

# Didactic knowledge in mathematics in the integration of computational thinking: Evidence in exploratory teaching practices of pre-service primary school teacher

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## Abstract

Computational thinking is a cognitive skill widely recognized as essential for problem-solving. Exploratory teaching practices constitute an appropriate methodology for this development, as they promote active learning through the resolution of challenging tasks. This qualitative and interpretative study analyzed the aspects of didactic knowledge in mathematics mobilized by three groups of pre-service primary school teachers in the implementation of exploratory teaching practices that integrated the development of computational thinking, as well as the challenges they faced in this process. The results show that the pre-service teachers demonstrated the knowledge necessary to integrate computational thinking into their teaching practice, with the teaching practice knowledge component standing out, particularly in pedagogical decisions such as requesting clarification and encouraging students during the implementation of tasks that mobilized dimensions of computational thinking. Regarding the main difficulties experienced by the pre-service teachers, the results indicate that these were related to classroom management, particularly time management and the management of whole-class discussions. The study offers relevant insights into the design of teacher education programs and for future research on the integration of computational thinking into mathematics teaching.

**Keywords:** didactic knowledge in mathematics, computational thinking, exploratory teaching practices, initial teacher training, pre-service primary school teachers

## INTRODUCTION

Computational thinking has increasingly assumed a central role in mathematics curricula, being recognized as an essential competency for the development of problem-solving skills and logical reasoning (Polat et al., 2025; Wing, 2006). At the same time, exploratory teaching practices have emerged as a pedagogical approach capable of promoting active learning, structured around the resolution of challenging tasks (Canavarro et al., 2012; Freitas et al., 2025a), making

them particularly suitable for fostering the development of computational thinking.

Despite the recognized potential of exploratory teaching practices to promote meaningful learning and the importance of developing computational thinking, the specialized literature reveals significant research gaps. To date, there is limited research on how to effectively support pre-service teachers in planning such practices (Zaragoza et al., 2024). In this context, Henriques and Martins (2022) highlight that exploratory teaching practices remain little known and experienced

### Contribution to the literature

- Provides evidence on how pre-service primary school teachers (PSPSTs) mobilize different components of didactic knowledge during the implementation of exploratory teaching practices that integrate computational thinking.
- Extends previous research by highlighting how structured teacher education programs that combine planning, microteaching session, and reflection foster the development of didactic knowledge for the integration of computational thinking.
- Identifies classroom management, particularly time management and orchestration of collective discussions, as the main challenges faced by PSPSTs.

by pre-service teachers, particularly during initial teacher training. More specifically, Duarte et al. (2025) identify a scarcity of studies investigating the development of didactic knowledge in mathematics in the context of exploratory teaching practices, representing a particularly relevant research gap. Regarding computational thinking, recent systematic reviews emphasize that its integration into higher education teaching remains underexplored, constituting a significant gap (Tariq et al., 2025). Moreover, they point out methodological limitations in existing studies, which tend to focus solely on teachers' conceptual understanding without analyzing how they design or implement tasks, nor incorporate classroom observation analysis as part of the training program (Espinal et al., 2024).

These gaps reinforce the need to investigate how initial teacher training programs can effectively prepare pre-service teachers to implement exploratory teaching practices that integrate computational thinking. The teaching practices analyzed in this study were implemented within a training program at a higher education institution in mainland Portugal, designed to develop the didactic knowledge in mathematics of PSPSTs necessary for integrating computational thinking into their teaching practices. The aim of this article is to analyze which aspects of didactic knowledge in mathematics are mobilized by PSPSTs in the implementation of exploratory teaching practices integrating computational thinking, as well as the challenges they face in this process. The main contribution of this study lies in addressing gaps identified in the literature, specifically the scarcity of research analyzing the development of PSPSTs' didactic knowledge in mathematics in the context of implementing exploratory teaching practices that integrate computational thinking.

Thus, the research questions (RQ) emerge:

- RQ1.** Which aspects of didactic knowledge in mathematics are mobilized by PSPSTs when implementing exploratory teaching practices that integrate computational thinking?
- RQ2.** What challenges do PSPSTs face when integrating dimensions of computational thinking into their teaching practice?

## THEORETICAL BACKGROUND

### Teachers' Didactic Knowledge in Mathematics

Didactic knowledge in mathematics constitutes a structuring element of professional practice, with initial teacher training playing a crucial role in its development (Viseu et al., 2025). According to Hlaela and Jita (2025) and Ponte (2012), it is defined as the knowledge that teachers must possess to teach, encompassing a set of domains that articulate mathematical content knowledge, understanding of curricular guidelines, knowledge about students and teaching practice. The literature shows that the quality of classroom mediation directly depends on the integrated mobilization of these four components, enabling teachers to transform mathematical knowledge into meaningful learning opportunities (Duarte et al., 2025; Rodrigues & Ponte, 2020).

The model proposed by Ponte (2012) systematizes the four fundamental components of didactic knowledge: knowledge of mathematics for teaching, knowledge of the curriculum, knowledge of students and their learning processes, and knowledge of teaching practice. The first component refers to the conceptual mastery of content and how it should be addressed in the classroom, being essential for mobilizing knowledge and promoting mathematical rigor during interactions with students (Gómez-Muñoz et al., 2025; Ponte, 2012). Knowledge of the curriculum corresponds to the teacher's ability to interpret and articulate curricular guidelines with the content to be taught, selecting appropriate resources and strategies to integrate those guidelines into practice (Duarte et al., 2024; Njiku, 2025). Knowledge of students and their learning processes concerns understanding students' characteristics, interests, and difficulties, allowing teachers to identify how they learn, which strategies are most effective, and how to promote different types of reasoning (Fonseca & Ponte, 2025; Hourigan & Leavy, 2019). According to Rodrigues and Ponte (2020), the didactic knowledge model is distinguished by the centrality attributed to knowledge of teaching practice, conceived as the core that articulates the remaining dimensions, which cannot be understood in isolation but are always interconnected

in teaching practices. Knowledge of teaching practice manifests itself clearly during classroom interactions, guiding pedagogical decisions and structuring the teaching process, being directly related to decisions on task management, encouraging student participation, and synthesizing learning (Ponte, 2012).

The development of didactic knowledge begins in a structured manner during the academic training of teachers, but it is mainly through classroom practice that it becomes consolidated and deepened (Viseu et al., 2025). However, such development requires more than mere exposure to school contexts; it involves the ability to reflect critically on one's own practice and to incorporate guided feedback (Hourigan & Leavy, 2019). As noted by Duarte et al. (2025), Karalar and Aslan Altan (2018), and Zaragoza et al. (2024), the gap between theory and practice remains one of the main weaknesses of initial teacher training. In this regard, Zaragoza et al. (2023) emphasize the relevance of iterative cycles of analysis of lesson plans developed by pre-service teachers, which allow articulation between design and reflection moments before implementation, fostering the development of didactic knowledge (Silva et al., 2024a). Complementarily, microteaching sessions have also been recognized as an effective strategy to consolidate this process (Täschner et al., 2025). Although initial teacher training provides practice experiences accompanied by reflection and feedback, particularly through curricular practicums, the development of didactic knowledge remains a challenging process in which several difficulties persist (Beckmann & Ehmke, 2023; Hlaela & Jita, 2025).

Recent studies indicate that pre-service teachers show weaknesses in various components of didactic knowledge, which are worth outlining. One of the difficulties identified concerns selecting and using specific resources that are appropriately aligned with the planned content, undermining didactic coherence and lesson effectiveness (Njiku, 2025). Another aspect highlighted in the studies is time management and classroom dynamics, identified as difficulties mainly during the early stages of the profession (Kajtazi, 2025; Vinci, 2025). Additionally, PSPSTs rarely anticipate students' learning difficulties (Silva et al., 2024a), which compromises the definition of adequate strategies to overcome them and limits the promotion of approaches that encourage the development and sharing of different types of reasoning in problem-solving (Copur-Gencturk & Li, 2023; Drot-Delange et al., 2021). Taken together, these findings reveal that didactic knowledge cannot be reduced to isolated dimensions; rather, it must be understood as an integrated construct that develops progressively through practice, reflection, and feedback in authentic teaching contexts (Ponte, 2012; Rodrigues & Ponte, 2020).

## Computational Thinking

Computational thinking, a term popularized by Wing (2006), refers to a set of fundamental competencies that, when developed and integrated, enhance problem-solving abilities (Polat et al., 2025; Rodrigues et al., 2025b). In Portugal, the official mathematics curriculum, *aprendizagens essenciais* (Ministério da Educação, 2021), already includes explicit references to computational thinking and provides guidelines for its development from the first year of primary school (Rodrigues et al., 2025a). According to this document (Ministério da Educação, 2021), the development of computational thinking requires the integrated cultivation of "practices such as abstraction, decomposition, pattern recognition, analysis and definition of algorithms, and the development of debugging and optimization habits" (p. 3). Thus, abstraction refers to the ability to identify the essential aspects of a task, disregarding irrelevant information (Candeias et al., 2025). Decomposition concerns the skill of breaking a problem into simpler parts, facilitating its resolution (Chaabi et al., 2025). Algorithmic thinking involves the ability to organize sequentially the necessary steps to solve a task (Yun & Crippen, 2025). Debugging consists of detecting and correcting errors or inaccuracies in the problem-solving process (Macann & Hartnett, 2025). Finally, pattern recognition involves identifying regularities and similarities, allowing the application of previously used strategies in new situations (Palop et al., 2025).

Although the integration of computational thinking is taking place in the curricula of several countries, recent studies continue to report that its implementation faces challenges, particularly related to teachers' limited understanding of this competency (Santos et al., 2025). The literature highlights that many teachers show gaps in their knowledge of computational thinking and lack specific training that would enable them to integrate it intentionally and meaningfully into their pedagogical practices (Angeli & Giannakos, 2019; Haşlamam et al., 2024; Pewkam & Chamrat, 2022). A study conducted by Drot-Delange et al. (2021) also found that when implementing computational thinking tasks, pre-service teachers often fail to adequately reflect on the progression of the selected tasks, the adopted methods, or the potential learning difficulties of their students.

In this regard, it is essential that teacher education, particularly during Initial Teacher Training, provides structured opportunities for developing the didactic knowledge required for the integration of computational thinking (Alrwaished, 2024; Chaabi et al., 2025). This involves not only introducing theoretical concepts but also creating conditions for future teachers to experiment with, plan, and analyze practices that incorporate computational thinking (Candeias et al., 2025; Macann & Hartnett, 2025; Tankiz & Atman Uslu, 2023).

## Exploratory Teaching Practices

Exploratory teaching practices constitute a pedagogical approach centered on the resolution of challenging mathematical tasks, in which students take an active role in constructing knowledge through exploration, sharing, and reflection (Canavarro et al., 2012; Oliveira et al., 2013). This approach values both the execution of the task and the analysis of underlying strategies and reasoning, promoting transversal skills such as mathematical reasoning, problem-solving, communication, and collaborative work (Ferreira & Ponte, 2017; Freitas et al., 2024).

An exploratory teaching practice is organized into four interconnected phases (Canavarro et al., 2012). In the introduction of the task, the teacher presents the task and clarifies its objectives, ensuring that all students understand the instructions (Freitas et al., 2025a). During the task development phase, students autonomously or collaboratively explore different solution strategies, while the teacher observes and provides guidance through challenging questions (Oliveira et al., 2013; Rodrigues et al., 2025c). In this context, the questions formulated by the PSPST play a central role in promoting students' engagement and reasoning, since, as highlighted by Suryana et al. (2021) and Yao (2025), the ability to formulate effective questions constitutes a key competence for fostering students' critical and analytical thinking. As Freitas et al. (2025b) mention, the task discussion is a collective moment in which selected strategies are shared, compared, and analyzed, allowing students to understand different reasoning processes and deepen their learning. Finally, in the systematization phase, the teacher takes on a more directive role, organizing and synthesizing the mathematical knowledge constructed throughout the lesson (Canavarro et al., 2012; Carvalho et al., 2024).

Implementing exploratory teaching practices entails specific demands on teachers, particularly in classroom management and the facilitation of collective discussions, moments that require anticipating solution strategies, interpreting students' approaches, and stimulating peer dialogue (Freitas et al., 2025b). For PSPSTs, these moments are even more challenging, due to the difficulty of predicting students' strategies and managing rich mathematical interactions (Martins et al., 2024; Silva et al., 2024b). In a study conducted by Jesus et al. (2020), which analyzed the implementation of exploratory teaching practices by mathematics teachers, the main difficulties reported were managing students' work during the task, managing the time required for developing solutions, and sequencing these solutions for sharing in the collective discussion. In this regard, Duarte et al. (2025) argue that the planning of an exploratory teaching practice must be meticulous to anticipate different scenarios and avoid unexpected situations during classroom implementation. Such

detailed preparation is essential for teachers to effectively connect the phases of the lesson and ensure that collective discussions genuinely lead to the construction of mathematical knowledge (Freitas et al., 2025b).

To prepare PSPSTs for integrating exploratory teaching practices into their future professional practice, it is important that they could experience and discuss them during initial teacher training (Henriques & Martins, 2022). This process can be supported through training contexts that simulate real classroom environments, allowing PSPSTs to experiment with different strategies and reflect on their own practice. Microteaching sessions play a particularly effective role in this process, as they allow PSPSTs to practice what they have learned and receive constructive feedback (Karalar & Aslan Altan, 2018).

## MATERIALS AND METHODS

This study is qualitative in nature and interpretative in orientation (Cohen et al., 2018), focusing on the analysis of practices implemented by PSPSTs. The following subsections present the participants, the training program in which the practices were embedded, and the procedures for data collection and analysis.

### Participants

The training program (Rodrigues et al., 2025c), in which the lessons analyzed in this study were included, was implemented during the 2023/2024 academic year at a higher education institution in mainland Portugal and involved the participation of 19 female PSPSTs aged between 20 and 54 years (mean [M] = 24.47; standard deviation [SD] = 9.576). The PSPSTs were enrolled in the first year of a master's degree, with 12 attending the master's degree program in primary school teaching and 2<sup>nd</sup> grade school teaching in mathematics and experimental sciences (master's degree program PS/MES), and 7 attending the master's degree program in primary school teaching and 2<sup>nd</sup> grade school teaching in Portuguese and history and geography of Portugal (master's degree program PS/PHGP). The sample was defined through convenience sampling, of a non-probabilistic nature, and included all participants who, being enrolled in the master's programs, voluntarily expressed their interest in participating.

Throughout the first year of the master's degree, the PSPSTs completed a curricular practicum in a primary school, organized into eight groups of two or three members. The composition of these groups was maintained throughout all sessions of the training program, ensuring continuity between academic training and practicum experience. It is important to note that the focus of the intervention was on content related to the topic data and probability (Ministério da Educação, 2021), with each practicum group having

**Table 1.** Main characteristics of group-implemented practices

Groups	Number of lessons	Integration of digital artefacts	School grade
Group 1	4	Yes	4 <sup>th</sup> grade
Group 2	2	No	1 <sup>st</sup> grade
Group 3	2	No	2 <sup>nd</sup> grade
Group 4	1	No	1 <sup>st</sup> grade
Group 5	1	No	1 <sup>st</sup> grade
Group 6	1	Yes	3 <sup>rd</sup> grade
Group 7	3	No	1 <sup>st</sup> grade
Group 8	5	Yes	3 <sup>rd</sup> grade

autonomy to define the number of lessons to be implemented in their respective contexts. **Table 1** presents the main characteristics of the practices implemented by the groups of PSPSTs.

For the present study, the lessons implemented by groups 1, 3, and 5 were analyzed, selected for being considered representative of the entire sample of participants, considering the number of lessons conducted and the presence or absence of digital artefact integration. The following section provides a brief characterization of the three groups analyzed in this study and of the practices they implemented.

### Group 1

Group 1 consisted of two PSPSTs, one enrolled in the master's degree program PS/MES, and the other in the master's degree program PS/PHGP. This group was conducting a practicum in a 4<sup>th</sup> grade class at a primary school, consisting of twenty-four students, eight male and sixteen female, aged between nine and ten years.

The group chose to implement four lessons, all utilizing a digital artefact, the HypatiaMat platform, a guide for accessing the platform to support students during the process, and exploration sheets containing the frames explored in each session and questions aimed at fostering computational thinking. Thus, these exploration sheets included tasks explicitly aimed at developing the five dimensions of this mathematical competency as outlined in the Portuguese curriculum, such as abstraction (e.g., "underline the most important information to solve the task"), algorithmic thinking (e.g., "describe the steps you followed to construct the stem-and-leaf diagram"), and debugging (e.g., "check whether the diagram includes all the necessary elements").

In the first session, the PSPSTs introduced the concept of a stem-and-leaf plot, addressing its structure composed of stems and leaves, and encouraged the step-by-step construction of a simple stem-and-leaf plot with the support of a table while interpreting the represented data. In the second session, the focus was on identifying the mode(s) and recognizing the minimum and maximum values in simple stem-and-leaf plots. The third session deepened the construction and

interpretation of simple stem-and-leaf plots, including the identification of the maximum value, but without providing the supporting table, thereby increasing the task's level of complexity. Finally, the fourth session explored the double stem-and-leaf plot, comparing it with the simple plot, including the construction of the graph and the identification of the mode, minimum, and maximum values.

### Group 3

Group 3 consisted of two PSPSTs enrolled in the master's degree program PS/MES. The group was conducting their practicum in a 2<sup>nd</sup> grade class at a primary school, consisting of twenty-one students, thirteen male and nine female, aged between seven and eight years.

The group implemented two lessons that were based on World Sports Day. In the first session, the PSPSTs introduced the topics of "physical activity" and "data and probability." The aim of the session was to collect, process, and interpret data on the students' favorite sports. To do so, they used a grid sheet for students to organize the data, allowing them to freely choose the type of graph they wanted to construct. They also used an exploration sheet containing questions related to data interpretation, designed to foster computational thinking. The second session began with physical activities outdoors. The PSPSTs reorganized the working groups and created four stations with different games that the students were required to complete. Upon returning to the classroom, the PSPSTs used an exploration sheet with questions aimed at identifying and analyzing regularities in the paths taken, followed by tasks designed to promote the development of computational thinking. Similar to group 1, the exploration sheets included tasks aimed at developing the five dimensions of computational thinking outlined in the Portuguese curriculum. However, due to the writing limitations of 2<sup>nd</sup> grade primary school students, some guiding questions were intentionally planned and presented orally, for example, for abstraction ("What is the relevant information you considered to solve the task?"), decomposition ("Is it possible to break the task of creating a graph into smaller parts?"), and pattern recognition ("What similarities can we find among the solutions presented?").

### Group 5

Group 5 consisted of three PSPSTs, two enrolled in the master's degree program PS/MES and one in the master's degree program PS/PHGP. The group was conducting their practicum in a 1<sup>st</sup> grade class at a primary school, consisting of twenty students, nine male and eleven female, aged between six and seven years.

The group chose to implement a single session, with the main objective being the construction of pictograms.

Starting with data collection on the students' favorite season, the students created graphical representations using emojis, images of the seasons, glue, and paper. Through the sharing and discussion of their solutions, the PSPSTs mediated students' interventions, guiding them to identify the essential elements of a pictogram and fostering the development of computational thinking.

Similarly to the other groups, group 5 included tasks aimed at developing the five dimensions of computational thinking outlined in the Portuguese curriculum. However, due to the writing limitations of 1st grade primary school students, as in group 3, the questions related to computational thinking were intentionally planned and presented orally, for example, for abstraction ("Which instructions did you consider most important to solve the task?"), for debugging ("Could we have formed these groups differently? Why?"), and for pattern recognition ("What do the solutions presented by the different groups have in common?").

### **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. Informed consent was obtained from participants following a detailed explanation of the study's objectives, the voluntary nature of participation, and their right to discontinue involvement at any stage without repercussions.

### **Pedagogical Intervention**

The training program was primarily designed to promote the development of PSPSTs' didactic knowledge in mathematics, with a focus on the integration of computational thinking, and was conducted throughout the 2023/2024 academic year. The program was organized in two phases distributed over the two semesters, adopting characteristics similar to those presented by Piedade et al. (2018), Silva et al. (2024a), and Tadeu et al. (2025). The interventions analyzed in this study took place during phase 2 of the training program. For contextual purposes, only a brief description of the program is provided here, while a detailed description can be found in Rodrigues et al. (2025c).

Phase 1 aimed primarily to deepen PSPSTs' knowledge on aspects relevant to the training program, such as computational thinking, lesson planning models, and exploratory teaching practices. During this phase, PSPSTs engaged in the resolution of tasks integrating

computational thinking with mathematical topics and developed intervention plans to be implemented in phase 2. Phase 1 concluded with the sharing and discussion of the proposed interventions in the practicum settings, conducted in tutorial sessions with the research team of this study and in coordination with the educational practice course. During this sharing, PSPSTs justified their pedagogical choices, received feedback from the research team and peers, and adjusted the plans according to the actual practicum contexts and the suggestions received.

Phase 2 continued the structuring of the intervention plans initiated in phase 1. Initially, microteaching sessions were conducted, in which PSPSTs implemented part of the plan with colleagues acting as primary school students, followed by discussion and reflection sessions with the research team and peers to identify aspects to retain or adjust. Subsequently, PSPSTs implemented the proposed plans in the practicum contexts, collecting different types of data that allowed the construction of the multimodal narratives (MN), which are the focus of analysis in this study. In the following subsections, the definition of MN will be presented, as well as the way they were constructed and analyzed in this study. Phase 2 concluded with the sharing and discussion of the implemented interventions, including the presentation of results and an individual critical reflection on the entire process.

### **Data Collection**

Data collection was carried out by the PSPSTs in coordination with one of the researchers (the first author of this study). Data were collected through participant observation by the PSPSTs, the writing of field notes, audio and photographic records, and documents produced by the students. All collected data were used to construct MN, following the protocol of Lopes et al. (2018), with seven MN analyzed in this article corresponding to each of the lessons implemented by the groups. The MN consist of chronological, self-contained, and multimodal descriptions of the classroom context, integrating the actions of both the teacher and the students, and are organized into episodes corresponding to the four phases of the lesson: task introduction, task execution, task discussion, and systematization of mathematical learning. All information included in the MN (Lopes et al., 2014) results from a comprehensive data collection process, making this document suitable for analyzing classroom teaching practices without the need for, and challenges associated with, using multiple separate data sources (Lopes et al., 2014).

**Table 2.** Categories and variables for the analysis of the MN

Categories	Analysis variables	Brief description
Knowledge of mathematics for teaching	C01. Use specific vocabulary accurately	The PSPST uses appropriate mathematical terminology.
	C02. Apply mathematical concepts accurately	The PSPST rigorously applies mathematical concepts in the mobilization of knowledge.
	C03. Recognize mathematical concepts in interactions with students	The PSPST identifies the emergence of mathematical concepts in students' actions.
	C04. Mobilize knowledge resulting from the interaction between content knowledge, students' actions, and the context	The PSPST, drawing on the context, students' actions, and their own knowledge of the mathematical concepts involved, fosters moments of consolidation or the development of new learning.
Knowledge of the curriculum	C05. Align content with the curriculum	The PSPST addresses mathematical content suggested in the <i>aprendizagens essenciais</i> (Ministério da Educação, 2021).
	C06. Use appropriate teaching resources	The PSPST uses teaching resources suitable for the educational stage and the development of the mathematical concepts involved.
	C07. Integrate different areas of knowledge	The PSPST articulates and integrates different areas of knowledge as outlined in the curriculum guidelines.
	C08. Integrate mathematical abilities into mathematical topics	The PSPST integrates the mathematical abilities described in the <i>aprendizagens essenciais</i> (Ministério da Educação, 2021) into the development of mathematical topics.
Knowledge of students and their learning processes	C09. Adapt tasks to students' age and learning	The PSPST considers students' age and their prior knowledge of the mathematical concepts involved when proposing challenges.
	C10. Demonstrate knowledge of the progression in developing mathematical concepts	The PSPST presents challenges within a learning trajectory, aiming to support progression in the development of mathematical concepts.
	C11. Understand students' responses and potential errors	The PSPST demonstrates knowledge of students' learning by interpreting and understanding their responses and the causes of potential errors.
Knowledge of teaching practice	C12. Manage the task	The PSPST provides information to students to streamline their actions or to allow collective work to benefit from the differences observed in the work of each student or group.
	C13. Promote autonomy	The PSPST gives students the opportunity to respond independently to the tasks posed, intervening only when necessary.
	C14. Provide information	The PSPST gives students information (hints, cues, or suggestions) to help them understand their reasoning or what they are doing, without undermining their autonomy in decision-making.
	C15. Monitor students' actions and learning	The PSPST observes students' actions to check whether they are engaged and/or whether these actions lead to learning.
	C16. Request clarifications	The PSPST asks students for additional information to understand and clarify their ideas.
	C17. Return the question to the students	The PSPST directs questions, difficulties, or requests for help back to the students.
	C18. Present to the whole group	The PSPST decides to turn a student's doubt/question into a question for the whole group, or to share with the group aspects observed in some students.
	C19. Summarize students' learning	The PSPST revisits the results of the student's epistemic practice to reinforce their understanding and extends it to the whole group.
	C20. Epistemically ignore	The PSPST intentionally does not address the knowledge-related ideas presented by students in their interventions.
	C21. Encourage students	The PSPST encourages an individual student or a small group of students to respond or to persist in seeking the answer to the posed question.
	C22. Promote peer communication	The PSPST encourages students to communicate and discuss their ideas with each other.
C23. Promote mathematical communication	The PSPST takes advantage of students' actions, when appropriate, to promote mathematical communication.	

### Data Analysis

The data analysis was based on the seven MN and was conducted using the content analysis technique, in accordance with the principles of Bardin (2016). In the analysis, registration units were sentences, paragraphs,

or text segments that described the pedagogical actions and decisions of the PSPSTs during the lessons. To support the process of coding the units of analysis, the software MAXQDA was used (Kuckartz & Rädiker, 2019; Silva et al., 2021), following the criteria presented in **Table 2**.

The coding of the first MN, which included 854 units of analysis, was carried out by two researchers (the first and second authors of this study) and served as a pilot MN to calibrate the application of the criteria in **Table 2**. Of these segments, 832 units were coded identically by both researchers, resulting in an agreement of 97.5%. The remaining discrepancies were discussed and resolved jointly until consensus was reached on the interpretation of each code. The remaining MNs were coded by the first author, with joint discussion whenever doubts arose, ensuring consistency in the application of the coding criteria. These criteria were developed based on the pedagogical decisions identified by Lopes et al. (2018) in alignment with the conceptual framework of the didactic knowledge model for mathematics teachers proposed by Ponte (2012). The use of these criteria is supported by versions previously adapted and implemented in research contexts (Jesus, 2022; Rodrigues, 2021).

These criteria were selected because they are considered appropriate for analyzing exploratory teaching practices that integrate the development of computational thinking. In particular, criterion C08 (integrating mathematical competencies into mathematical topics) is highlighted, as it relates directly to computational thinking, given that, in the official Portuguese mathematics curriculum, computational thinking is explicitly defined as a mathematical skill. Additionally, although the remaining criteria do not explicitly refer to computational thinking, they are fundamental to the appropriate implementation of tasks that integrate its development. Given the gaps in teachers' knowledge of computational thinking identified in the literature (Haşlamani et al., 2024; Santos et al., 2025), it is particularly relevant to analyze aspects of the knowledge of mathematics for teaching when implementing tasks that integrate computational thinking. Evidence that pre-service teachers tend not to sufficiently reflect on task progression, adopted methods, or students' potential learning difficulties when implementing computational thinking tasks (Drot-Delange et al., 2021) further justifies the relevance of analyzing criteria related to the components of knowledge of the curriculum and knowledge of students and their learning processes. Considering the five dimensions of computational thinking established in the Portuguese curriculum, it is essential to analyze pedagogical decisions associated with knowledge of teaching practice. These decisions play a central role in promoting classroom practices that support the development of the different dimensions of computational thinking, such as encouraging the identification of essential aspects of the task (abstraction (Candeias et al., 2025)) or the detection and correction of errors or inaccuracies in the problem-solving process (debugging, Macann & Hartnett, 2025). Thus, although the adopted criteria are transversal in nature, their mobilization is fundamental to the effective integration

of computational thinking development within exploratory teaching practices.

To quantify the occurrence of each criterion, relative frequency tables were constructed, enabling the identification of patterns of PSPSTs' actions in each session implemented by the groups. Based on these data, graphs were developed to visualize the frequency of each code's occurrences across all lessons by group. Complementarily, co-occurrences between the criteria were analyzed, allowing the observation of the articulation between different components of didactic knowledge and highlighting how pedagogical decisions were related and occurred simultaneously during the implementation of the practices (Silva et al., 2021). The co-occurrences were represented through weighted graphs, considering a minimum frequency of five occurrences between codes. In these graphs, the thickness of the lines indicates the frequency of co-occurrences, while the size of the nodes represents the number of coding associated with each criterion (Kuckartz & Rädiker, 2019).

## RESULTS

The presentation of the results is organized into four subsections. It begins by presenting the findings from the analysis of the MN for each group. Subsequently, the co-occurrences identified in the produced documents are presented, considering the complete dataset for each group.

### Group 1

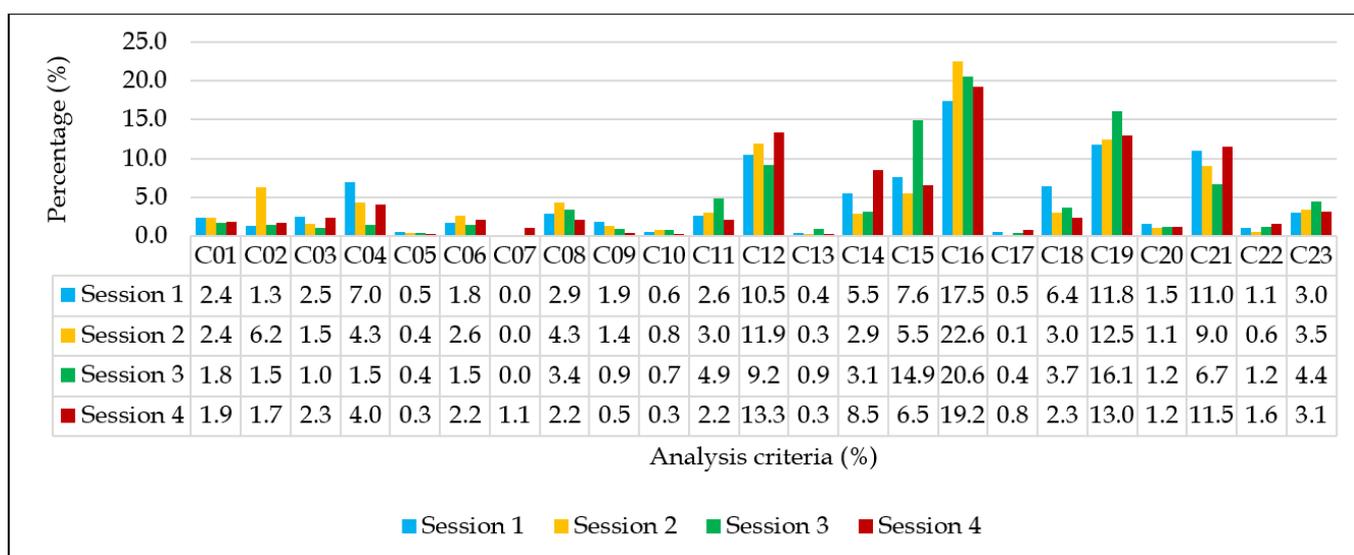
**Figure 1** presents the relative frequencies of the pedagogical decisions of the PSPSTs in group 1, observed in the four MN analyzed.

It can be observed that the knowledge of teaching practice component represents more than 70% of the total recorded evidence in all lessons, reaching values above 80% in the last two lessons. The most frequent pedagogical decision in all lessons was "request clarifications" (C16). In the first three lessons, this was followed by "summarize students' learning" (C19), whereas in the last session the decision "manage the task" (C12) was more prominent.

In the first session, during which group 1 introduced the concept of a stem-and-leaf plot, it was observed that the pedagogical decision "mobilize knowledge resulting from the interaction between content knowledge, students' actions, and the context" (C04) recorded the highest percentage of evidence.

The dialogue presented below occurred after one of the PSPSTs asked a group of students how an external student might interpret the stem-and-leaf plot they had created (excerpt from MN 1, group 1).

**PSPST B:** Go ahead, student H! (C21)



**Figure 1.** Evidence of the didactic knowledge of the PSPSTs in group 1 across the four MN analyzed (Source: Authors’ own elaboration)

**Student H (group 1):** She knew because of the legend.

**PSPST B:** She knew ... what is the legend? (C16)

**Student M (group 1):** The title.

**PSPST B:** What is it, what is the legend? Which one is the legend? (C04, C16)

**Student H (group 1):** It’s the 11 over 5, it means ...

**PSPST B:** The 11 over 5 means ... 115 is our legend (while writing on the board). Good! And what about our title that student M mentioned? What’s our title? (C04, C16)

**Student M (group 1):** It’s, uh, the heights in centimeters of the students from Hypatia’s class.

**PSPST B:** Good, that’s our title (while noting it on the board). So, through this, she could understand what we were analyzing. (C04)

This excerpt highlights the PSPST’s ability to mobilize mathematical knowledge based on the students’ actions and responses, as well as the task context. By creating a situation that prompted students to reflect on the fundamental elements of the stem-and-leaf plot, the teacher, through successive questions, encouraged the articulation of their ideas and reinforced the importance of the legend and title for the correct reading and interpretation of the stem-and-leaf plot.

In session 2, which focused on identifying the mode, minimum, and maximum, it is important to highlight that this was the session with the highest frequency of the pedagogical decision “apply mathematical concepts accurately” (C02).

The excerpt from the MN presented below illustrates the PSPST’s rigor in mobilizing the mathematical concepts involved in the task (excerpt from MN 2, group 1).

**PSPST B:** That value that was the largest of all, what was it called? Go ahead, student Z! (C02, C16, C19)

**Student Z (group 5):** Maximum.

**PSPST B:** Maximum, good! And the smallest one of all? Go ahead, student H! (C02, C16, C19)

**Student H (group 1):** Minimum.

**PSPST B:** Minimum. And the one that appeared most often? Go ahead, student A! (C02, C16, C19)

**Student A (group 2):** Mode!

**PSPST B:** Mode! (C02)

By directing questions to different students, the PSPST promoted the use of the concepts of maximum, minimum, and mode, ensuring their correct association with the situations explored. This pedagogical decision allowed the reinforcement and summarization of the learning developed, ensuring that the concepts were mobilized clearly.

The excerpt below once again illustrates the PSPST’s attention to maintaining terminological rigor at another stage of the session (excerpt from MN 2, group 1).

**Student Q (group 9):** We looked at the table and found the smallest number.

**PSPST B:** The table? (C03, C16)

**Student Q (group 9):** The ... the stem-and-leaf plot.

**PSPST B:** The stem-and-leaf plot, good! (C02)

In this dialogue, it can be observed that, when a student incorrectly referred to the stem-and-leaf plot as a “table,” the PSPST immediately intervened, guiding the student to rephrase and use the correct term. In doing so, she ensured terminological rigor and raised students’ awareness of the importance of precision in mathematical communication.

In the third session, in addition to the pedagogical decision “request clarifications” (C16), which was the most frequent in all lessons and is evident in the dialogues presented, the decision “summarize students’ learning” (C19) stands out. This decision recorded the second-highest frequency in this session and, simultaneously, the highest percentage across all analyzed lessons. The aim of this session was to deepen the construction of the simple stem-and-leaf plot, previously explored, but using frames from the HypatiaMat platform which, unlike those used in prior lessons, did not provide a supporting table for construction.

The excerpt presented below explicitly illustrates how the PSPST revisited the procedures implemented in previous lessons (excerpt from MN 3, group 1).

**PSPST B:** So now that almost everyone has logged into HypatiaMat, we’re going to follow the same methodology as in the previous lessons, alright? (C19) We have a worksheet where you’ll find the frames you need to access. (...) Also, don’t forget to underline again. And today, just like yesterday (C19), there are some frames here that might be a little different from the ones that will appear for you in HypatiaMat (referring to the fact that the data shown on the worksheet may not match exactly what appears in HypatiaMat).

In this excerpt, it can be observed how the PSPST synthesizes the procedures adopted in previous lessons while introducing the new task. Her mediation demonstrates a concern for ensuring methodological continuity and guiding the exploration of the HypatiaMat platform based on the experiences and learning previously constructed by the students.

It is evident that the increased frequency of the pedagogical decision “summarize students’ learning” (C19) is grounded in the way the PSPST established connections between the procedures of this session and those explored in previous lessons. To illustrate this trend, the following excerpt presents a dialogue between the PSPST and a group of students, in which, when one student expresses doubt, it is a peer who explicitly draws on the experience from past lessons (excerpt from MN 3, group 1).

**Student C (group 3):** I don’t understand because we’ve already done the calculation, we just can’t explain it right now.

**PSPST B:** You have to explain it step by step, write it down. (C16)

**Student B (group 3):** Like last time.

**PSPST B:** So, first, what did you do? (C19)

This excerpt shows how the PSPST leveraged a student’s reference to previous lessons (“like last time”) to question the group about the procedures carried out. By doing so, she enabled the mobilization of knowledge based on students’ interventions and simultaneously encouraged the step-by-step articulation of the solution, promoting the summarization of the learning developed. In addition to this example, the PSPST’s mediation repeatedly demonstrated a concern for linking common aspects across problem-solving processes, thereby fostering the development of the pattern recognition dimension of computational thinking. The following excerpt illustrates another such moment (excerpt from MN 2, group 1).

**PSPST B:** So, what did you find in common to determine the two modes in both tasks? (C08)

In the fourth intervention session, and consistent with what was observed in previous lessons, the pedagogical decision with the highest frequency was “request clarifications” (C16). Analysis of the coded excerpts reveals that a significant portion of these requests for clarification was related to the construction of the double stem-and-leaf plot, which was one of the objectives of the session (excerpt from MN 4, group 1).

**PSPST B:** So, what are we writing here? (C16) Tell me the steps you followed to build the diagram! (C08)

**Student X (group 11):** We looked at the numbers in the table ...

**PSPST B:** Hmm hmm.

**Student X (group 11):** Then we placed the tens on the stem!

**PSPST B:** Good! How did you place the tens on the stem? (C16)

**Students (group 11):** In ascending order.

**PSPST B:** Good!

**Student X (group 11):** And the units on the leaves in ascending order.

**PSPST B:** Good!

This excerpt illustrates how the PSPST, through successive requests for clarification, promoted the articulation of the procedures conducted by the students in constructing the double stem-and-leaf plot. By asking the students to describe their work step by step, her intervention not only clarified the strategies used but also fostered the development of the algorithmic dimension of computational thinking.

Throughout the mediation of learning, the PSPST also made requests for clarification related to the other objective defined by group 1 for this session: identifying the minimum and maximum in the double stem-and-leaf plot (excerpt from MN 4, group 1).

**PSPST B:** What was the best time you found? (C16)

**Student R (group 9):** Twenty-five!

**PSPST B:** Twenty-five, which is in both schools, right? And what does this twenty-five mean in the data set? Is it the highest or ...? (C16)

**Student R (group 9):** More ... smaller.

**PSPST B:** It's the smallest value, so what is that? (C16)

**Student R (group 9):** The minimum.

**PSPST B:** You need to write that down (giving instructions for the task), and the worst time? (C16)

**Student Q (group 9):** It's 58.

**PSPST B:** Okay, so what is 58? (C16)

**Students (group 9):** The maximum.

It is also noteworthy that this was the only session in which evidence of the pedagogical decision "integrate different areas of knowledge" (C07) was recorded. It is important to clarify that all decisions registered under this criterion are related to the context of the implemented task, which referred to an athletics event, as illustrated in the following dialogue (excerpt from MN 4, group 1).

**PSPST B:** It's a ... it says here. (pointing to the frame 59 instructions)

**Student P (group 7):** In seconds. A 200-meter race in seconds.

**PSPST B:** A 200-meter race. In a race, who wins? (C07, C16)

**Student P (group 7):** The fastest.

**PSPST B:** The fastest, and you're telling me that the worst time ... you're giving me the smallest times. The worst time will be the one that took how long? (C07, C16)

**Student P (group 7):** Uh, uh, slower.

This dialogue illustrates how the PSPST needed to articulate mathematical concepts (such as minimum and maximum) with the rules of an athletics event. By questioning the student about the meaning of the fastest and slowest times, she guided them in relating the numerical data to the context of the event, promoting an understanding of the mathematical concept in a contextualized and meaningful way.

In addition to the algorithmic and pattern recognition dimensions already mentioned, throughout the four lessons there was evidence of the PSPST's intention to foster the development of various dimensions of computational thinking using, for example, previously prepared guiding questions. Regarding abstraction, it can be observed that in all lessons the PSPST encouraged students to identify the most important information, as illustrated in the following excerpt (excerpt from MN 1, group 1).

... you in this frame here (pointing to the frame on the exploration sheet) will underline the most important data that allowed you to solve this (referring to the task), okay? (C08)

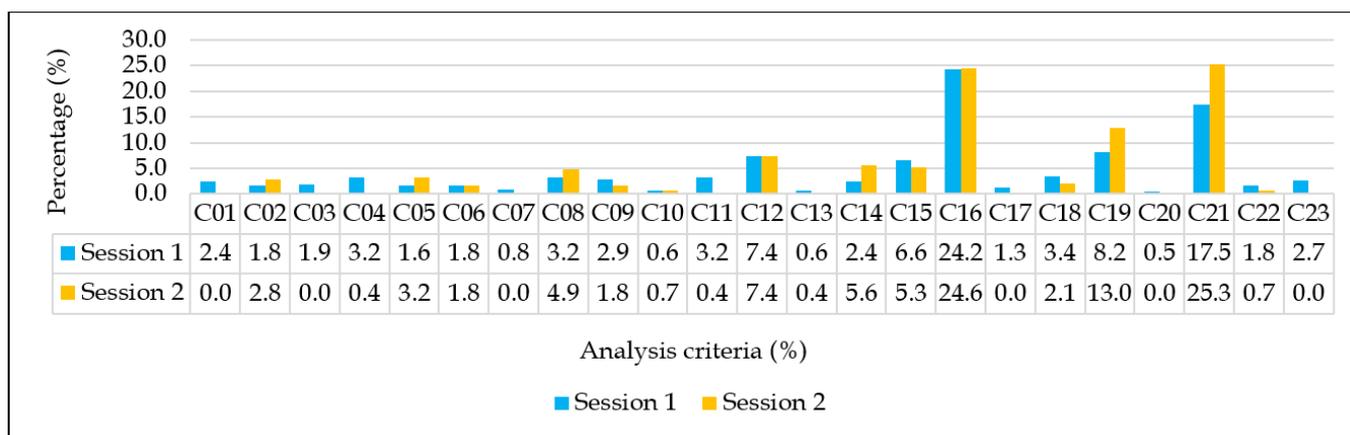
The PSPST's mediation was characterized, in all tasks, by asking students to explicitly describe what they were doing step by step, a strategy that facilitated the decomposition of the problem into smaller parts and, consequently, the development of this dimension of Computational Thinking. The following excerpt exemplifies this mediation (excerpt from MN 1, group 1).

**PSPST A:** You're going to explain, first, what you did, then what you did next, and then what you did after that. (C08)

Regarding the development of the debugging dimension, it was observed that the PSPST encouraged students to review the procedures they had carried out to identify possible inconsistencies or confirm the accuracy of the strategies adopted. An example can be found in the following excerpt (excerpt from MN 2, group 1).

**PSPST B:** ... check again the steps you took in 1.2 and 2.2, which was this one. Was the way you found the mode of the sets similar? (C08, C16)

It is important to highlight that, throughout the four MN, some evidence of difficulties in managing the different phases of the lesson was detected.



**Figure 2.** Evidence of the didactic knowledge of the PSPSTs in group 3 across the four MN analyzed (Source: Authors' own elaboration)

In the first session, during the task discussion phase, the PSPSTs did not change the projected task statements, which caused some confusion among the students, as illustrated in the following excerpt (excerpt from MN 1, group 1).

Student C (group 3): Lower.

PSPST B: Now it's the lowest? There it's still the lowest, but I've ... we're on task 4 now (referring to the question projected on the board, which was still the previous one)

In the second session, still during the task execution phase, the PSPST did not collect photographic records of the students' solutions, despite having appropriately selected and sequenced the groups to conduct the task discussion. Consequently, as recorded in the MN, it was necessary to begin the task discussion phase by collecting this evidence (excerpt from MN 2, group 1).

The PSPST forgot to take photos of the groups' exploration sheets during the task implementation phase, so she went on to photograph the exploration sheets of the groups she had noted on her own records.

This oversight had repercussions on the conduct of the task discussion, as during this phase the PSPST realized that she still did not have photographic records of some of the solutions she intended to use for collective analysis, as described in the MN excerpt presented below (excerpt from MN 2, group 1).

PSPST B looked on the computer for the photo of the next task's resolution, task 3, but didn't find it, so she went on to photograph the resolution of the group she had selected.

In the third session, difficulty in conducting the task discussion was also identified. In this session, the PSPST selected a group to share their solution that, in fact, had

not been able to complete the proposed task, as illustrated in the following excerpt (excerpt from MN 3, group 1).

PSPST B: Student Z and student J, tell me what you were asked to do in this task!

Student Z (group 5): We didn't do this!

Student J (group 5): Yeah.

PSPST B: Ah?

Student Z (group 5): We didn't do it here.

It is important to note that, in the final intervention session, no evidence of difficulties related to classroom management was identified.

### Group 3

Figure 2 presents the relative frequencies of the pedagogical decisions observed in the two MN developed by the PSPSTs in group 3.

In group 3, similarly to group 1, the combined frequencies of the criteria within the knowledge of teaching practice component exceed 70% in the first session and reach 80% in the second session. The pedagogical decision "request clarifications" (C16) remains one of the most frequent throughout the lessons. However, unlike group 1, the second most recurrent pedagogical decision in this group is "encourage students" (C21).

In the first session, whose goal was to allow students to organize data into a chart of their choice, the most frequent pedagogical decision was "request clarifications" (C16), followed by "encourage students" (C21). Similar to what was observed in group 1, the mediation of the PSPSTs in this group was characterized using guiding questions. The constant need to encourage students can be explained by the open-ended nature of the task. By providing materials such as a blank grid

sheet and granting complete freedom in constructing the chart, the pedagogical decisions made by the PSPSTs reveal their effort to actively encourage and support the students, ensuring progress in solving the proposed task.

The following dialogue illustrates how the PSPST, given the autonomy students to construct their own chart, used questions to encourage them to articulate and explain their ideas (excerpt from MN 1, group 3).

**PSPST G:** So, you were saying, what names are you going to write? (C16)

**Student C (group 4):** Football, swimming, judo, tennis, dance.

**PSPST G:** And what is that? (C16)

**Student K (group 4):** Sports.

**PSPST G:** Ok. These are the sports, and then? And where will this go ...? (C16)

**Student K (group 4):** In the title ... favorite sports in the ... of the class.

**PSPST G:** Of which class? (C16)

**Student K (group 4):** Of the 2<sup>nd</sup> year.

By monitoring the students' problem-solving process and questioning them about the elements they were recording and the role these played in the chart, the PSPSTs encouraged them to clarify and structure their proposal, guiding them toward formulating an appropriate title. This intervention highlights the PSPSTs' concern with encouraging students, ensuring that the data were organized coherently.

The following dialogue illustrates another instance in which the PSPSTs encouraged the students (excerpt from MN 1, group 3).

**Student N (group 1):** And now it's the graph.

**PSPST G:** And you made a graph, what is this graph called? (C16, C21)

**Student N (group 1):** Bar ch ... (the student was going to say bar graph), dot graph.

**PSPST G:** Dot graph? What is this? Is this a dot? (C16, C21)

**Student N (group 1):** No, it could be anything, it could be a dot, or it could be something else ...

**PSPST G:** And is this a dot graph? (C16, C21)

**Student N (group 1):** It is ...

The excerpt highlights the students' difficulty in correctly identifying the type of chart they were constructing. In response to this situation, the PSPST persisted in seeking a correct answer to the question posed, encouraging the student to justify their response.

Regarding session 1, it is also important to note that it was the only session in which pedagogical decisions related to "integrate different areas of knowledge" (C07) were recorded. These decisions are linked to the context of the task, which involved World Sports Day, as illustrated in the following excerpt (excerpt from MN 1, group 3).

**PSPST G:** In this image (projected on the board showing people doing different sports), what sport is this, student E? (C07, C16)

In the second session, similarly to what was observed in the first, the most frequent pedagogical decisions were "encourage students" (C21) and "request clarifications" (C16). After conducting physical activities outdoors, the session led by the PSPSTs, as described in the MN, focused on identifying and analyzing patterns in the paths taken, with the aim of promoting the development of dimensions of computational thinking. It was observed that the PSPSTs' mediation was characterized using guiding questions and by encouraging active student participation, prompting them to construct their own answers. The following excerpt illustrates this mediation, after a student asked to be given the answer directly (excerpt from MN 2, group 3).

**Student N (group 2):** So, what should we write?

**PSPST F:** You need to figure out how to prepare the answer. But what information do you have? What information do you have? (C08, C16, C21)

**Student O (group 2):** Don't repeat the same places, ah, start from the starting point.

**Student N (group 2):** And nothing else.

**PSPST F:** So, imagine ... nothing else. In other words, what you're saying is that you had to start from the starting point, couldn't repeat any station. But did you have to go to all of them or could you just go to one or two? (C08, C16, C21)

In this session, it is also important to highlight the emphasis placed by the PSPSTs on the development of the dimensions of computational thinking. The following excerpt illustrates a set of guiding questions posed by the PSPST, specifically aimed at promoting the pattern recognition dimension (excerpt from MN 2, group 3).

**PSPST F:** Look here, children. What similarities do you find between these routes and yours? Is there anything the same? (C08, C16)

**Student D (group 3):** They start at point P.

**PSPST F:** Okay, that can be one similarity. Anything else? Is that all? (C08, C16)

Regarding the decomposition dimension, the PSPST encouraged students to plan the execution of tasks by breaking problems down into simpler steps. An example of this can be seen when at the start of constructing one of the graphical representations that the students identified as a pictogram, the PSPST questioned the students, promoting reflection on the steps to be taken, as shown in the following excerpt (excerpt from MN 1, group 3).

**PSPST G:** A pictogram? You are going to make the pictogram, what are you going to start with? (C08, C16)

Regarding the algorithms dimension, after completing the tasks, the PSPSTs frequently asked students to describe, step by step, the process they had followed, reinforcing the importance of the sequential organization of actions. An example of this is presented in the following excerpt, when PSPST G questions the students about the steps taken to construct the chart, thereby promoting the development of algorithms (excerpt from MN 1, group 3).

... PSPST G begins by asking which steps they followed to construct the graph, since they had already built it. (C08)

Throughout the entire implementation, evidence was observed of careful planning by the PSPSTs, aimed at promoting computational thinking. As mentioned earlier, the exploration sheets themselves included questions specifically designed for this purpose. Regarding the abstraction dimension, this is evident right at the beginning of the task on the exploration sheet in the second session, as shown in the following dialogue (excerpt from MN 2, group 3).

**PSPST F:** Okay, students (group 2). First question, what is it? (C21)

**Student O (group 2):** What are the most important pieces of information that the group considered to visit all the stations?

**PSPST F:** Okay, and what were those pieces of information? (C08, C16)

Regarding debugging, it is noteworthy that, in her mediation, the PSPST encouraged students to review the calculations they had performed and to validate the

results obtained. Through questioning, students were guided to identify errors and recognize discrepancies, such as the difference between the total number of students in the class and the number of votes recorded (excerpt from MN 1, group 3).

**PSPST G:** So here, students? How do you confirm the total? How many students voted there? (C08, C16)

...

**Student D (group 3):** Eighteen.

**PSPST G:** Is that correct? How many students are there in total? (C08, C16)

**Student Q (group 3):** Twenty-one.

**PSPST G:** There are twenty-one, okay, but how many voted? (C08, C16)

**Student Q (group 3):** Ah ... eighteen!

It is important to note that, at the end of the first session implemented by group 3, the MN describes how the PSPSTs were forced to modify the initially planned schedule due to insufficient time to complete the formative assessment task. The following excerpt illustrates this adjustment (excerpt from MN 1, group 3).

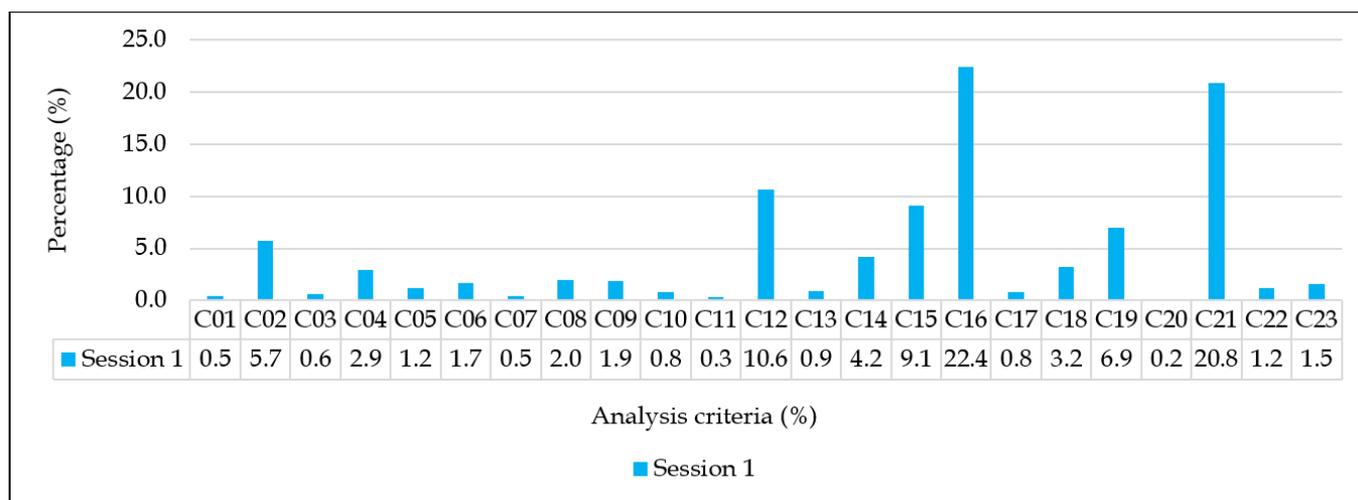
The PSPSTs talked among themselves about doing the formative assessment task in the next morning session (referring to the teaching period after the morning break).

In the second session, difficulties related to classroom time management became even more evident, constraining the completion of tasks, as illustrated in the following excerpt (excerpt from MN 2, group 3).

Subsequently, the PSPST F discussed with PSPST G about the remaining time and realized they needed to speed up the task completion. Consequently, they asked the class to move on to question 1.3 and informed them that it would be carried out orally.

Even with this adjustment, the MN description shows that the PSPSTs continued to face difficulties in managing the time for the different phases of the lesson, having to conclude the task execution phase early to ensure that all planned phases were completed (excerpt from MN 2, group 3).

... the PSPSTs discussed the remaining time and decided to conclude the task completion phase in order to have enough time to conduct the discussion and, subsequently, the systematization of the students' learning.



**Figure 3.** Evidence of the didactic knowledge of the PSPSTs in group 5 across the four MN analyzed (Source: Authors’ own elaboration)

During this session, a difficulty was also observed in the PSPSTs’ organization of the task discussion, as they selected a group to share their solution that had, in fact, not completed the task. The following dialogue illustrates this moment (excerpt from MN 2, group 3).

**PSPST F:** Group four, last one. Tell me another one different from these.

**Student H (group 4):** We didn’t do it.

**PSPST F:** You didn’t do it?

**Group 5**

**Figure 3** presents the relative frequencies of the pedagogical decisions of the PSPSTs from group 5, as observed in the analyzed MN.

In group 5, it can be observed, similarly to the other two analyzed groups, that the sum of the frequencies for the criteria of the knowledge of teaching practice component exceeds 80%. Notably, the most frequently recorded pedagogical decision continues to be “request clarifications” (C16), highlighting the PSPSTs’ tendency to promote students’ clarification and understanding of tasks. In group 5, the second most frequent pedagogical decision relates to the need to “encourage students” (C21), reflecting a concern to foster active participation and engagement during task completion.

In the session implemented by group 5, the central objective was the construction of pictograms, with various materials provided for students to independently create graphical representations of the collected data. It is important to note that, in the PSPSTs’ mediation, evidence was recorded regarding “apply mathematical concepts accurately” (C02). It was observed, on several occasions, that the PSPSTs used students’ solutions as a starting point to rigorously

introduce specific pictogram terminology, as shown in the following dialogue (excerpt from MN 1, group 5).

**PSPST M:** Imagine that someone just entered the classroom now, looked at this ... what does this graph talk about? They wouldn’t know! Tell me, student C. (C16, C21)

...

**PSPST L:** Imagine, when you write a text... how do you know what the text is about? What is always at the beginning? A very small thing at the top. What is it? Tell me, student I. (C07, C16)

**Student I:** Title.

**PSPST L:** A title! (C02)

It is also observed that the PSPST established an explicit connection with another area of knowledge (C07), Portuguese, drawing on concepts of textual structure, namely the title, to support students in understanding the function of this element in the pictogram.

Since the students created their graphical representations freely, the PSPSTs’ mediation was marked by the formulation of guiding questions and by encouraging students to relate their productions to the elements that should be included in a pictogram. Using guiding questions and the solicitation of clarifications, the PSPSTs stimulated the explicit articulation of the procedures followed while directing students’ reflection toward understanding the essential characteristics of this type of graphical representation, as illustrated in the following dialogue (excerpt from MN 1, group 5).

**PSPST K:** So, why are you doing it like this? Explain it to me. (C16, C21)

**Student S:** Here there are 8 (referring to the number of images of summer season stations on their sheet).

**PSPST K:** 8, why? (C16)

**Student S:** Because there are 8 there (points to the board with the seasons).

**PSPST K:** So what do you think these here mean... these emojis? (C16, C21)

**Student S:** It means that it's for ... it means 8 ... 8

**PSPST K:** 8 what? (C16)

**Student S:** 8 students who like summer.

**PSPST K:** Very good! 8 students who like summer. Alright then! (C19)

During the task discussion, the PSPSTs' mediation involved the formulation of several guiding questions aimed at promoting the development of the dimensions of computational thinking. In particular, the following excerpt illustrates the fostering of the abstraction dimension, as the PSPST sought to guide students in identifying the most relevant aspects of the instructions for solving the task (excerpt from MN 1, group 5).

**PSPST M:** ... PSPST K, at the beginning, gave you instructions on what you had to do. What did you think was very important from what she told you? In order to be able to solve it? (C08, C16)

The following excerpt illustrates the promotion of the algorithms dimension, as the PSPST encouraged students to explicitly describe, step by step, the procedures they carried out (excerpt from MN 1, group 5).

**PSPST M:** So, group 2. Imagine you want to explain to group 1 what you did, as if they didn't know anything at all, nothing, nothing, nothing. What would you say? How would you explain, step by step, what you did? (C08, C16)

Similarly to group 1, the PSPSTs of group 5 also requested students to describe the steps they had carried out, promoting the decomposition of the problem into simpler steps and supporting the development of this dimension of computational thinking. The following excerpt illustrates this mediation (excerpt from MN 1, group 5).

**PSPST M:** But if you had to explain it in words? So, what was the very first thing you did? (C08, C16)

Regarding the debugging dimension, the PSPST sought to encourage students to review and refine the solutions they had constructed, promoting reflection on

possible improvements in how to organize and present the results. This aspect is illustrated in the following excerpt (excerpt from MN 1, group 5).

**PSPST M:** ... Couldn't there have been a way to organize this a little bit better? (C08, C16)

It was also observed that the PSPST encouraged students to identify similarities and patterns among the different solutions presented by the groups. This mediation, aimed at developing the Pattern Recognition dimension of computational thinking, is illustrated in the following excerpt (excerpt from MN 1, group 5).

**PSPST M:** So, group 3, of all the solutions we've seen here ... that all the groups did, what did they all have in common? What was the same in all of them? (C08, C16)

In some notes recorded in the MN, difficulties faced by the PSPSTs in classroom management became evident, particularly regarding the organization of time and the materials needed to carry out the tasks, as illustrated in the excerpt presented below (excerpt from MN 1, group 5).

(The teachers discuss the fact that the students are taking too long to cut out the pieces and that they should have brought the images already pre-cut.)

As observed in group 3, this group also showed difficulties in time management, which affected the execution of the initially planned tasks and led to adjustments in the lesson planning (excerpt from MN 1, group 5).

(The PSPSTs discussed whether or not to carry out the formative assessment task with the students, since the bell for break had already rung.)

### Co-Occurrences

The analysis of co-occurrences among the different criteria made it possible to identify association patterns that reveal how the PSPSTs' pedagogical decisions were interrelated during the implementation of the exploratory teaching practices. This analysis complements the previously presented results regarding the frequency of each criterion by illustrating how they are interconnected throughout classroom interactions.

**Figure 4** presents the co-occurrences identified in group 1.

The strongest co-occurrence between C16 (request clarification) and C21 (encourage students) suggests that the PSPSTs sought not only to clarify the tasks but also to actively foster student participation, confirming the central role of teacher mediation in exploratory Teaching practices. The fact that C16 appears associated with several other criteria reinforces the previously presented

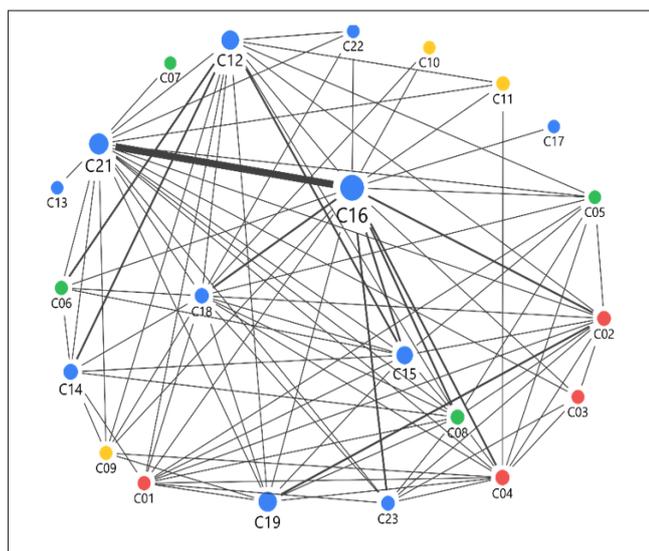


Figure 4. Co-occurrences of criteria in group 1 (Source: Authors' own elaboration)

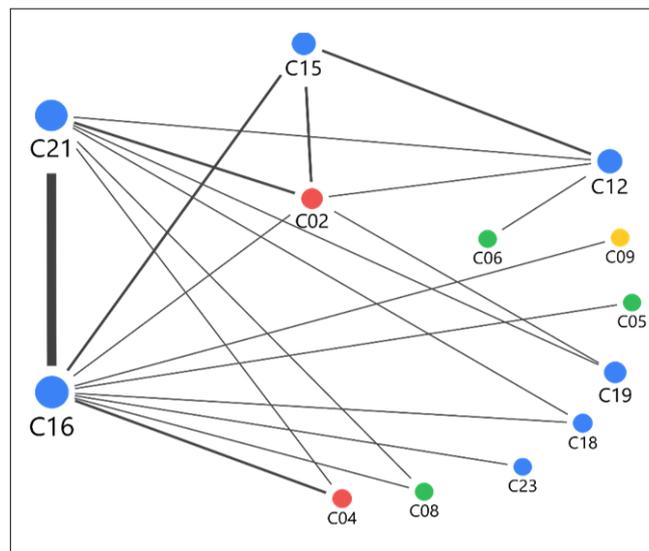


Figure 6. Co-occurrences of criteria in group 5 (Source: Authors' own elaboration)

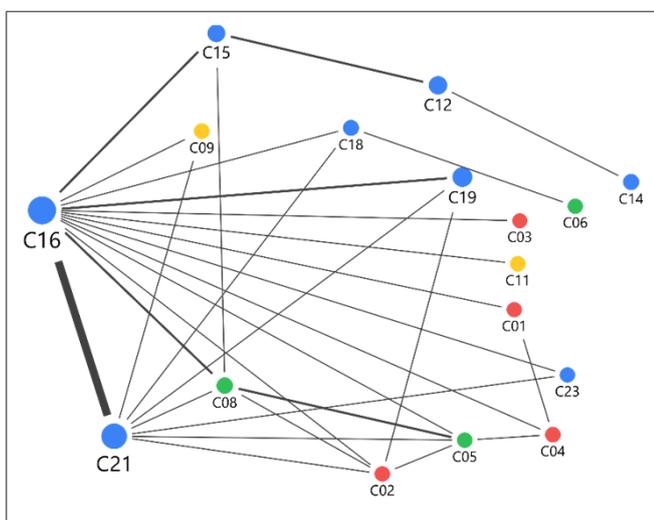


Figure 5. Co-occurrences of criteria in group 3 (Source: Authors' own elaboration)

results for group 1. The mediation carried out by the PSPSTs was based on the use of guiding questions and functioned as a transversal strategy, articulated with mathematical rigor (C02 and C04), mathematical communication (C18 and C23), monitoring of learning (C15), and the development of mathematical skills (C08). The co-occurrence of C02 (apply mathematical concepts accurately) with C19 (summarize students' learning) also shows that the rigorous use of mathematical concepts was often associated with the synthesis of learning, reinforcing the pedagogical intentionality in building meaningful learning. Meanwhile, the co-occurrences of C15 (monitor students' actions and learning) with C12 (manage the task), which in turn was linked to C06 (use appropriate teaching resources) and C14 (provide information), highlight the intention to connect task and resource management with the monitoring of students' learning.

Following, the co-occurrences for group 3 are presented (Figure 5).

The co-occurrence between C16 (request clarification) and different criteria such as C08 (Integrate mathematical abilities into mathematical topics), C15 (monitor students' actions and learning), C19 (summarize students' learning), and C21 (encourage students) suggests that the act of requesting clarification served as a central strategy in teacher mediation, connecting both mathematical content aspects and the management of student participation. As in group 1, the strongest co-occurrence was observed between C16 and C21, indicating that the mediation of the PSPSTs was characterized by encouraging students through the formulation of guiding questions, thereby promoting their active participation in task solving. The co-occurrence of C16 with C08 and subsequently with C05 (align content with the curriculum) highlights the PSPSTs' concern with ensuring that mathematical skills were integrated in alignment with the curriculum, reinforcing the didactic intentionality of their intervention. The connections between C15 (monitor students' actions and learning) and C12 (manage the task), and between C12 and C14 (provide information), emphasize the importance placed on closely monitoring student learning, supported by decisions related to task management and the provision of guiding information.

Finally, Figure 6 presents the co-occurrences for group 5.

In group 5, the presence of C16 (request clarification) co-occurring with C04 (mobilize knowledge resulting from the interaction between content knowledge, students' actions, and the context), C15 (monitor students' actions and learning), and C21 (encourage students) shows that, similarly to the previous groups, requests for clarification played a mediating role by linking student engagement with the mobilization of

mathematical knowledge and the monitoring of learning. It is important to highlight that, as in the other groups, the strongest co-occurrence was observed between C16 and C21, reinforcing the central role of requesting clarifications as a mediation strategy associated with encouraging students and fostering classroom interactions. The co-occurrence of C15 with C02 (apply mathematical concepts accurately) and C12 (manage the task) further reveals a concern with ensuring mathematical rigor alongside careful task management, reflecting classroom practices in which monitoring considers both conceptual and organizational aspects.

## DISCUSSION

To achieve the aim of this study, which is to analyze which aspects of didactic knowledge in mathematics are mobilized by PSPSTs in the implementation of exploratory teaching practices that integrate the development of computational thinking, as well as the challenges they face in this process, we will answer the RQs posed. To answer the **RQ1**, regarding the aspects of didactic knowledge in mathematics mobilized by PSPSTs when implementing exploratory teaching practices with the integration of computational thinking, the study results are discussed based on the relevant literature. The analysis of results showed that, across all groups, the knowledge of teaching practice component presented the highest number of occurrences, although the registered co-occurrences are mainly concentrated in items C16 and C21, which stand out, as well as in C12 and C19, although these appear less frequently. These findings confirm the centrality of this component, as highlighted by Ponte (2012) and Rodrigues and Ponte (2020). Although the remaining three components recorded fewer occurrences, the knowledge of teaching practice component was consistently articulated with them, as evidenced by the co-occurrences among criteria from different components, in line with what these authors had previously emphasized. The pedagogical decisions related to the knowledge of teaching practice component were mainly reflected in the encouragement of student participation, the formulation of guiding questions, and the synthesis of students' learning. These criteria, which showed the highest number of occurrences within this component, demonstrate the appropriation of the principles of exploratory teaching practices addressed during phase 1 of the training program and are consistent with the findings of Duarte et al. (2025).

When the PSPSTs intervened, they often formulated additional questions to guide students' reasoning and help them progress in solving the task, as indicated by Oliveira et al. (2013). This tendency aligns with the high number of occurrences of criterion C16 (request clarifications), which highlighted the role of the PSPSTs

as active mediators in the exploratory teaching process, as defined in the framework for exploratory mathematics teaching proposed by Canavarro et al. (2012). The PSPSTs also tended to acknowledge and value the contributions of all students, in line with the perspective advocated by Ferreira and Ponte (2017).

Although the literature indicates that PSPSTs rarely anticipate students' learning difficulties, thus compromising the definition of appropriate strategies (Copur-Gencturk & Li, 2023), the interventions analyzed in this study revealed carefully prepared tasks, as reflected in the evidence collected. The most frequently recorded co-occurrences across all groups, between C16 (request clarifications) and C21 (encourage students), suggest that the PSPSTs anticipated potential difficulties, using guiding questions not only to clarify the tasks but also to foster students' motivation and active participation. These results are in line with the findings of Suryana et al. (2021), highlighting that requesting clarifications was linked to encouraging students, thereby promoting their engagement and active participation in task completion. The pedagogical decisions of the PSPSTs demonstrated that they planned progressive sequences of task exploration, developed guiding scripts and worksheets, and made use of diverse resources. Group 1 stood out for its detailed planning of the exploration of the HypatiaMat platform, which included access guides and worksheets with frames from the application. This careful planning was later reflected in classroom practices, as evidenced by the co-occurrences between C15 (monitor students' actions and learning), C12 (manage the task), and C06 (use appropriate teaching resources). These results lead to slightly different conclusions from those presented by Drot-Delange et al. (2021), who noted that PSPSTs often plan insufficiently and fail to reflect adequately on their interventions. Another challenge identified in previous studies (Njiku, 2025) concerns the difficulty of selecting and using specific resources aligned with the intended content. However, in the groups analyzed here, a coherent and purposeful use of resources was observed, such as pictograms, graph paper, and the digital platform, each appropriately matched to the goals of the respective session. This reinforces the didactic consistency of the practices observed. It can be argued that these results are explained by the design of the teacher education program, which allowed the PSPSTs to plan their interventions over a semester, share and discuss their proposals with peers, and implement parts of their plans during microteaching sessions. These specific features of the program align with what is advocated by Duarte et al. (2025) and Zaragoza et al. (2023), who emphasize the importance of iterative cycles of planning, reflection, and analysis for successful implementation.

Regarding the implementation of computational thinking in the classroom, previous research has

highlighted teachers' limited knowledge of this competency and their challenges in integrating it into teaching practices (Angeli & Giannakos, 2019; Haşlamam et al., 2024; Pewkam & Chamrat, 2022; Santos et al., 2025). However, the PSPSTs involved in this study demonstrated explicit understanding of computational thinking and intentionally incorporated tasks aimed at developing its dimensions, an outcome largely attributed to the training carried out in phase 1 of the program. The observed co-occurrences, such as the link between C16 (request clarifications) and C08 (integrate mathematical abilities into mathematical topics), indicate that the mediation provided by the PSPSTs fostered an articulation between mathematical concepts and the development of computational thinking skills, reflecting an intentional and theoretically grounded approach. Across all groups, evidence was found of actions promoting the development of the five dimensions of computational thinking outlined in the Portuguese national curriculum (ME, 2021). This finding supports the results of Alrwaished (2024) and Chaabi et al. (2025), who emphasize the importance of a structured and explicit teacher education framework in initial teacher training to develop the didactic knowledge necessary for the effective integration of computational thinking in classroom practice.

To answer the **RQ2**, the challenges faced by PSPSTs during the integration of computational thinking dimensions into their teaching practice were analyzed. It was observed that the difficulties faced by the PSPSTs were not related to their knowledge of computational thinking, as suggested by Santos et al. (2025), but rather to classroom management, particularly regarding time allocation for task execution and the facilitation of whole-class discussions. Time management issues, most evident in group 3 and group 5, required the reorganization of tasks and adjustments to the initial plan due to time constraints. Nevertheless, all groups showed co-occurrences between criteria C15 (monitor students' actions and learning) and C12 (manage the task), indicating that, while monitoring students' learning, the PSPSTs were also actively managing the ongoing classroom activity. These findings align with previous studies (Kajtazi, 2025; Vinci, 2025), which identify time management and class dynamics as some of the greatest challenges faced by novice teachers in the early stages of their professional careers. The difficulties related to leading whole-class discussions, more visible in group 1 and group 3, corroborate the findings of Freitas et al. (2025b), Silva et al. (2024b), and Martins et al. (2024), who argue that facilitating collective discussions is particularly demanding for beginning teachers due to the need to encourage peer dialogue and manage complex mathematical interactions. The co-occurrences of C16 (request clarifications) with C21 (encourage students) and C18 (present to the whole group), the latter more prominent in group 1, further

indicate that, even when facing challenges in managing discussions, the PSPSTs maintained pedagogical mediation strategies that fostered student participation, sharing, and task clarification.

Having answered the RQs and achieved the research objective, we affirm that the results of this study contribute directly to filling gaps identified in the literature. Until now, there has been limited research on supporting PSPSTs in effectively planning teaching practices (Zaragoza et al., 2024), and exploratory teaching practices remained underrepresented and rarely implemented during initial teacher education (Henriques & Martins, 2022). Moreover, Duarte et al. (2025) highlight the scarcity of studies analyzing the development of didactic knowledge specifically in the context of exploratory teaching practices. Recent literature reviews also indicate that the integration of computational thinking in higher education is still underexplored, particularly regarding task creation and implementation and the analysis of classroom interactions (Espinal et al., 2024; Tariq et al., 2025). In this study, PSPSTs had the opportunity to plan sequences of structured tasks, develop guides and exploration sheets, implement microteaching sessions, and reflect on their interventions, fostering the development of the didactic knowledge necessary for integrating computational thinking. These features of the teacher education program allowed PSPSTs to experience exploratory teaching practices and analyze concrete pedagogical decisions in the classroom, helping to address the gaps identified in the literature. As a limitation, it is important to note that this study is part of a broader research project and focused only on a small number of groups. Future research could replicate this analysis model in different contexts, using the same coding criteria, to determine whether PSPSTs exhibit similar patterns in mobilizing didactic knowledge during classroom practice.

## CONCLUSIONS

The study analyzed the mobilization of didactic knowledge in mathematics by PSPSTs during the implementation of exploratory teaching practices that integrated the development of computational thinking. The analysis of the interventions highlighted that the knowledge of teaching practice component emerged as central, while remaining interconnected with other dimensions of didactic knowledge. The results showed that PSPSTs primarily mobilized aspects of knowledge of teaching practice related to encouraging student participation and posing guiding questions, reflecting the appropriation of the principles of exploratory teaching practices. It was also observed that the integration of mathematical content with computational thinking was intentionally promoted, demonstrating the relevance of the structured teacher education program provided. Careful task planning, the use of diverse

resources, the formulation of guiding questions, and the monitoring of student learning reflected the development of the PSPSTs' didactic knowledge. The study also concluded that the challenges observed were related to time management and the conduct of collective discussions, aspects that proved particularly demanding for the PSPSTs. Overall, this study aims to address gaps identified in the literature by identifying and presenting the aspects of didactic knowledge observed in the practice of PSPSTs during the implementation of a teacher education program, as well as the difficulties they still encountered in this process. Although the present study sought to diversify the groups analyzed, selecting groups 1, 3, and 5 as representative of the entire participant population, future research aims to expand the analysis to other groups in the training program to explore whether the observed patterns are maintained across different contexts.

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**AI statement:** The authors stated that no generative artificial intelligence tools or AI-based software were used in the design, data collection, analysis, or writing of this study.

**Declaration of interest:** No conflict of interest is declared by the authors.

**Data sharing statement:** Data supporting the findings and conclusions are available upon request from the corresponding author.

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