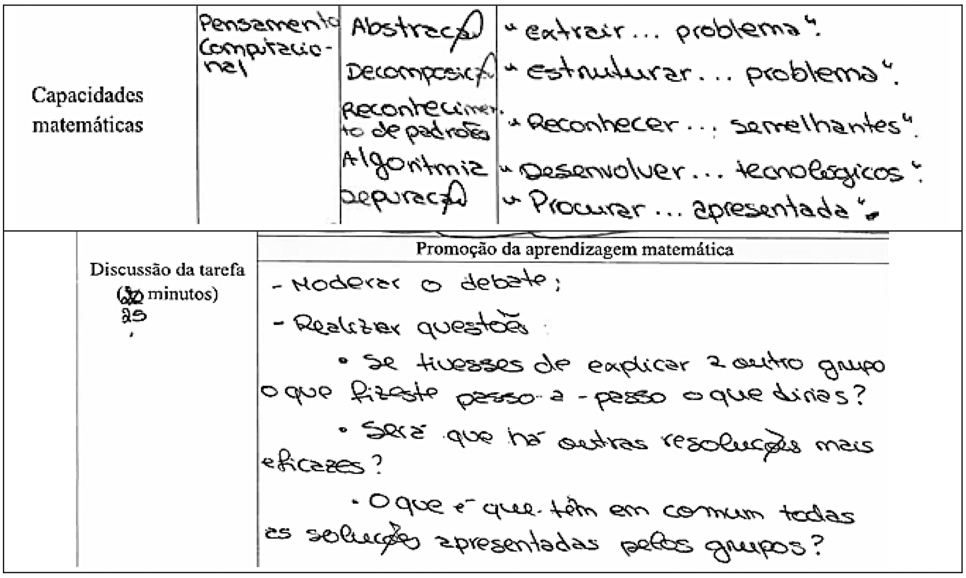
Figure 4 shows excerpts from the PSPST resolution in M3.

The PSPST L resolutions in M3 show KMT by defining Computational Thinking as a skill to be developed and by devising guiding questions that promote the development of the five dimensions. For this reason, its resolution was classified as Totally Suitable (Level 4 of Suitability).

These qualitative findings are further supported by the PSPSTs' critical reflections written after completing the training program. For example, one PSPST reported that, during the microteaching sessions, "*by receiving feedback from both the teacher and my classmates, I realized that some of the mathematical concepts we had used were not the most appropriate*" (PSPST K), highlighting the refinement of her mathematical knowledge for teaching. The same PSPST also stated that "*I developed my own mathematical knowledge and skills, learned how to implement Computational Thinking in the classroom, and how to design more meaningful lessons*", reinforcing the quantitative evidence that the training program promoted the development of KMT and supported the integration of Computational Thinking into lesson planning.

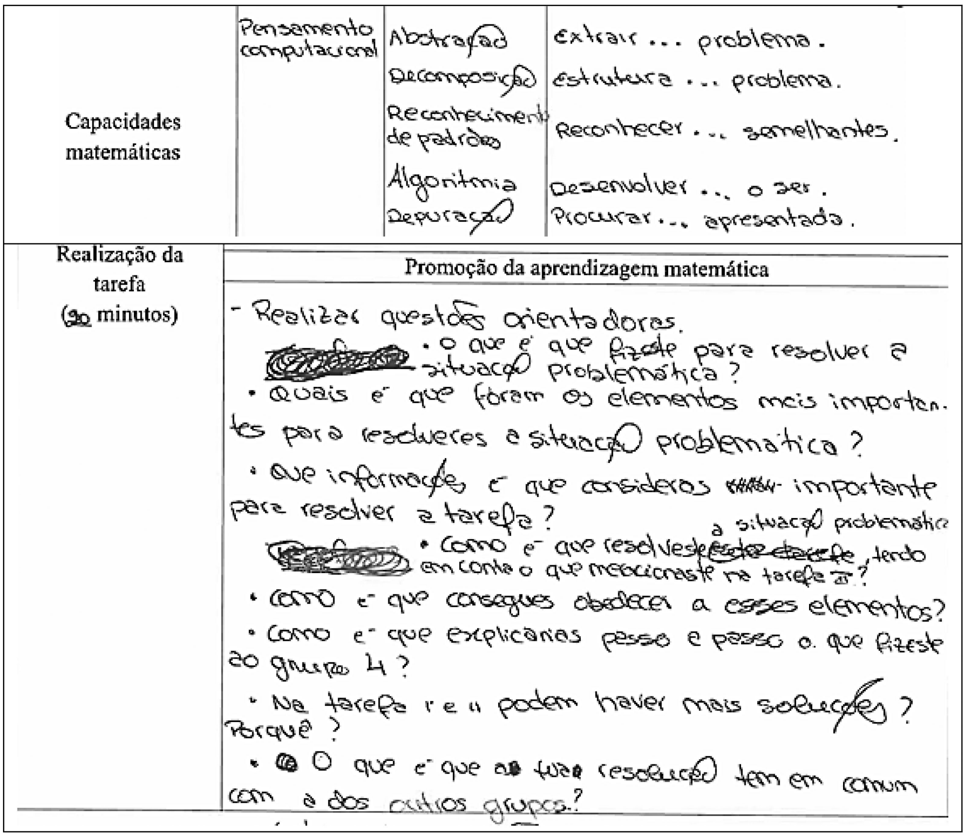
4.2 Knowledge of the curriculum (KC)

Table 8 shows the results of the distribution of absolute and relative frequencies (%) of the Levels of Suitability assigned to the categories associated with KC.



Capacidades matemáticas	Pensamento Computacional	Abstração	"extrair ... problema".
		Decomposição	"estruturar ... problema".
		Reconhecimento de padrões	"Reconhecer ... semelhantes".
		Algoritmia	"Desenvolver ... tecnológicos".
		Depuração	"Procurar ... apresentada".
Discussão da tarefa (20 minutos) 25	Promoção da aprendizagem matemática		
	- Moderar o debate; - Realizar questões: • Se tivesses de explicar a outro grupo o que fizeste passo-a-passo o que dirias? • Será que há outras resoluções mais eficazes? • O que é que têm em comum todas as soluções apresentadas pelos grupos?		

FIGURE 3
Excerpt from pre-service primary school teacher L's resolution (post-intervention I—M2). (Source: Authors own elaboration).



Capacidades matemáticas	Pensamento computacional	Abstração	extrair ... problema.
		Decomposição	estrutura ... problema.
		Reconhecimento de padrões	Reconhecer ... semelhantes.
		Algoritmia	Desenvolver ... o ser.
		Depuração	Procurar ... apresentada.
Realização da tarefa (20 minutos)	Promoção da aprendizagem matemática		
	- Realizar questões orientadoras. • O que é que fizeste para resolver a situação problemática? • Quais é que foram os elementos mais importantes para resolveres a situação problemática? • Que informações é que consideras importante para resolver a tarefa? • Como é que resolveste a situação problemática, tendo em conta o que mencionaste na tarefa 1? • Como é que consegues obedecer a esses elementos? • Como é que explicarias passo a passo o que fizeste ao grupo 4? • Na tarefa 1 e 2 podem haver mais soluções? Porquê? • O que é que a tua resolução tem em comum com a dos outros grupos?		

FIGURE 4
Excerpt from pre-service primary school teacher L's resolution (post-intervention II—M3). (Source: Authors own elaboration).

The data in Table 8 shows that, in M1, all PSPST resolutions were considered inadequate in all descriptors (d6 to d9), with percentages at Level 1 of Suitability equal to or greater than 94.7%. This pattern reveals the PSPSTs' initial difficulty in aligning their lesson plans with the curriculum and in selecting and integrating resources in an informed way. After Phase 1 of the training program (M2), there was an increase in tasks classified as adequate, particularly in descriptor d8, which

TABLE 8 Distribution of relative (%) and absolute frequencies of the KC levels of suitability.

Categories		M1 [%(n)]				M2 [%(n)]				M3 [%(n)]			
		Inadequate		Adequate		Inadequate		Adequate		Inadequate		Adequate	
		1	2	3	4	1	2	3	4	1	2	3	4
Curricular Alignment	d6	94.7 (18)	5.3 (1)	0.0 (0)	0.0 (0)	21.1 (4)	15.8 (3)	47.4 (9)	15.8 (3)	15.8 (3)	5.3 (1)	42.1 (8)	36.8 (7)
	d7	100.0 (19)	0.0 (0)	0.0 (0)	0.0 (0)	21.1 (4)	15.8 (3)	42.1 (8)	21.1 (4)	15.8 (3)	5.3 (1)	36.8 (7)	42.1 (8)
Use and Integration of Resources	d8	100.0 (19)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	21.1 (4)	26.3 (5)	52.6 (10)	0.0 (0)	10.5 (2)	10.5 (2)	78.9 (15)
	d9	100.0 (19)	0.0 (0)	0.0 (0)	0.0 (0)	5.3 (1)	15.8 (3)	26.3 (5)	52.6 (10)	0.0 (0)	10.5 (2)	15.8 (3)	73.7 (14)

TABLE 9 Descriptive statistics and comparison of KC levels of suitability between pre-intervention (M1), post-intervention I (M2) and post-intervention II (M3).

Categories	M1	M2	M3	F	p	η_p^2	ES	π
Curricular Alignment	$1.00 \pm 0.01^{a,b}$	$2.61 \pm 1.04^{a,c}$	$3.34 \pm 0.58^{b,c}$	60.061	0.001	0.769	Strong effect	1.000
Use and Integration of Resources	$1.00 \pm 0.00^{a,b}$	$3.29 \pm 0.87^{a,c}$	$3.87 \pm 0.23^{b,c}$	195.007	0.001	0.915	Strong effect	1.000

One-way repeated measures ANOVA: significantly different at $p < 0.05$ for the following comparisons [a]Pre-Intervention vs. Post-Intervention I; [b]Pre-Intervention vs. Post-Intervention II; & [c]Post-Intervention I vs. Post-Intervention II.

analyzes the quality and relevance of the resources selected. This went from 100% of inadequate resolutions in M1 to 78.9% of responses at levels 3 and 4, showing an improvement in the selection of quality and relevant resources for the intervention. In M3, compared to both M1 and M2, there was an increase in the number of answers considered adequate in all descriptors. The increase in level 4 answers observed in descriptor 7 (from 21.1% to 42.2%) shows that the PSPSTs were able to mobilize their KC, presenting teaching sequences with greater coherence.

Table 9 shows the descriptive statistics and the comparison between the three moments when the tasks were applied regarding KC.

The results presented (Table 9) show improvements in the Levels of Suitability attributed to Curriculum Alignment and the Use and Integration of Resources over the three moments analyzed, with statistically significant differences in the two categories analyzed. Regarding Curriculum Alignment, the mean increased from 1.00 (SD = 0.01) in the pre-intervention (M1), to 2.61 (SD = 1.04) after Phase 1 of the training program (M2), reaching 3.34 (SD = 0.58) after Phase 2 of the training program (M3). This evolution was confirmed by the results of the one-way repeated measures ANOVA (F = 60.061; $p = 0.001$), with a strong effect size ($\eta_p^2 = 0.769$). These results suggest an improvement in the PSPST's ability to plan more coherent teaching sequences and to articulate objectives and content in a way that is more consistent with the official curriculum. Regarding the Use and Integration of Resources, the results indicate an even more significant evolution. The mean went from 1.00 (SD = 0.00) in M1 to 3.29 (SD = 0.87) in M2, reaching 3.87 (SD = 0.23) in M3. The difference was statistically significant (F = 195.007; $p = 0.001$), also with a strong effect size ($\eta_p^2 = 0.915$). These results show that PSPSTs have improved their ability to select relevant resources and articulate them effectively in their practice. In summary, the results reflect an evolution in the KC, indicating that the training program contributed to the improvement of PSPST lesson plan practices, both in terms of curricular coherence and the strategic use of didactic resources in the teaching and learning process.

The qualitative analysis of the lesson plans over the three moments reveals greater coherence in both curriculum alignment and resource integration, confirming the improvements found in the quantitative analysis of the KC.

Figure 5 shows two excerpts from the lesson plan prepared by PSPST C in M1.

PSPST C defines an objective that doesn't suit the problem-solving situations and, throughout the lesson description, doesn't define any strategy to achieve it. It also doesn't present quality resources or integrate them effectively into the lesson plan, so its resolution was considered Totally Unsuitable (Level 1 of Suitability).

Figure 6 shows excerpts from solving the PSPST in M2, including the learning objective field and one of the resources created.

PSPST C defines two learning objectives that can be worked on through the proposed problem-solving situations. However, it only presents strategies for one of them, the achievement of which throughout the lesson is not clearly defined, and it is also the only objective systematized at the end. Therefore, its resolution was classified as Level 2 of Suitability in terms of curriculum alignment. Regarding the integration of resources, we can see that a systematization sheet suitable for one of the objectives was created, which justified the classification as Partially Suitable (Level 3 of Suitability).

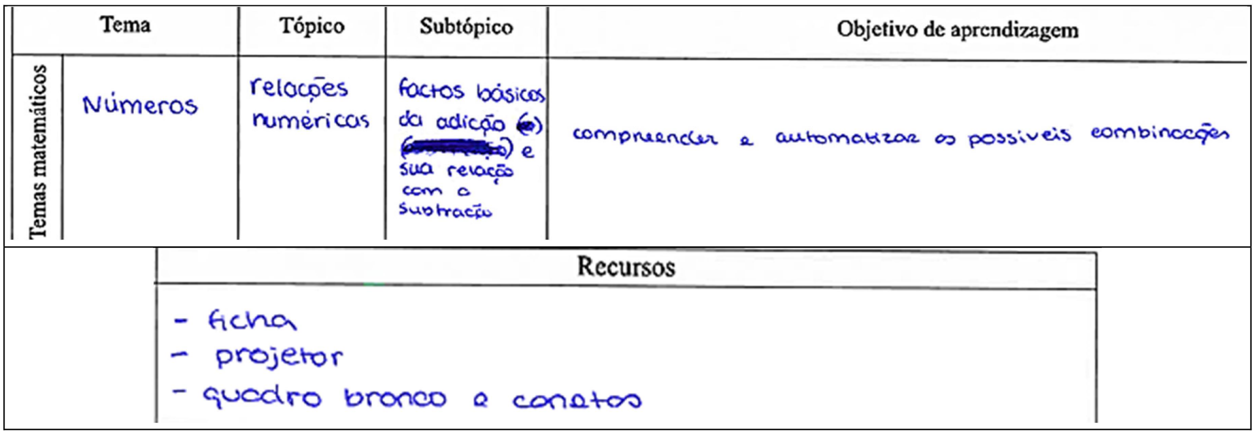


FIGURE 5
Excerpt from pre-service primary school teacher C's resolution (Pre-intervention—M1). (Source: Authors own elaboration).

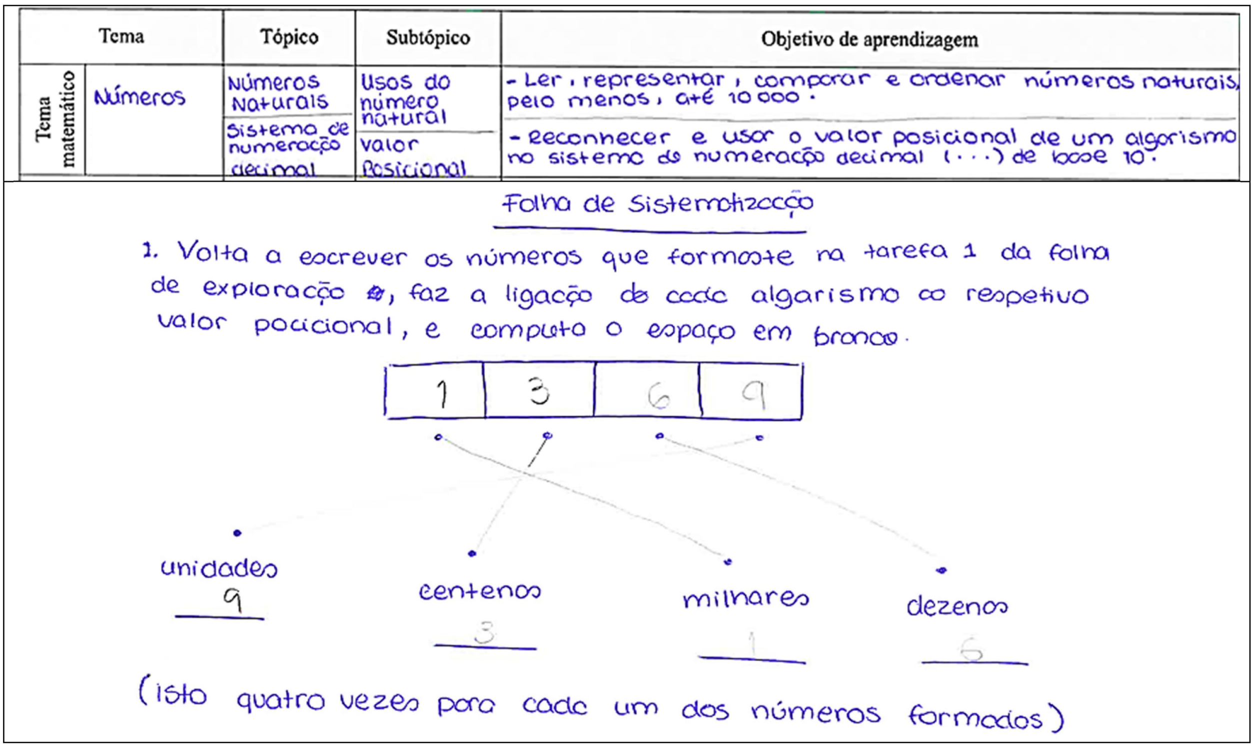
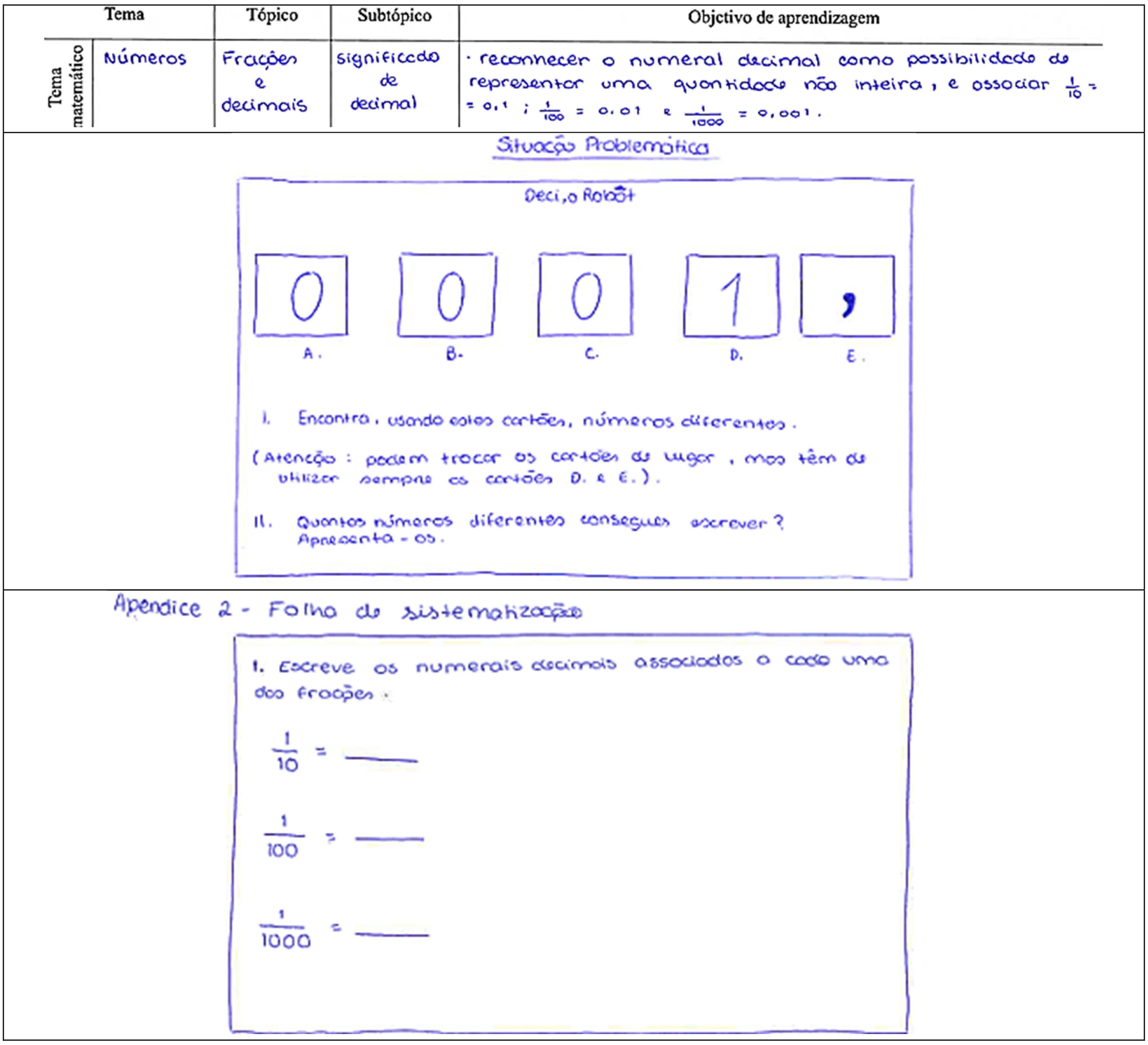


FIGURE 6
Excerpt from pre-service primary school teacher C's resolution (post-intervention I—M2). (Source: Authors own elaboration).

Figure 7 shows excerpts from the resolution of PSPST C in M3.

In M3, PSPST C presents a learning objective that is clear and appropriate to the problem-solving situations. The lesson plan shows a lesson structured to achieve this objective. The PSPST also provides two relevant resources: an exploration sheet and a systematization sheet. As a result, its resolutions have been classified as Totally Suitable (Level 4 of Suitability).

These qualitative findings are further supported by the PSPSTs' critical reflections written after completing the training program. For example, one PSPST acknowledged that "*I used to define several learning objectives without realizing that, in practice, it would be completely impossible to develop all of them*" (PSPST S), revealing an increased awareness of the need for coherence between lesson objectives and classroom practice. The same PSPST further stated that "*I learned to focus on fewer learning objectives and to identify the potential of a single task and how knowledge could be developed through it*", highlighting the development of her ability to align learning objectives with mathematical tasks and to design more coherent lesson plans. These reflections reinforce the quantitative evidence that the training program promoted the development of KC, particularly



Tema		Tópico	Subtópico	Objectivo de aprendizagem
Tema matemático	Números	Frações e decimais	significado de decimal	• reconhecer o numeral decimal como possibilidade de representar uma quantidade não inteira, e associar $\frac{1}{10}$ = 0,1 ; $\frac{1}{100}$ = 0,01 e $\frac{1}{1000}$ = 0,001.

Situação Problemática

Deci, o Robot

0	0	0	1	,
A.	B.	C.	D.	E.

I. Encontra, usando estes cartões, números diferentes.

(Atenção: podem trocar os cartões de lugar, mas têm de utilizar sempre os cartões D. e E.).

II. Quantos números diferentes consegues escrever? Apresenta-os.

Apendice 2 - Folha de sistematização

1. Escreve os numerais decimais associados a cada uma das frações.

$\frac{1}{10}$ = ____

$\frac{1}{100}$ = ____

$\frac{1}{1000}$ = ____

FIGURE 7
Excerpt from pre-service primary school teacher C's resolution (post-intervention II—M3). (Source: Authors own elaboration).

regarding curricular alignment and the strategic integration of resources.

4.3 Knowledge of students and their learning processes (KSLP)

Regarding the KSLP, Table 10 shows the distribution of the relative and absolute frequencies (%) of the Levels of Suitability of the three categories at the three moments analyzed.

In the KSLP, there was a gradual decrease in the number of resolutions classified as inadequate, and it should be noted that in M1, all the resolutions were classified as inadequate in all the descriptors (Table 10). These results show that the PSPSTs were unable to mobilize their KSLP while solving the tasks. In M2, there was a significant reduction in all the resolutions classified as Totally Unsuitable (Level 1 of Suitability), highlighting the improvement observed in the PSPSTs' ability to value the diversity of their students (d13). The reduction in resolutions classified as inadequate became even more evident in M3, with descriptor 15 registering only 2 resolutions classified as Partially Unsuitable. In this way, we can see that the PSPSTs were able to mobilize their KSLP, showing indications that encourage students to explore different problem-solving strategies.

Table 11 shows the descriptive statistics and the comparison between the three moments when the tasks were applied, of the three categories that make up the KSLP.

The KSLP data (Table 11) shows significant progress in the three categories analyzed, between M1, M2 and M3. Regarding the mean values of the three categories, it should be noted that all of them went from the lowest level in M1 (1.00) to values close to 3.00 in M2, reaching values equal to or greater than 3.50 in M3. About the results of the one-way repeated measures ANOVA, it should be noted that all the categories showed statistically significant differences with a Strong Effect size, with a varying between 0.860 and 0.894, which shows that the

TABLE 10 Distribution of relative (%) and absolute frequencies of the KSLP levels of suitability.

Categories	Descriptors	M1 [%(n)]				M2 [%(n)]				M3 [%(n)]			
		Inadequate		Adequate		Inadequate		Adequate		Inadequate		Adequate	
		1	2	3	4	1	2	3	4	1	2	3	4
Methodological Strategies	d10	84.2 (16)	15.8 (3)	0.0 (0)	0.0 (0)	10.5 (2)	15.8 (3)	36.8 (7)	36.8 (7)	0.0 (0)	26.3 (5)	10.5 (2)	63.2 (12)
	d11	100.0 (19)	0.0 (0)	0.0 (0)	0.0 (0)	10.5 (2)	26.3 (5)	31.6 (6)	31.6 (6)	0.0 (0)	10.5 (2)	15.8 (3)	73.7 (14)
Connection with Students' Reality	d12	100.0 (19)	0.0 (0)	0.0 (0)	0.0 (0)	5.3 (1)	15.8 (3)	47.4 (9)	31.6 (6)	0.0 (0)	15.8 (3)	21.1 (4)	63.2 (12)
	d13	100.0 (19)	0.0 (0)	0.0 (0)	0.0 (0)	5.3 (1)	21.1 (4)	36.8 (7)	36.8 (7)	0.0 (0)	10.5 (2)	26.3 (5)	63.2 (12)
Creativity and Innovation	d14	100.0 (19)	0.0 (0)	0.0 (0)	0.0 (0)	5.3 (1)	26.3 (5)	26.3 (5)	42.1 (8)	0.0 (0)	10.5 (2)	5.3 (1)	84.2 (16)
	d15	94.7 (18)	5.3 (1)	0.0 (0)	0.0 (0)	5.3 (1)	26.3 (5)	31.6 (6)	36.8 (7)	0.0 (0)	10.5 (2)	15.8 (3)	73.7 (14)

TABLE 11 Descriptive statistics and comparison of KSLP levels of suitability between pre-intervention (M1), post-intervention I (M2) and post-intervention II (M3).

Categories	M1	M2	M3	F	p	η_p^2	ES	π
Methodological Strategies	$1.00 \pm 0.01^{a,b}$	$2.92 \pm 0.99^{a,c}$	$3.50 \pm 0.73^{b,c}$	110.640	0.001	0.860	Strong effect	1.000
Connection with Students' Reality	$1.00 \pm 0.00^{a,b}$	$3.05 \pm 0.83^{a,c}$	$3.50 \pm 0.73^{b,c}$	130.738	0.001	0.879	Strong effect	1.000
Creativity and Innovation	$1.00 \pm 0.01^{a,b}$	$3.03 \pm 0.90^{a,c}$	$3.76 \pm 0.42^{b,c}$	152.185	0.001	0.894	Strong effect	1.000

One-way repeated measures ANOVA: significantly different at $p < 0.05$ for the following comparisons [a]Pre-Intervention vs. Post-Intervention I; [b]Pre-Intervention vs. Post-Intervention II; & [c]Post-Intervention I vs. Post-Intervention II.

training program influenced the resolutions presented by the PSPSTs. The results obtained in the Methodological Strategies category indicate an improvement in the way the participants began to diversify and adjust their teaching approaches, promoting greater student involvement and stimulating critical thinking. As for the Connection with Students' Reality, the results indicate that there has been an improvement in the PSPSTs' ability to value the diversity of the students and adapt the proposals to the educational context. Finally, the results obtained in the Creativity and Innovation category suggest that, throughout M1, M2 and M3, the PSPSTs showed an evolution in the integration of creative, original approaches that promoted the exploration of different problem-solving strategies in their lesson plans.

The qualitative analysis identified evidence of the evolution of their KSLP in the lesson plans prepared by the PSPSTs, corroborating the quantitative results found.

Figure 8 shows excerpts from PSPST E's lesson plan describing the task development phase.

PSPST E indicates that students will solve the task individually, which reveals a limited understanding of learning processes, as it does not promote active participation, the confrontation of ideas or the development of critical thinking. He also says that the sharing of solutions will be voluntary, which shows a lack of intent in the selection and exploration of relevant solutions. For this reason, his resolutions were classified as Level 1 of Suitability.

Figure 9 shows excerpts from the lesson plan made by the PSPST in M2.

In M2, PSPST E indicates that he will organize the students into pre-defined pairs, showing that he values diversity and intends to promote participation and the sharing of ideas, aspects that demonstrate knowledge of learning processes. For this reason, his resolution was classified as Level 4 of Suitability. He also mentions that he will accompany the students as they carry out the task and note down relevant aspects of the resolutions in order to organize the final discussion. However, he doesn't explain which aspects will be recorded or how he will structure this discussion. Therefore, the PSPST's resolution regarding methodological strategies was classified as Partially Suitable (Level 3 of Suitability).

Figure 10 shows excerpts from the PSPST resolution in M3.

In M3, PSPST E indicates that it will organize students into previously defined groups, considering their abilities and competences to form heterogeneous groups. He also mentions identifying different resolutions to organize the final discussion. This evidence demonstrates pedagogical intent and effective adaptation of teaching strategies, justifying the classification of the resolution with Level 4 of Suitability.

These qualitative findings are further supported by the PSPSTs' critical reflections written after completing the training program. For example, the PSPST E explained that "*…when implementing the lesson, I considered the characteristics of my placement class. Since the students were in the first grade, although they had already developed reading and writing skills, many still experienced difficulties. Therefore, I consistently adapted the tasks and the progression of the mathematical concepts, considering each student's cognitive level and learning difficulties*". This reflection highlights the PSPST's growing ability to adapt instruction to students' characteristics, demonstrating the development of Connection with Students' Reality. The same PSPST also stated that "*I further developed my ability to understand students' responses, solution strategies, and possible errors. Throughout my teaching practice, I sought to*

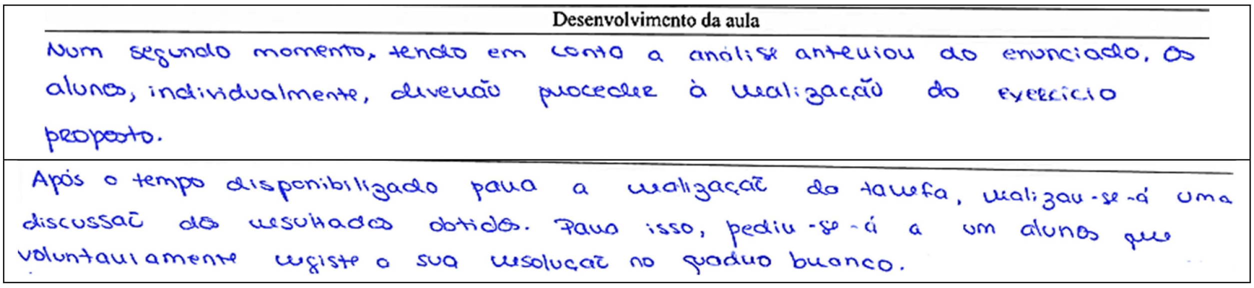


FIGURE 8
Excerpt from pre-service primary school teacher E's resolution (Pre-intervention—M1). (Source: Authors own elaboration).

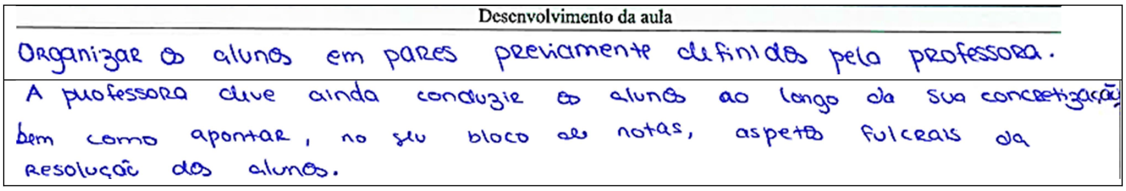


FIGURE 9
Excerpt from pre-service primary school teacher E's resolution (post-intervention I—M2). (Source: Authors own elaboration).

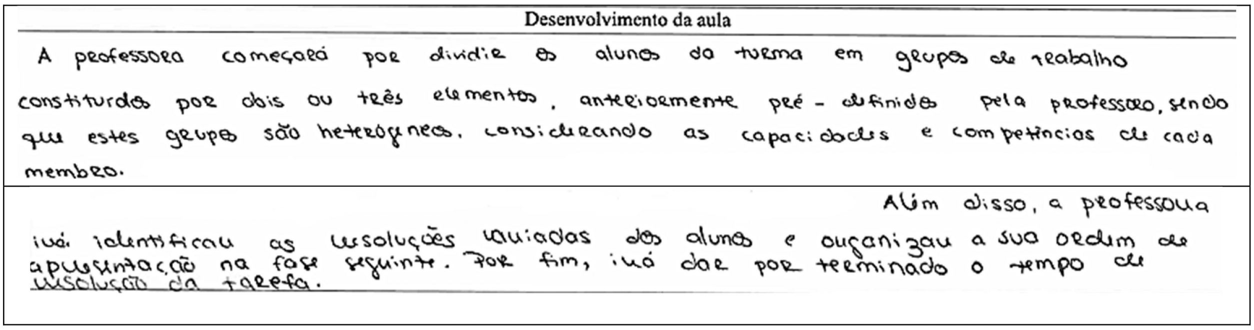


FIGURE 10
Excerpt from pre-service primary school teacher E's resolution (post-intervention II—M3). (Source: Authors own elaboration).

support students' reasoning by guiding them without validating their answers", revealing an enhanced understanding of students' learning processes and the use of more effective Methodological Strategies. Additional qualitative evidence is provided by the reflective conclusions included in the written group assignments submitted at the end of Phase 2 of the training program. Group 2 (PSPSTs C, D, and E) stated that "*we developed our ability to help students acquire better problem-solving methods in different everyday contexts. Furthermore, we improved the way we communicated with students by adapting our communication so that everyone could understand what we intended to convey.*" This group reflection highlights the participants' growing ability to adapt their teaching strategies to students' characteristics and learning needs, reinforcing the quantitative evidence of the development of KSLP.

4.4 Knowledge of teaching practice (KTP)

For KTP, Table 12 shows the distribution of the relative and absolute frequencies (%) of the Levels of Suitability of the tasks applied at the three moments, organized by the five categories that make up this component.

As with the previous components, all the resolutions in the five categories that make up the KTP were classified as inadequate in M1 (Table 12). It is worth noting the increase from M1 to M2 in the number of answers considered adequate in the Lesson Structure category, which shows an improvement in the PSPSTs' ability to clearly define the structure of the various phases of their classes, after implementing Phase 1 of the training program. As for M3, it should be noted that 100% of the resolutions were classified as adequate for descriptor 16.

TABLE 12 Distribution of relative (%) and absolute frequencies of the KTP levels of suitability.

Categories	Descriptors	M1 [%(n)]				M2 [%(n)]				M3 [%(n)]			
		Inadequate		Adequate		Inadequate		Adequate		Inadequate		Adequate	
		1	2	3	4	1	2	3	4	1	2	3	4
Clarity and Overall Coherence	d16	100.0 (19)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	36.8 (7)	31.6 (6)	31.6 (6)	0.0 (0)	0.0 (0)	21.1 (4)	78.9 (15)
	d17	100.0 (19)	0.0 (0)	0.0 (0)	0.0 (0)	5.3 (1)	42.1 (8)	31.6 (6)	21.1 (4)	15.8 (3)	0.0 (0)	42.1 (8)	42.1 (8)
Lesson Structure	d18	94.7 (18)	5.3 (1)	0.0 (0)	0.0 (0)	0.0 (0)	10.5 (2)	57.9 (11)	31.6 (6)	0.0 (0)	0.0 (0)	15.8 (3)	84.2 (16)
	d19	84.2 (16)	15.8 (3)	0.0 (0)	0.0 (0)	0.0 (0)	15.8 (3)	63.2 (12)	21.1 (4)	0.0 (0)	0.0 (0)	47.4 (9)	52.6 (10)
Flexibility and Management of Unexpected Events	d20	100.0 (19)	0.0 (0)	0.0 (0)	0.0 (0)	10.5 (2)	5.3 (1)	42.1 (8)	42.1 (8)	0.0 (0)	15.8 (3)	21.1 (4)	63.2 (12)
	d21	100.0 (19)	0.0 (0)	0.0 (0)	0.0 (0)	10.5 (2)	5.3 (1)	42.1 (8)	42.1 (8)	0.0 (0)	15.8 (3)	21.1 (4)	63.2 (12)
Systematization and Reflection	d22	94.7 (18)	5.3 (1)	0.0 (0)	0.0 (0)	15.8 (3)	31.6 (6)	42.1 (8)	10.5 (2)	5.3 (1)	10.5 (2)	63.2 (12)	21.1 (4)
	d23	68.4 (13)	31.6 (6)	0.0 (0)	0.0 (0)	15.8 (3)	31.6 (6)	42.1 (8)	10.5 (2)	5.3 (1)	10.5 (2)	42.1 (8)	42.1 (8)
Evaluation and Feedback	d24	94.7 (18)	5.3 (1)	0.0 (0)	0.0 (0)	15.8 (3)	5.3 (1)	68.4 (13)	10.5 (2)	0.0 (0)	5.3 (1)	31.6 (6)	63.2 (12)
	d25	100.0 (19)	0.0 (0)	0.0 (0)	0.0 (0)	10.5 (2)	21.1 (4)	47.4 (9)	21.1 (4)	5.3 (1)	0.0 (0)	31.6 (6)	63.2 (12)

TABLE 13 Descriptive statistics and comparison of KTP levels of suitability between pre-intervention (M1), post-intervention I (M2) and post-intervention II (M3).

Categories	M1	M2	M3	F	p	η_p^2	ES	π
Clarity and Overall Coherence	$1.00 \pm 0.00^{a,b}$	$2.82 \pm 0.82^{a,c}$	$3.45 \pm 0.62^{b,c}$	110.513	0.001	0.860	Strong effect	1.000
Lesson Structure	$1.00 \pm 0.01^{a,b}$	$3.13 \pm 0.57^{a,c}$	$3.68 \pm 0.30^{b,c}$	295.017	0.001	0.942	Strong effect	1.000
Flexibility and Management of Unexpected Events	$1.00 \pm 0.00^{a,b}$	3.37 ± 0.60^{a}	3.47 ± 0.77^{b}	148.992	0.001	0.892	Strong effect	1.000
Systematization and Reflection	$1.18 \pm 0.30^{a,b}$	$2.47 \pm 0.90^{a,c}$	$3.32 \pm 0.42^{b,c}$	81.260	0.001	0.819	Strong effect	1.000
Evaluation and Feedback	$1.00 \pm 0.00^{a,b}$	$2.92 \pm 0.58^{a,c}$	$3.55 \pm 0.66^{b,c}$	168.698	0.001	0.904	Strong effect	1.000

One-way repeated measures ANOVA: significantly different at $p < 0.05$ for the following comparisons [a]Pre-Intervention vs. Post-Intervention I; [b]Pre-Intervention vs. Post-Intervention II; & [c]Post-Intervention I vs. Post-Intervention II.

This shows that, at the end of the training program, the PSPST were able to mobilize their KTP and present a well-structured and organized lesson plan.

Table 13 shows the descriptive statistics and the comparison between the three moments for the five categories that make up the KTP.

As in the previous components, the Knowledge of Teaching Practice (Table 13) also showed that the mean values for the Levels of Suitability in M1 were at the minimum (1.00) or very close to it (1.18 for the category of Systematization and Reflection). It is important to highlight that, across all categories, there was a significant increase in the mean values in M2, with the category of Flexibility and Management of Unexpected Events registering the highest mean value (3.37) among all the categories analyzed at that point. Although there was a further increase in the mean for this category in M3 (3.47), no statistically significant differences were observed, as the mean was already at a high level in M2. For the remaining categories, all observed differences between the three moments were statistically significant, with a Strong Effect Size (ranged from 0.819 to 0.942). Thus, the results obtained for the category of Clarity and Overall Coherence indicate progress in the PSPSTs' ability to better structure their lesson plans, ensuring a connection between objectives, content, and proposed tasks. Regarding Lesson Structure, the observed evolution suggests improvements in the organization of the different phases of the lesson and in the time, management defined by the PSPSTs in their planning. In the category of Flexibility and Management of Unexpected Events, the results suggest that participants became more effective at anticipating possible disruptions and planning how to adapt their strategies in response to unexpected events. Concerning Systematization and Reflection, the PSPSTs showed progress in defining strategies to deepen the knowledge addressed in the lesson and to stimulate students' reflection on their learning. Finally, the results related to Evaluation and Feedback reveal an evolution in the definition of assessment methods and in the intention to provide relevant and appropriate feedback within the submitted lesson plans.

The qualitative analysis of the lesson plans developed by the PSPSTs reveals progress in the planning of pedagogical practices, which supports the changes identified in the KTP.

Figure 11 presents excerpts from the lesson plan developed by PSPST A in M1.

PSPST A did not describe the lesson phase related to task implementation and left other sections of the plan blank. This absence reveals the gaps in the knowledge required to develop a

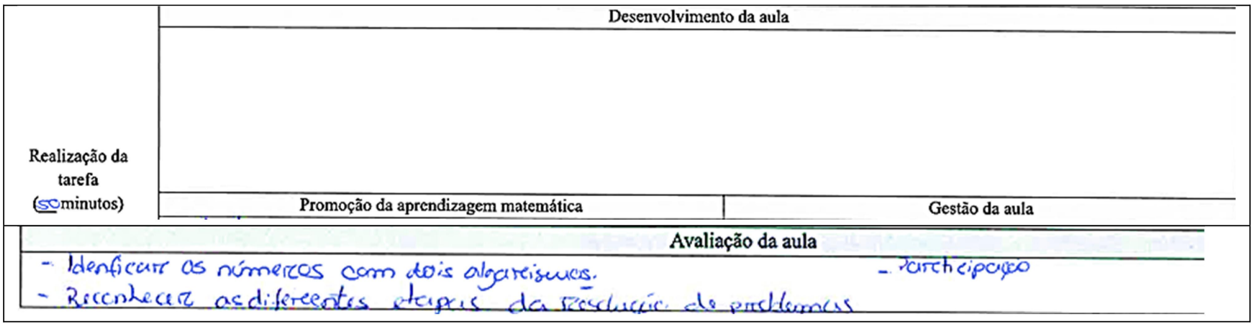

Desenvolvimento da aula
Realização da tarefa (50 minutos)
Promoção da aprendizagem matemática
Gestão da aula
Avaliação da aula
- Identificar os números com dois algarismos.
- Reconhecer as diferentes etapas da resolução de problemas
- Participação

FIGURE 11
Excerpt from pre-service primary school teacher A's resolution (Pre-intervention—M1). (Source: Authors own elaboration).

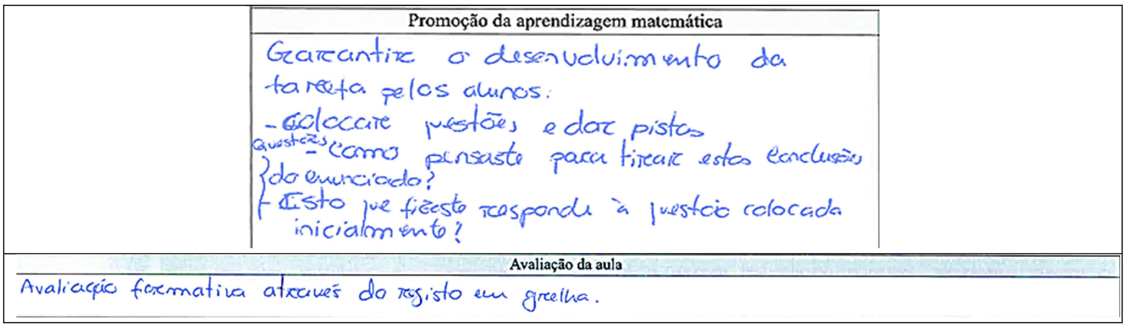

Promoção da aprendizagem matemática
Garantir o desenvolvimento da tarefa pelos alunos:
- Colocar questões e dar pistas
Questões: - Como pensaste para tirar estas conclusões do enunciado?
- Isto que fizeste responde à questão colocada inicialmente?
Avaliação da aula
Avaliação formativa através do registo em grelha.

FIGURE 12
Excerpt from pre-service primary school teacher A's resolution (post-intervention I—M2). (Source: Authors own elaboration).

structured lesson plan. Regarding assessment, only parts of the learning objectives are presented, with no criteria, strategies, or instruments, rendering the proposal completely inadequate and resulting in a classification of Level 1 of Suitability.

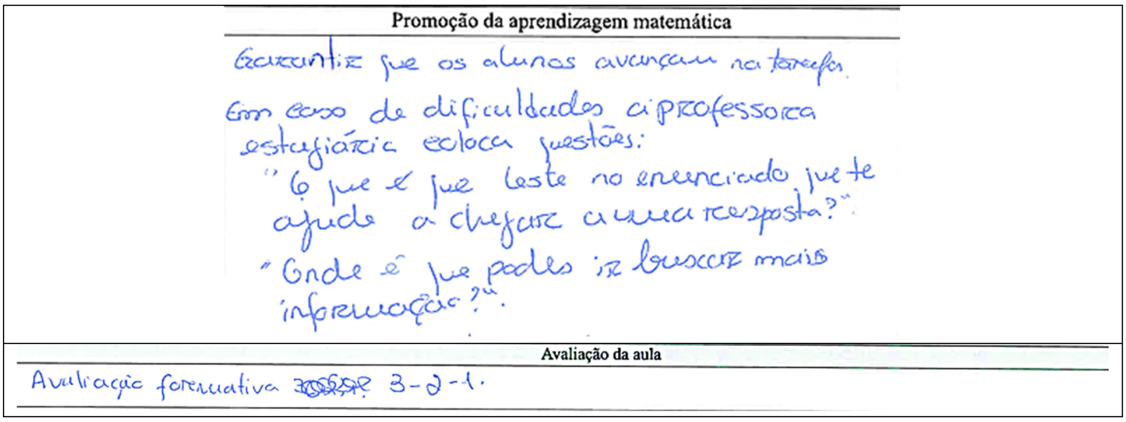
Figure 12 presents two excerpts from the lesson plan developed by this PSPST in M2.

In M2, PSPST A indicates that they will ensure the task is carried out and that they will ask students questions, showing an intention to adapt strategies according to students' needs. However, the questions could be better aligned with the task objectives. As for assessment, the proposal is appropriate but incomplete, as it does not specify the parameters of the assessment rubric. During the lesson, the PSPST expresses an intention to provide feedback, demonstrating an effort to monitor student learning, although some aspects still require greater clarity and development. Therefore, the plan was classified as Partially Suitable (Level 3 of Suitability).

Figure 13 presents excerpts from the lesson plan developed by PSPST A in M3.

In M3, PSPST A states that, to support students' progress in completing the task and in response to potential difficulties or unforeseen situations, they will use relevant guiding questions, demonstrating intentionality in adapting teaching strategies according to students' needs. Regarding assessment, they propose a Formative Assessment Task that is appropriate for the lesson, showing quality in the instruments used. Therefore, their responses were classified as Level 4 of Suitability.

These qualitative findings are further supported by the PSPSTs' critical reflections. For example, one PSPST stated that "*I feel more competent in guiding students during task implementation and in identifying when pair or group work is more beneficial*" (PSPST C), highlighting improvements in lesson management and instructional decision-making. The same PSPST also reflected that "*I can provide guidance that helps identify students' lines of thinking without taking away their autonomy, intervening only when necessary*", demonstrating a more intentional use of feedback to support students' learning. Furthermore, the PSPST reported that "*I improved the way I address students' questions. Previously, I answered them individually, whereas now I realize it is more beneficial to discuss them with the whole class as a way of systematizing and assessing learning*" (PSPST C), illustrating the development of strategies for whole-class discussion, systematization, and formative assessment. These reflections reinforce quantitative evidence that the training program strengthened the PSPSTs' Knowledge of Teaching Practice by improving lesson management, formative assessment practices, and the organization of meaningful learning opportunities. Additional qualitative evidence is provided by the reflective conclusions included in the written group assignments submitted at the end of Phase 2 of the training program. Group 1 (PSPSTs A and B) stated that "*By experiencing exploratory teaching, we were able to understand the appropriate role that the teacher should adopt in this type of lesson and how they should act. We also recognized the*



Promoção da aprendizagem matemática

Garantir que os alunos avançam na tarefa.
Em caso de dificuldades a professora estagiária coloca questões:
"O que é que leste no enunciado que te ajude a chegar a uma resposta?"
"Onde é que podes ir buscar mais informação?".

Avaliação da aula

Avaliação formativa 3-2-1.

FIGURE 13
Excerpt from pre-service primary school teacher A's resolution (post-intervention II—M3). (Source: Authors own elaboration).

effectiveness of this approach in implementing different tasks and acknowledged its importance as an approach to be adopted in our future teaching practice." This group reflection highlights the participants' growing understanding of effective teaching practices and lesson implementation, reinforcing the quantitative evidence of the development of KTP.

4.5 Global performance

Table 14 presents the absolute and relative frequencies of the PSPSTs' Global Performance across the three moments (M1, M2, and M3), distributed by categories.

Regarding the results presented in Table 14, it is noteworthy that in M1, all PSPSTs showed a negative Global Performance, with values below 25%. After Phase 1 of the training program (M2), there was a decrease in the percentage of PSPSTs with a negative Global Performance (from 100.0% to 31.6%), with 31.6% of PSPSTs achieving a Global Performance above 75%. In M3, although one PSPST still showed a negative Global Performance (between 25% and 50%), it is important to highlight that the majority of PSPSTs (73.7%) reached a Global Performance above 75%.

TABLE 14 Frequency distribution of global performance.

Class	M1 [%(n)]	M2 [%(n)]	M3 [%(n)]
[0; 25[	100.0 (19)	10.5 (2)	0.0 (0)
[25; 50[	0.0 (0)	21.1 (4)	5.3 (1)
[50; 75[	0.0 (0)	36.8 (7)	21.1 (4)
[75; 100[	0.0 (0)	31.6 (6)	73.7 (14)

Table 15 presents the descriptive statistics and comparison of PSPSTs' Global Performance across M1, M2, and M3.

The results of the one-way repeated measures ANOVA (Table 15) reveal progress in the Global Performance of PSPSTs across the three evaluated moments. A substantial increase in the mean was observed between the Pre-Intervention phase ($M1 = 0.67$, $SD = 0.79$) and the Post-Intervention phases ($M2 = 61.39$, $SD = 21.73$; $M3 = 82.04$, $SD = 16.97$). The observed differences were statistically significant ($F = 197.058$; $p = 0.001$), with a Strong Effect Size (= 0.916), indicating that the training program had a significant impact on the PSPSTs' Global Performance in lesson planning from M1 to M3, demonstrating positive progress over the course of the program. These results suggest that there was development in the PSPSTs' ability to plan Exploratory Teaching Practices integrating Computational Thinking, reflecting greater mastery and mobilization of Didactic Knowledge in Mathematics. The improvement observed in Global Performance translates into consistent progress in how PSPSTs developed and articulated the different types of knowledge: Knowledge of Mathematics for Teaching, Knowledge of the Curriculum, Knowledge of Students and their Learning Processes, and ultimately, Knowledge of Teaching Practice.

5 Discussion

This section presents a discussion of the study's results, taking into account the relevant literature, with particular focus on the initial difficulties demonstrated by the Pre-Service Primary School Teachers (PSPSTs) and the evolution of their Didactic Knowledge in Mathematics (DKM) when planning Exploratory Teaching Practices that integrate Computational Thinking.

Returning to the first hypothesis formulated, the study's results confirm its validation: statistically significant differences were found in the Levels of Suitability of the Exploratory Teaching Practices integrating Computational Thinking planned by the PSPST between the Pre-Intervention, Post-Intervention I, and Post-Intervention II moments.

These results suggest significant progress in the development of the PSPSTs' DKM, as evidenced by the evolution in the Levels of Suitability of their lesson plans. Therefore, it is important to discuss the findings in light of the four types of knowledge considered in this study: Knowledge of Mathematics for Teaching (KMT), Knowledge of the Curriculum (KC), Knowledge of Students and their Learning Processes (KSLP), and Knowledge of Teaching Practice (KTP).

The results obtained in this study corroborate the difficulties previously identified in the literature regarding lesson planning,

TABLE 15 Descriptive statistics and comparison of global performance across Pre-intervention (M1), post-intervention I (M2), and post-intervention II (M3).

Measure	M1	M2	M3	F	p	η_p^2	ES	π
Global	$0.67 \pm 0.79^{a,b}$	$61.39 \pm 21.73^{a,c}$	$82.04 \pm 16.97^{b,c}$	197.058	0.001	0.916	Strong effect	1.000

One-way repeated measures ANOVA: significantly different at $p < 0.05$ for the following comparisons [a]Pre-Intervention vs. Post-Intervention I; [b]Pre-Intervention vs. Post-Intervention II; & [c]Post-Intervention I vs. Post-Intervention II.

which is recognized as a complex task for pre-service teachers, with its demands increasing significantly in contexts of curricular change, as highlighted in Pepin et al. (2025). With regard to KMT, it was observed that prior to the implementation of the training program, the PSPSTs did not demonstrate the knowledge necessary to recognize the Computational Thinking capability within the context of the problem-solving situations, nor to define pedagogical actions aligned with the proposed task, in line with what was identified in Vieira et al. (2022). Throughout the training program, the PSPSTs were able to deepen their understanding of Computational Thinking (Stage 1), experience solving tasks integrating this capability (Stage 2), and plan lessons while receiving feedback from both peers and the research team (Stages 3–6). The integration of theoretical, practical, and reflective components—where PSPSTs could develop knowledge about this capability and experience its implementation—resulted in improved ability to integrate it effectively into teaching, as also noted in Amante et al., 2023. In both M2 and M3, improvements were observed in the suitability of pedagogical actions aligned with the mathematical content to be developed, indicating a positive evolution in KMT, as suggested in Kurt and Çakıroğlu, 2025.

With regard to KC, the results of this study corroborate the difficulties highlighted in the literature, particularly in relation to the alignment between learning objectives, curriculum guidelines, and the selection of appropriate pedagogical resources (Duarte et al., 2024). Prior to the intervention, the PSPSTs demonstrated significant weaknesses both in the curricular alignment of their lesson plans and in the integration of resources, which compromised the coherence and effectiveness of their teaching proposals, as also mentioned in Njiku, 2025. The absence of clear objectives and relevant resources illustrates their difficulty in mobilizing KC in a well-founded manner. However, following the implementation of the training program, consistent and statistically significant improvements were observed in both M2 and M3, indicating a positive evolution in this type of knowledge. It is worth noting that throughout the training program—particularly during the preparation of lesson plans for school placements and microteaching sessions—the PSPSTs continuously received feedback on the lesson plans they produced. These training program approaches, which led to improved ability among the PSPSTs to plan lessons with coherence between defined learning objectives, selected resources, and applied strategies, are aligned with the recommendations found in the specialized literature (Karalar and Aslan Altan, 2018; Täschner et al., 2025). Thus, the presentation of coherent lesson plans—with objectives aligned with the curriculum and well-structured pedagogical sequences—by the PSPSTs after the implementation of the training program supports the conclusion that there was a development of KC, as noted by Rodrigues and Ponte, 2020.

Before the implementation of the training program, it was observed that the PSPSTs demonstrated very limited knowledge about Students and their Learning Processes, which hindered their ability to anticipate difficulties, promote meaningful interactions, or diversify pedagogical strategies, as noted in Cardoso et al., 2025. Both in the resolution and adaptation of problem-solving situations (during Phase 1) and in the development and implementation of intervention plans for the practicum context (Phase 2), PSPSTs were required to find strategies to adapt tasks to the realities of their classes. Thus, it was observed that through these approaches during the training program, the PSPSTs began to more explicitly value the diversity of their students and the appropriateness of learning processes, particularly by defining strategies that fostered teamwork and idea-sharing among students—corroborating the position of Hourigan and Leavy, 2019. Based on these evidences observed in the lesson plans, it is possible to state that KSLP was developed with the implementation of the training program, as indicated in Copur-Gencturk and Li, 2023.

The results of this study regarding KTP align with what is stated in the specialized literature. Before the implementation of the training program, it was observed that the PSPSTs could not develop coherent and structured lesson plans, evidencing weaknesses in their KTP. These findings reinforce the importance of training programs that develop the capacity to plan effective teaching practices, as advocated by Alrwaished, 2024. Both from M1 to M2 and from M2 to M3, it was observed that the PSPSTs increasingly presented more coherent and complete proposals, defining strategies to manage unforeseen events and ensure task completion by students. The observed improvements demonstrate that KTP developed with the implementation of the training program, as noted in Beckmann and Ehmke, 2023.

Regarding the second hypothesis, it can be stated that there were statistically significant differences in the Global Performance of the pre-service primary school teachers when planning Exploratory Teaching Practices that integrate Computational Thinking between Pre-Intervention, Post-Intervention I, and Post-Intervention II.

The results of this study showed that, before the training program (M1), all participants had negative Global Performance scores, below 25%, revealing weaknesses in the mastery and mobilization of the different types of DKM necessary for planning Exploratory Teaching Practices, as mentioned in Duarte et al., 2024. The low Global Performance of the PSPSTs reflects gaps in the various types of DKM analyzed, whose development is essential for planning lessons focused on Exploratory Teaching Practices (Ferreira and Ponte, 2017).

The development of the various types of DKM of the PSPST throughout the implementation of the training program was directly reflected in the Global Performance of the PSPST, aligning with what Beckmann and Ehmke, 2023 mentioned. Additionally, the PSPST experienced the implementation of Exploratory Teaching

Practices during the training program. This experience allowed the PSPST to gain a deeper understanding of the demands of the approach and to apply it more effectively in their own lesson planning, which may explain the positive progression observed in their Global Performance, as noted in Henriques and Martins, 2022 and Täschner et al., 2025. The improvement observed in the Global Performance of the PSPST after the implementation of the training program thus evidences an effective development of DKM, which is fundamental to promoting meaningful mathematical learning aligned with the principles of Exploratory Teaching Practices.

In summary, the findings of this study suggest that the observed development of the pre-service primary school teachers' Didactic Knowledge in Mathematics may be associated with the main characteristics of the implemented training program. In particular, these include the articulation between opportunities to deepen conceptual understanding and practical experiences involving the solving and adaptation of tasks integrating Computational Thinking, the progressive development of Exploratory Teaching Practice lesson plans, microteaching sessions, the implementation of these lesson plans during the school practicum, and the continuous formative feedback provided by both the research team and peers. These characteristics created opportunities for pre-service primary school teachers to critically reflect on their pedagogical decisions, revise their lesson plans, and progressively mobilize the different components of Didactic Knowledge in Mathematics in a more integrated manner. Taking together, these elements may explain the consistent improvement observed across the different components of Didactic Knowledge in Mathematics and, consequently, in the pre-service primary school teachers' global performance throughout the three assessment moments.

6 Conclusion

This study presents a procedure to evaluate the Didactic Knowledge in Mathematics of Pre-Service Primary School Teachers through the planning of Exploratory Teaching Practices integrating Computational Thinking. The Levels of Suitability of the lesson plans developed by the pre-service teachers evidenced the development of their Didactic Knowledge in Mathematics across the four components of the Framework of the Didactic Knowledge of Teachers who Teach Mathematics, which was reflected in their Global Performance within the implemented training program. These results reinforce the importance of developing training programs in Initial Teacher Training that articulate theory, practice, reflection, and active methodologies, providing Pre-Service Primary School Teachers with sustainable development of didactic knowledge that will enable them to respond to the various challenges inherent in teaching and learning processes.

7 Strengths and limitations of the study

The study provides evidence of a positive evolution in the development of the Didactic Knowledge in Mathematics of the Pre-Service Primary School Teachers. Considering the statistical results presented, it is possible to confirm the formulated hypotheses. Based on the discussion of results grounded in recent literature, the credibility and relevance of this study within the scope of teacher education for mathematics teaching are highlighted. A limitation of this study is that the sample is one of convenience, non-probabilistic in nature, and predominantly female. Nevertheless, it is highlighted that the characteristics of the sample used in this study are consistent with the reality of Initial Teacher Training courses in Portugal. For future studies, it is suggested that the sample includes participants from different institutions and educational contexts to enhance the potential for generalizing the results.

8 Perspective for future studies and practical implications

As a practical implication, the importance of providing pre-service teachers with formative experiences that include the modeling of teaching practices, task-solving, and continuous feedback is highlighted, as these contribute to the development of their Didactic Knowledge in Mathematics. Such experiences promote a deeper understanding of current pedagogical approaches and enhance their application in real teaching contexts. For future studies, in addition to expanding the sample as previously mentioned, it is recommended to analyze the impact of these practices during the early years of teaching, to understand the sustainability and continuity of the learning fostered during initial teacher education.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Polytechnic University Coimbra's Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

RR: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. FM: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing. SG: Conceptualization, Methodology, Resources, Visualization, Writing – original draft, Writing – review & editing. SB-C: Conceptualization, Methodology, Resources, Visualization, Writing – original draft, Writing – review & editing. CC: Conceptualization, Data curation, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Alarcão, I. (2020). *Formação Reflexiva de Professores: Estratégias de Supervisão*. 2nd ed. Coimbra: Edições Almedina.

Alrwaished, N. (2024). Mathematics pre-service teachers' preparation program for designing STEM based lesson plan: enhanced skills and challenges. *Cogent Educ.* 11, 1. doi: 10.1080/2331186X.2024.2320467

Amante, L., Souza, E., Quintas-Mendes, A., and Miranda-Pinto, M. (2023). Designing a MOOC on computational thinking, programming and robotics for early childhood educators and primary school teachers: a pilot test evaluation. *Educ. Sci.* 13, 863. doi: 10.3390/educsci13090863

Angeli, C., Diakou, P., and Anastasiou, V. (2024). "The effects of learning with dash and dot on primary-school students' computational thinking," in *EDULEARN24 Proceedings: 16th International Conference on Education and New Learning Technologies, ed. IATED (Palma: IATED Academy)*, 1, 8562. doi: 10.21125/edulearn.2024

Azevedo, N. (2020). Investigações matemáticas na sala de aula dos autores: joão pedro da ponte, joana brocardo e hélia oliveira. *Ensino Matemática Debate* 7, 303–307. doi: 10.23925/2358-4122.2020v7i2p261-265

Beckmann, T., and Ehmke, T. (2023). Informal and formal lesson planning in school internships: practices among pre-service teachers. *Teach. Teach. Educ.* 132, 104249. doi: 10.1016/j.tate.2023.104249

Bezerra, C., and Quaresma, M. (2023). Desenvolvimento do conhecimento didático de futuros professores no contexto do estudo de aula. *Rev. Paranaense Educ. Matemática* 12, 325–349. doi: 10.33871/22385800.2023.12.29.325-349

Canavarro, A., and Reis, C. (2018). "The interactive whiteboard and the development of dialogic interaction in the context of problem-solving," in *Broadening the Scope of Research on Mathematical Problem Solving: A Focus on Technology, Creativity and Affect*, eds. N. Amado, S. Carreira, and K. Jones (Cham: Springer), 101–127. doi: 10.1007/978-3-319-99861-9_5

Canavarro, A., Brunheira, L., Vicente, M., and Brito, S. (2022). *Coletânea de Tarefas—3. o ano de Escolaridade*. Lisboa: Direção-Geral da Educação.

Canavarro, A., Oliveira, H., and Menezes, L. (2012). Práticas de ensino exploratório da matemática: o caso de célia. *Investig. Educ. Matemática*, 255–266.

Candeias, A., Felix, A., Dumitrache, A., Almăşan, B., Gencel, I. E., Zadworna, M., et al. (2025). Enhancing socio-emotional learning and mental health through computational thinking: a cross-cultural analysis of the COMPUSEL programme. *Front. Psychol.* 16, 1480731. doi: 10.3389/fpsyg.2025.1480731

Cardoso, L., Ponte, J., and Quaresma, M. (2025). Lesson study in primary initial teacher education: participants' perspectives on potential and challenges. *Eurasia J. Math. Sci. Technol. Educ.* 21, em2629. doi: 10.29333/ejmste/16306

Chaabi, H., Azmani, A., and Dodero, J. (2025). Bridging computational thinking research and practice of pre-service and in-service teachers. *Humanit. Soc. Sci. Commun.* 12, 666. doi: 10.1057/s41599-025-04895-9

Cohen, L., Manion, L., and Morrison, K. (2018). *Research Methods in Education*. 8th ed. London: Routledge.

Conceição, T., Baptista, M., and Ponte, J. (2022). Examining pre-service science teachers' pedagogical content knowledge through lesson study. *Eurasia J. Math. Sci. Technol. Educ.* 18, em2060. doi: 10.29333/ejmste/11442

Copur-Gencturk, Y., and Li, J. (2023). Teaching matters: a longitudinal study of mathematics teachers' knowledge growth. *Teach. Teach. Educ.* 121, 103949. doi: 10.1016/j.tate.2022.103949

Council of the European Union and European Commission (2015). *2015 Joint Report of the Council and the Commission on the Implementation of the Strategic Framework for European Cooperation in Education and Training (ET 2020): New Priorities for European Cooperation in Education and Training*. Brussels: Publications Office of the European Union.

Creswell, J. W., and Creswell, J. D. (2017). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. 4th ed. Thousand Oaks, CA: SAGE Publications.

Duarte, N., Ponte, J., and Pinto, H. (2024). Estudo de aula como promotor do desenvolvimento do conhecimento de futuros professores sobre preparação de aulas. *Avances Investig. Educ. Matemática* 26, 21–39. doi: 10.35763/aiem26.5428

Espinal, A., Vieira, C., and Magana, A. (2024). Professional development in computational thinking: a systematic literature review. *ACM Trans. Comput. Educ.* 24, 1–24 doi: 10.1145/3648477

Ferguson, C. (2009). An effect size primer: a guide for clinicians and researchers. *Prof. Psychol. Res. Pr.* 40, 532–538. doi: 10.1037/a0015808

Ferreira, N., and Ponte, J. (2017). "O conhecimento para ensinar matemática na prática letiva de uma futura professora do 2o ciclo: o conceito de percentagem," in *A Prática dos Professores: Planificação e Discussão Coletiva na Sala de Aula*, ed. GTI (Grupo de Trabalho de Investigação da Associação de Professores de Matemática) (Lisboa: APM), 197–222.

Field, A. (2018). *Discovering Statistics Using IBM SPSS Statistics*. 5th ed. London: SAGE Publications Ltd.

Fonseca, G., and Ponte, J. (2025). Building didactic knowledge from reflection in lesson studies. *Int. J. Lesson Learn. Stud.* 14, 14–26. doi: 10.1108/IJLLS-08-2024-0188

Freitas, Y., Abbasi, M., Brito-Costa, S., Pinto, R., Rato, V., and Martins, F. (2024). Exploratory teaching: integrating applet to teach arithmetic multiplication operation. *Eurasia J. Math. Sci. Technol. Educ.* 20, em2546. doi: 10.29333/ejmste/15666

Freitas, Y., Guiomar, B., Gonçalves, S., Pinto, R., Pinto, E., Rato, V., et al. (2025a). Using serious games with exploratory teaching to develop mental arithmetic in primary education. *Educ. Process Int. J.* 15, e2025151. doi: 10.22521/edupij.2025.15.151

Freitas, Y., Martins, F., Moral-Sánchez, S., and Ruiz-Rey, F. (2025b). Actions of a trainee teacher in orchestrating mathematical discussions. *Educ. Process Int. J.* 14, e2025038. doi: 10.22521/edupij.2025.14.38

Giacomelli, C., and Lopes, A. (2020). Early years math: a study with undergraduates in mathematics based on the principles of cultural—historical theory. *Acta Sci.* 22, 84–101. doi: 10.17648/acta.scientiae.5819

Henriques, A., and Martins, M. (2022). Mathematical reasoning in linear systems learning: a higher education exploratory teaching experiment with prospective teachers. *Avances Investig. Educ. Matemática* 21, 65–85. doi: 10.35763/aiem21.4238

Hourigan, M., and Leavy, A. (2019). Learning from teaching: pre-service primary teachers' perceived learning from engaging in formal lesson study. *Ir. Educ. Stud.* 38, 283–308. doi: 10.1080/03323315.2019.1613252

Karalar, H., and Aslan Altan, B. (2018). New technologies in microteaching: is it possible for web 2.0 tools to affect prospective teachers' web pedagogical content knowledge and teacher self-efficacy? *Int. Online J. Educ. Teach. (IOJET)* 5, 535–551.

Kurt, G., and Çakıroğlu, E. (2025). Prospective mathematics teachers' TPACK development in graphical data displays: a microteaching lesson study. *Int. J. Math. Educ. Sci. Technol.* 56, 445–475. doi: 10.1080/0020739X.2023.2246970

Macann, V., and Hartnett, M. (2025). Exploring the influence of self-efficacy beliefs on computational thinking instruction. *J. Technol. Teach. Educ.* 33, 37–66. doi: 10.70725/055215qudqwf

Machuqueiro, F., and Piedade, J. (2024). Game on: a journey into computational thinking with modern board games in Portuguese primary education. *Educ. Sci.* 14, 1182. doi: 10.3390/educsci14111182

Marôco, J. (2021). *Análise Estatística com o SPSS Statistics*. 8th ed. Lisboa: ReportNumber.

Martin, D., and Jamieson-Proctor, R. (2022). Pre-service Teachers' perceptions of problem-based learning for developing their mathematics teaching pedagogy. *Interdiscip. J. Problem-Based Learn.* 16, 1. doi: 10.14434/ijpbl.v16i1.28739

Martins, M., Mata-Pereira, J., and Ponte, J. (2021). Os desafios da abordagem exploratória no ensino da matemática: aprendizagens de duas futuras professoras através do estudo de aula. *Bolema* 35, 343–364. doi: 10.1590/1980-4415v35n69a16

Martins, M., Ponte, J., and Mata-Pereira, J. (2024). O desenvolvimento do conhecimento didático de futuros professores: o estudo de aula como processo formativo integrado na formação inicial. *PNA Rev. Investig. Didáctica Matemática* 18, 105–130. doi: 10.30827/pna.v18i2.27258

Ministério da Educação (2021). *Aprendizagens Essenciais de Matemática*. Lisboa: ME.

Njiku, J. (2025). Pre-service teachers manifested mathematics pedagogical content knowledge: the role of the teaching practicum. *Pedagog. Res.* 10, em0229. doi: 10.29333/pr/15647

Noviyanti, M., Sudirman, S., and Rodríguez-Nieto, C. (2025). Investigating mathematical knowledge for teaching early childhood education teachers: a starting point for designing a professional development program. *Educ. Process Int. J.* 16, e2025210. doi: 10.22521/edupij.2025.16.210

Nóvoa, A. (2021). *Os Professores: O Presente e o Futuro*. Coimbra: Edições Almedina.

Oliveira, H., Menezes, L., and Canavarro, A. (2013). Conceptualizando o ensino exploratório da matemática : contributos da prática de uma professora do 3.o ciclo para a elaboração de um quadro de referência. *Quadrante XXII* 22, 29–53.

Pallant, J. (2020). *SPSS survival Manual: A Step by Step Guide to Data Analysis Using IBM SPSS*. London: Routledge.

Palop, B., Díaz, I., Rodríguez-Muñiz, L., and Santaengracia, J. (2025). Redefining computational thinking: a holistic framework and its implications for K-12 education. *Educ. Inf. Technol. (Dordr)* 30, 13385–13410. doi: 10.1007/s10639-024-13297-4

Pepin, B., Kohanová, I., and Lada, M. (2025). Developing pre-service teachers' capacity for lesson planning with the support of curriculum resources. *ZDM Math. Educ.* 57, 1003–1017 doi: 10.1007/s11858-025-01685-0

Pestana, M., and Gageiro, J. (2014). *Análise de Dados Para Ciências Sociais: A Complementaridade do SPSS [Data Analysis for Social Sciences: The Complementarity of SPSS]*. Lisboa: Edições Sílabo, Lda.

Piedade, J., Pedro, A., and Matos, J. (2018). "Cenários de aprendizagem como estratégia de planificação de aulas na formação inicial de professores: o exemplo da área de informática," in *Congresso Internacional de TIC e Educação*, eds. A. Pedro, J. Piedade, J. F. Matos, N. Dorotea, and N. Pedro (Lisboa: Instituto de Educação da Universidade de Lisboa), 1833–1851.

Ponte, J. (2012). "Estudiando el conocimiento Y el desarrollo profesional Del profesorado De matemáticas," in *Teoria, Crítica y Prática de la Educación Matemática*, ed. N. Planas (Barcelona: Graó), 83–98.

Quaresma, M., Macedo, A., Neves, R., and Ponte, J. (2024). Apropriação pelos futuros professores de matemática da abordagem do ensino exploratório em processo de estudo de aula. *Zetetike* 32, e024005. doi: 10.20396/zet.v32i00.8676684

Rodrigues, B., and Ponte, J. (2020). Desenvolvimento do conhecimento didático de professores em estatística. *Zetetike* 28, e020002. doi: 10.20396/zet.v28i0.8656882

Rodrigues, R. N., Costa, C., and Martins, F. (2024). Integration of computational thinking in initial teacher training for primary schools: a systematic review. *Front. Educ. (Lausanne)* 9, 1–8. doi: 10.3389/feduc.2024.1330065

Rodrigues, R. N., Costa, C., Brito-Costa, S., Abbasi, M., and Martins, F. (2025). Impact of a training program on developing computational thinking in Pre-service primary school teachers: from theory to practice. *Educ. Process Int. J.* 14, e2025037. doi: 10.22521/edupij.2025.14.37

Santos, J., Abar, C., Breda, A., and Lavicza, Z. (2025). Automatic feedback in mathematics education: a pathway to robotics and computational thinking. *Acta Sci.* 27, 1–27. doi: 10.17648/acta.scientiae.8240

Serrazina, M. L. (2017). "Planificação do ensino e aprendizagem da matemática," in *A Prática dos Professores: Planificação e Discussão Coletiva na Sala de Aula*, ed. GTI (Grupo de Trabalho de Investigação da Associação de Professores de Matemática) (Lisboa: APM), 9–32.

Silva, C., Mendonça, C., Cadima, J., Rodrigues, R. N., Sacramento, J., Pires, E., et al. (2024a). "The exploration of the SuperDoc robot through an explanatory teaching model," in *STEAMING AHEAD: Fostering Critical Thinking, Problem-Solving and Creativity*, eds. M. Bento, and J. A. Lencastre (Braga: Research Centre on Education (CIEd), Institute of Education, University of Minho), 127–154.

Silva, G., and Ponte, J. (2025). Primary school teachers and their engagement with critical mathematics education via landscapes of investigation. *Eurasia J. Math. Sci. Technol. Educ.* 21, em2636. doi: 10.29333/ejmste/16393

Silva, R., Costa, C., and Martins, F. (2024b). Pre-service teachers' perceptions towards integrating educational robotics in the primary school. *Eurasia J. Math. Sci. Technol. Educ.* 20, em2419. doi: 10.29333/ejmste/14356

Tabachnick, B., and Fidell, L. (2021). *Using Multivariate Statistics*. 7th ed. Hoboken, NJ: Pearson.

Tadeu, P., Kaya, D., and Kutluca, T. (2025). Enhancing computational thinking in preservice elementary math teachers through design-based learning. *Mill. J. Educ. Technol. Health* 2, e40841. doi: 10.29352/mill0227.40841

Tankiz, E., and Atman Uslu, N. (2023). Preparing pre-service teachers for computational thinking skills and its teaching: a convergent mixed-method study. *Technol. Knowl. Learn.* 28, 1515–1537. doi: 10.1007/s10758-022-09593-y

Tariq, R., Aponte Babines, B. M., Ramirez, J., Alvarez-Icaza, I., and Naseer, F. (2025). Computational thinking in STEM education: current state-of-the-art and future research directions. *Front. Comput. Sci* 6, 1480404. doi: 10.3389/fcomp.2024.1480404

Täschner, J., Dicke, T., Reinhold, S., and Holzberger, D. (2025). "Yes, I can!" a systematic review and meta-analysis of intervention studies promoting teacher self-efficacy. *Rev. Educ. Res* 95, 3–52. doi: 10.3102/00346543231221499

Tripon, C. (2022). Supporting future teachers to promote computational thinking skills in teaching STEM—a case study. *Sustainability* 14, 12663. doi: 10.3390/su141912663

Trocado, A., Santos, J., and Lavicza, Z. (2022). "Developing computational thinking in Portuguese mathematics curricula with collatz conjecture," in *The 27th Asian Technology Conference in Mathematics (ATCM 2022)*.

Vieira, R., Ponte, J., and Mata-Pereira, J. (2022). Conhecimento matemático de futuros professores: aprendizados realizados num estudo de aula. *Bolema* 36, 822–843. doi: 10.1590/1980-4415v36n73a10

Wing, J. (2006). Computational thinking. *Commun. ACM* 49, 33–35. doi: 10.1145/1118178.1118215

Yun, M., and Crippen, K. (2025). Computational thinking integration into pre-service science teacher education: a systematic review. *J. Sci. Teacher Educ* 36, 225–254. doi: 10.1080/1046560X.2024.2390758

Zaragoza, A., Seidel, T., and Hiebert, J. (2024). Exploring preservice teachers' abilities to connect professional knowledge with lesson planning and observation. *Eur. J. Teach. Educ.* 47, 120–139. doi: 10.1080/02619768.2021.1996558

Zaragoza, A., Seidel, T., and Santagata, R. (2023). Lesson analysis and plan template: scaffolding preservice teachers' application of professional knowledge to lesson planning. *J. Curric. Stud.* 55, 138–152. doi: 10.1080/00220272.2023.2182650