

Science teacher education and non-formal learning: Collaborative self-study in Latin American contexts

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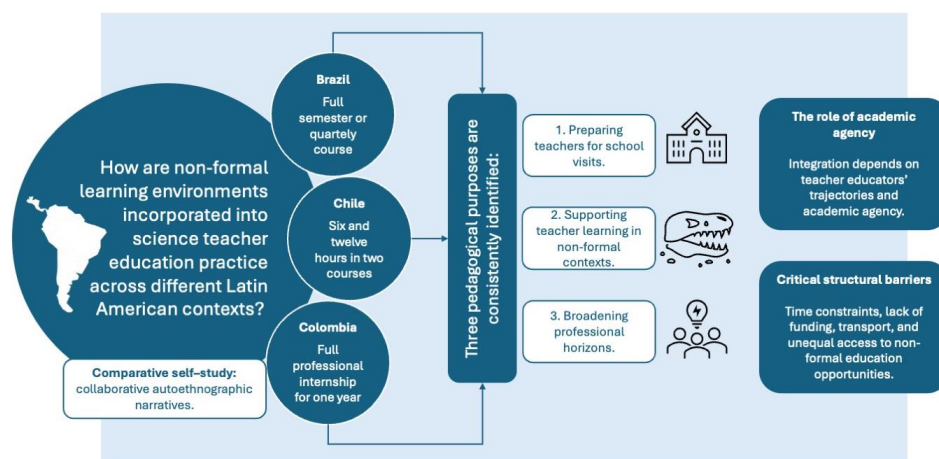
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Abstract: Although museums, science centres, and other non-formal institutions are widely recognised as valuable contexts for science learning, their role in teacher education remains underdeveloped. This paper explores how non-formal science learning environments are incorporated into science teacher education in Latin America, a region marked by significant inequalities in access to scientific culture and educational resources. Drawing on a comparative self-study, the study analyses collaborative autoethnographic narratives from six teacher educators in Brazil, Chile, and a joint Colombia–Argentina case. Through iterative individual and cross-case analysis, the research examines how non-formal environments are mobilised within three teacher education experiences. Findings from these cases reveal heterogeneous forms of integration, including course-based approaches, multi-site experiences, and an immersive internship. Across the cases, three shared purposes emerged: preparing teachers for school visits, supporting their own learning through engagement with non-formal environments, and expanding their professional horizons. The analysis also suggests that teacher educators' trajectories and academic agency interact with institutional conditions such as curricular flexibility, limited resources, time, and unequal access to non-formal institutions. These situated findings illuminate possibilities and tensions in recognising non-formal science settings as legitimate spaces for learning and professional development in teacher education.

Keywords: teacher training, non-formal education, self-study, Latin American contexts, science education

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1 Introduction

There is growing recognition of non-formal science learning environments, such as science museums, science centres, zoos, aquariums, and botanical gardens, as valuable settings for science education (Behrendt & Franklin, 2014; Cândido & Pugliese, 2024). Nevertheless, the relationship between schools and non-formal science institutions is often underdeveloped (Fenichel & Schweingruber, 2010). While school visits to museums or science centres are common, research indicates that they are often treated as isolated events rather than integrated learning experiences (Anderson et al., 2006; DeWitt & Osborne, 2007; Morentin & Guisasola, 2015).

Teachers play a central role in shaping how students experience non-formal learning environments, since they are responsible for planning and implementing the visits and for connecting them to curricular goals. With adequate preparation, teachers can leverage institutions such as science museums as valuable resources for science teaching and learning (Bustamante & Vanegas, 2018; Mazzitelli et al., 2026; Morentin & Guisasola, 2015). However, if teacher education programmes do not explicitly address non-formal learning environments, future teachers may lack the necessary pedagogical tools to meaningfully integrate these contexts into their practice (Anderson et al., 2006; Cox-Petersen et al., 2003; Kisiel, 2006).

In addition to preparing future teachers to organise and facilitate educational activities in these contexts, incorporating non-formal learning environments into teacher education can serve additional purposes (Mazzitelli et al., 2026). First, non-formal environments can provide learning contexts in which pre-service and in-service teachers engage with scientific concepts and practices and examine approaches to science teaching beyond the classroom (Monteiro et al., 2016; Oliveira & Marandino, 2024). Second, engagement with these settings and their professional communities may broaden teachers' perspectives regarding possible professional trajectories (Pugliese & Marandino, 2015).

However, empirical research examining the incorporation of non-formal environments into science teacher education programmes remains relatively limited and fragmented (Monteiro et al., 2016). Existing studies have primarily examined trainee teachers' perceptions and the outcomes of particular experiences (Bustamante & Vanegas, 2018; Soto-Lombana et al., 2024). Less attention has been given to how teacher educators design and shape these opportunities within teacher education.

This paper approaches the question from within, through the practitioner-researchers' own experiences, and from Latin American contexts. By analysing our pedagogical practices and professional trajectories, we seek to generate local and situated knowledge about how non-formal education is incorporated into teacher education, while making these practices public and available for deliberation by teacher educators working in other contexts (LaBoskey, 2004; Vanassche & Berry, 2020).

2 Non-formal teacher education in Latin America

The relationship between schools and non-formal settings varies greatly across different countries and cultural contexts (Gupta et al., 2010). In this sense, examining Latin American practices is particularly relevant, as it is one of the world's most culturally and ethnically diverse regions. This diversity is reflected in the wide range of exhibitions, scientific discourses, and audiences present in non-formal science education settings (Cândido & Pugliese, 2024).

Empirical studies in the region demonstrate that engagement with science and attendance at institutions such as museums are strongly conditioned by educational capital, income, and social position. These conditions produce uneven patterns of participation and leave large segments of the population excluded from these spaces (Norberto Rocha et al., 2021; Polino et al., 2024).

Considering these conditions, research in Latin America contributes to rethinking the relationship between museums, education, and teacher education. Non-formal science institutions are not simply neutral spaces for disseminating knowledge, but actively shape meanings about science and society, with the potential to both reproduce and challenge existing inequalities (Marandino, 2017; Marandino et al., 2022). This perspective is particularly relevant for teacher education, as it challenges programs to consider not only how teacher educators use non-formal environments, but also who has access to them and under what conditions.

From a local and situated perspective in Latin America, a self-study allows professional trajectories and institutional characteristics to be considered as relevant entry points for examining practice. At the same time, it provides a situated relationship between trajectories and experiences, institutional conditions, and pedagogical decision-making to be made visible and critically examined (LaBoskey, 2004; Vanassche & Berry, 2020).

3 Research questions

In this context, this paper explores how non-formal science learning environments are incorporated into science teacher education across different Latin American contexts. The study explores three selected, information-rich cases from four countries: Brazil, Chile and a collaborative case from Colombia-Argentina. The cases provide situated accounts through which to discuss the following research questions:

- How do teacher educators' professional trajectories influence the incorporation of non-formal learning practices into science teacher education?
- How are non-formal learning environments incorporated into science teacher education practice across different Latin American contexts?

4 Methodology

4.1 Research design

This study adopts a qualitative, comparative design grounded in the self-study of Teaching and Teacher Education practices (S-STTEP). The S-STTEP goal is to build a deep understanding of the educational setting and practices conducted within it, to contribute to broader comprehension of teacher education practices (Vanassche & Berry, 2020).

Self-study is particularly relevant in contexts where researchers are also practitioners, as it enables a systematic and critical examination of professional practice from within (Loughran, 2004; Tidwell et al., 2009), making this practice public and open to critique (LaBoskey, 2004). Its purpose is to illuminate practice and generate local and situated knowledge that may prompt further deliberation in other contexts (Ritter & Quiñones, 2020).

Within this framework, we adopt autoethnographic and collaborative co-autoethnographic perspectives. Autoethnography allows us to examine personal experience in relation to the cultural and institutional contexts in which it is produced (Ellis et al., 2011). Co-autoethnography recognises that professional practice can be more rigorously examined through interaction with others, whose questions and alternative readings help expose assumptions and blind spots that may remain invisible in solitary reflection (Butler et al., 2026; Coia & Taylor, 2009).

4.2 Contexts, participants and research process

The study involves six teacher educators working in science teacher education across four Latin American countries: Brazil, Chile, Colombia, and Argentina. The group was purposefully assembled by the first author, who invited colleagues who had researched and published on teacher education experiences involving non-formal science learning environments. Each participant is directly involved in the design and implementation of courses or training experiences that incorporate non-formal science learning environments, such as museums, science centres, zoos, and related institutions. The sample is therefore small, selective, and information-rich.

The research was conducted through an iterative and collaborative process involving all authors in four stages, during 2026. The first stage consisted of an initial meeting in January, in which the authors shared and discussed their experiences, initial ideas, and approaches to integrating non-formal science learning environments into teacher education in their respective contexts. In this meeting, the authors agreed on a common structure for the narratives.

In a second stage, from January to early March, each pair of authors developed an in-depth joint narrative account of their experience in a specific national context: Chile

(Eduardo and Natalia), Brazil (Adriana and Jessica), and Colombia-Argentina (Carlos and Claudia). The narratives were expected to have approximately 2,000 words and were written in a shared document accessible to all six authors.

In a third stage, during March, all authors cross-read the three narratives and added written comments and analytical memos. Authors were invited to relate their observations to the two research questions while also recording emergent ideas, similarities, differences, and questions for collective discussion.

Finally, in a fourth stage, the co-autoethnographic cross-contexts interpretation and theoretical discussion was developed through two recorded online meetings of approximately two hours each, held in March and April. In these meetings, the six authors discussed the written memos, compared the cases, and developed shared interpretations, integrating insights from all cases and relating them to existing literature on non-formal science learning and teacher education, particularly in Latin America, aiming to discuss our two research questions.

Email exchanges were used throughout January to April to clarify questions and document agreements. Recordings, correspondence, comments, analytical memos, and successive versions of the narratives and manuscript were retained as an audit trail of the process, seeking to improve trustworthiness.

4.3 Data sources and analysis

Data were generated through two sources consistent with self-study and co-autoethnographic research. These include (1) three reflective narratives jointly written by each pair of authors and (2) written analytical memos and recorded collaborative discussions among the six authors.

The narratives were constructed following five shared dimensions agreed during the initial meeting so that each account would be sufficiently comprehensive and comparable: (a) the authors' professional trajectories related to science education, (b) the institutional and programmatic context, (c) the ways in which non-formal environments were incorporated into the current teacher education courses taught by the authors, (d) the pedagogical focus of this integration, and (e) reflections on tensions, challenges, and learning specifically related to incorporating non-formal environments into teacher education. These joint narrative accounts constitute the primary data of the study.

Data analysis followed an iterative and interpretive process consistent with collaborative self-study and co-autoethnography (Coia & Taylor, 2009; LaBoskey, 2004). The five shared narrative dimensions provided an initial deductive structure, but the cross-case themes were not established in advance.

First, each author conducted an individual analysis of their own case, identifying key features of how non-formal learning environments were incorporated into teacher education and how our own personal journeys were reflected in our teaching practices and decisions.

Subsequently, all six authors independently cross-read the three narratives and produced comments and memos linked to the research questions and to emergent issues. This process involved a careful examination of our colleagues' experiences, allowing each author to identify emerging themes, resonances, and tensions across contexts from our own analytical perspective.

Finally, we conducted a cross-context analysis. The memos and comments were compared during two collaborative meetings (2 hours each). Recurring observations were grouped and discussed in relation to the narrative evidence, while differences among cases were retained as contextual distinctions. For example, the recurring observations that the experiences prepared teachers to use non-formal settings, supported teachers' own learning, and opened alternative professional possibilities were compared across the three narratives and progressively formulated as the three pedagogical purposes reported in Section 5.2.2. No substantial interpretive disagreements arose, but wording and the scope of claims were negotiated until all authors agreed that the themes were adequately supported by the cases and allowed the discussion of our research questions.

Trustworthiness was supported through several complementary strategies: cross-reading of every narrative by all six authors; collective review and approval of the cross-case themes; return of interpretations to each pair for confirmation or further discussion; use of narrative excerpts to make the evidential basis of interpretations visible; and maintenance of an audit trail comprising meeting recordings, emails, memos, and successive narrative and manuscript versions. These procedures align with collaborative approaches to self-study that use dialogue, multiple researchers, and transparent analytic records to interrogate individual interpretations (Butler et al., 2026; Mena & Russell, 2017).

5 Results

5.1 Autoethnography

The following accounts are constructed as collaborative autoethnographic narratives (Coia & Taylor, 2009; Ellis et al., 2011), in which we, as teacher educators, examine our own professional trajectories and pedagogical practices from within. We position ourselves as both researchers and practitioners, making explicit the values, decisions, and contradictions that shape how we integrate non-formal learning environments into teacher education.

5.1.1 Chile

Professional trajectories of the authors

Natalia. During my undergraduate biology degree, I began working in a botanical garden as a mediator in non-formal science education activities, which became a turning point in my professional trajectory. Engaging directly with diverse audiences allowed me to experience science education beyond the classroom and to recognise the potential of non-formal environments to foster curiosity, dialogue, and contextualised understandings of science.

A significant aspect of this experience emerged from my work with school groups. In an initial study for my undergraduate thesis, we explored why teachers brought their students to the garden, and while they frequently articulated goals related to supporting their teaching and expanding disciplinary knowledge (Cândido et al., 2013), in practice many remained peripheral to the learning experience (Kisiel, 2006). As a result, the educational potential of the visit was often underutilised.

These experiences led me to recognise a persistent disconnection between the potential of non-formal environments and their integration into school practices (DeWitt & Osborne, 2007). During my graduate studies, I began to understand this not as an isolated issue, but as a structural and pedagogical problem linked to teacher education. This perspective shaped my subsequent research on non-formal science education, particularly on mediation practices and the professionalisation of educators in these contexts (Cândido et al., 2024, 2025).

At the same time, as I became involved in teacher education, I made a deliberate decision to incorporate non-formal learning environments into my teaching. This was not only to better prepare future teachers to work with these contexts, but also to position them as legitimate spaces for learning in their own right.

Eduardo. Towards the end of my undergraduate degree in Agronomy, I began working in an NGO focused on promoting scientific skills among students and teachers through activities such as science camps and clubs. This experience marked the beginning of my engagement with non-formal science education.

A key aspect of this experience was realising that teachers were unaware of these opportunities and did not know how to incorporate them into their teaching (Mazzitelli et al., 2026). Throughout my time working with them, I focused on developing their scientific skills and training them in teaching strategies to use with their students. I also showed them how to enhance their science lessons in non-traditional settings, such as science fairs, science camps, parks, and museums.

Based on these experiences, it became clear that, even though teachers valued the experiences offered in non-formal education settings, they lacked the skills to integrate them

into their everyday teaching practices. This situation began to reveal itself to me as a persistent tension between what teachers valued or wished to integrate and what they actually managed to bring into their classrooms (Morentin & Guisasola, 2015).

I recognised the need to create learning opportunities for pre-service and in-service teachers to develop the skills and knowledge required to incorporate non-formal educational settings into their teaching practice. As my professional development remained linked to science education, I worked in new settings to help teachers enrich their approaches by linking with non-formal educational spaces. Alongside this, through collaborative work with other academics, we have sought to strengthen how we develop this topic among pre-service teachers who will, in the future, teach natural sciences in a contextualised manner, creating challenging learning environments for their students.

Institutional and programmatic context

The Chilean case is situated at the Pontificia Universidad Católica de Chile within an initial teacher education program in Primary Education. Non-formal learning environments are incorporated across two science education courses at different stages of the program.

The first course, Science Education I, is a compulsory course offered in the third year of the program and enrolls approximately 45 students per section. Across recent offerings, six contact hours have been devoted to non-formal education. The course is jointly designed and taught by Natalia and Eduardo. At this stage, most pre-service teachers have little or no prior experience with non-formal learning environments. The second course, Science Education III, is compulsory for students who choose a specialisation in science education, typically in the fifth year. It has a smaller cohort of approximately 10 students and devotes 12 contact hours to non-formal learning, including at least five field visits. Natalia is responsible for this course, while Eduardo collaborates in selected modules. The account reflects the functioning of these courses across their recent offerings.

The incorporation of non-formal environments is not formally institutionalised and depends largely on the initiative of teacher educators, shaping both the possibilities and limitations of this approach.

Ways of incorporating non-formal learning environments

In the course Science Education I, the incorporation of non-formal learning environments is primarily oriented towards helping pre-service teachers understand the educational value of these spaces and become familiar with relevant theoretical perspectives such as non-formal learning (Falk & Dierking, 2013), school visits and teaching-learning sequences (Morentin & Guisasola, 2015), and mediation in non-formal contexts (Cândido et al., 2024). This work is mainly developed through the analysis of literature, case discussions, and reflective activities,

as structural constraints of time, number of students and transportation limit the possibility of organising visits to external institutions.

In the course Science Education III, these topics are further developed by incorporating more specific theoretical frameworks related to the phases of museum visits (Allard et al., 1994), the contextual learning model (Falk & Dierking, 2013), and specific models of mediation in non-formal learning environments (Cândido et al., 2024). Students participate in at least 5 visits to different settings, including science and technology museums, natural history museums, and zoos. During and after the visits, students analyse the learning opportunities offered by exhibitions, participate in mediated visits when available, and critically examine mediation practices from a pedagogical perspective, drawing on theoretical models of mediation. They also reflect on how these spaces can be meaningfully connected to the school science curriculum.

Building on these experiences, students develop a teaching sequence aligned with the primary science curriculum. This includes selecting a learning objective, choosing a specific non-formal institution, and developing a proposal that integrates activities before, during, and after the visit. As part of this process, they are asked to make their pedagogical decisions explicit.

Focus of the integration

The integration of non-formal learning environments in our context shows differentiated emphases across the two courses.

In Science Education I, the focus is primarily on enabling students to recognize non-formal environments as legitimate learning contexts and to begin understanding their educational potential. In Science Education III, this focus is maintained but develops into a more complex level, centred on the planning of teaching experiences that integrate non-formal environments and articulate curriculum objectives with the learning opportunities offered by museums, zoos, and other settings.

Additionally, this second course incorporates a focus on teacher learning in non-formal environments as we explicitly discuss scientific phenomena and scientific practices. Each visit is organised around specific disciplinary themes (for example, species, habitats, and ecosystems in the case of the zoo; energy in the case of the science centre), allowing students to position themselves not only as future teachers but also as learners of science in contexts beyond the classroom.

By contrast, the broadening of professional horizons within non-formal science education is not an explicit focus in either course. However, this dimension emerges spontaneously through students' experiences. Following the visits, students frequently raise questions about the possibility of working in museums, zoos, or similar institutions, and express interest in roles such as mediators or educators in these contexts. This suggests that, even when not

intentionally addressed in the curriculum, exposure to these environments contributes to broadening pre-service teachers' professional perspectives.

Overall, the integration is primarily oriented towards preparing future teachers to design and implement meaningful learning experiences in these contexts, responding to previously observed tensions in how school visits are enacted.

Reflections on tensions, challenges, and learning as teacher educators

This experience has involved both opportunities and ongoing tensions.

One key challenge lies in the initial resistance or uncertainty that pre-service teachers express when encountering non-formal education as part of their training. Many students do not immediately recognise these environments as legitimate spaces for teaching and learning, often because they have not experienced them in that way during their own schooling. This has led us to recognise the importance of dedicating time to early familiarisation to help students value these environments as pedagogically meaningful.

In Science Education I, structural constraints like the large number of students and the lack of funding for transportation limit the possibility of organising visits to external institutions. As a result, the work tends to focus on theoretical and analytical approaches, complemented by visits to spaces within the university campus. In contrast, the smaller size of Science Education III course enables more sustained engagement with non-formal environments, including visits to museums, zoos, and other institutions.

Time constraints also represent a significant challenge across both courses. The weekly schedule is organised into separate sessions (one and two hours), which makes it difficult to carry out full visits to external institutions within the available time. These structural conditions influence not only the frequency and type of experiences that can be offered, but also the pedagogical decisions regarding how non-formal learning is integrated into teacher education.

Designing the second course, in particular, has required ongoing decision-making around which institutions to include. This involves not only ensuring diversity in terms of types of institutions, such as science and technology museums, natural history museums, and zoos, but also selecting spaces that embody different approaches to non-formal education. This selection process reflects an underlying pedagogical intention: to expose students to different ways of understanding what non-formal science education can be.

Finally, one source of institutional tension is the structural invisibility of this work, given that this entire experience is neither valued nor included in academic productivity metrics, meaning it depends solely on the willingness of each course teacher educator.

At a more personal level, this work remains deeply connected to our own trajectory. The tensions we observed in practice continue to shape our pedagogical decisions as teacher

educators. At the same time, we see this work as an ongoing process, one that continues to evolve as we navigate the possibilities and limitations of our context.

5.1.2 Colombia-Argentina

Professional trajectories of the authors

Carlos. My training in the fields of museum education and research was not acquired through any of the academic programs in which I participated as a student. Rather, my interest in museums is linked to my role as Dean of Education and to my participation in the development of public policy related to the construction of interactive centres and library parks in the city of Medellín between 2004 and 2007. This interdisciplinary and interinstitutional work experience allowed me to recognise the relevance of museums and their contribution to science education, topics that faculties of education have not traditionally considered within their scope.

Once my term as Dean of Education had ended, my research group and I decided to establish a line of research and training in museum education aimed at the training of future science teachers. For this purpose, we developed a work agenda that included collaboration with researchers in museum education from the United States, Spain, Argentina, Brazil, and Mexico. Particularly noteworthy was our personal contact with professors John Falk and Lynn Dierking, who visited us in 2009 and held a series of workshops over three weeks on topics such as free-choice learning, the contextual learning model, and lifelong learning. These workshops were aimed at the research group's researchers and students. We also invited museum educators from the city to participate, which helped establish a strong connection between the research group and the museums, which later became an important factor for strengthening this line of research and training.

The curricular space that enabled us to incorporate museums into the training of future teachers was the one related to professional practices. Teacher training programs in Colombia include a line of pedagogical practices that run from the first semester of the degree through to the final semester. The professional internship cycle, also called immersive internships, takes place during the last three semesters of the program. For fifteen years (2007-2022), my research group offered training in museum education within the context of professional internships, focusing on the study of complementary relationships between museums and schools (Soto Lombana et al., 2011; Soto-Lombana & Angulo-Delgado, 2025).

These previous initiatives with pre-service teachers have made it possible to involve doctoral students in education in this initiative to study the contributions that museum immersion offers to the training of future science teachers (Cardona-Arango & Soto-Lombana, 2025; Muñoz-Candamil & Soto-Lombana, 2025; Quintero & Soto-Lombana, 2025). The findings of these doctoral theses have enabled me to document, review, provide

feedback, and guide the work carried out in the undergraduate degree, thereby contributing to the ongoing discussion about the profile of future teachers, their fields of professional action, and the contribution of this type of teaching experience to the transformation of school practices.

Claudia. Since the beginning of my teaching career, I have been involved in the education of science teachers, carrying out various roles within the context of disciplinary training courses, pedagogical training, and internships and residencies during the final stages of teacher training programs. This, together with my participation in science education projects, led me to pursue postgraduate studies focused on topics and research lines that would allow me to deepen my understanding of teacher training, with the aim of proposing methodological approaches and actions that would support teacher training processes. With this in mind, I developed my doctoral thesis from the perspective of Social Representations, seeking to further examine science education from a psychosocial perspective. The results allowed me to identify the Social Representations related to some of the disciplines that constitute Natural Science, as well as to the knowledge of Natural Science, and to their teaching and learning processes. Based on this thesis, my research has focused on studying different aspects related to both initial and continuing teacher training from this theoretical-methodological perspective, always within the context of formal education.

The collaboration with my Colombian colleagues and their work on teacher training in the context of museum internships enabled the possibility of testing reflective models of pedagogical practices designed for formal education in non-formal educational settings such as museums. Within this framework, we have undertaken different approaches. Initially, we identified the Social Representations held by pre-service teachers regarding museums and pedagogical practice in museum settings, following the completion of their museum internships (Mazzitelli et al., 2026). Subsequently, we have been interested in conducting longitudinal studies to examine the changes in these Social Representations regarding concepts such as museums and pedagogical practice among pre-service teachers, in order to assess the contribution that museums can make to the professional development of future teachers. In addition, we are currently conducting a preliminary approach in the Argentine context, inquiring, where possible, with museum directors and those responsible for the education area, to explore museums' perspectives regarding the incorporation of museum educators and the professional profile they believe they should have (Zorrilla et al., 2026).

Institutional and programmatic context

The Colombia-Argentina case is developed at the University of Antioquia (Colombia) within the context of the final year immersive internships of the Bachelor's degree in Natural Science (undergraduate programs that train teachers for preschool, primary, and secondary education). Carlos directly teaches the internship and its associated theoretical course. Claudia

participates as an external researcher and collaborator in the reflective practice model.

The museum internship program emerged as an initiative to broaden the range of professional practice settings available to future science teachers by offering experiences in institutions situated within the non-formal and informal education modes. In this context, museums can operate as a "third space" where laboratory-like conditions can be recreated to develop educational innovations, as they are not subject to the same regulations or normative frameworks as schools.

These final-year internships take place during the eighth and ninth semesters of the degree and have a weekly intensity of 16 hours over a period of 32 weeks. Of these 16 hours, 12 are carried out in the context of the museum internship, while the remaining 4 hours correspond to a theoretical course on the educational role of museums. These pedagogical practices are developed by a teaching team composed of professors from the Faculty of Education and museum educators from the University Museum.

In order to examine the contribution of museum internships to pre-service teachers, we have implemented a model of reflective practice (Mazzitelli et al., 2023, 2026), which we also use as a research device.

Ways of incorporating non-formal learning environments

Given that the immersive experience developed by future science teachers focuses on understanding and experiencing museums, two complementary components are implemented simultaneously over the course of two academic semesters. A first component focuses on the participants' conceptual foundation regarding museum topics (history, concept, definition, contemporary challenges), as well as on conceptual approaches including the contextual model of learning (Falk & Dierking, 2013), models of museum pedagogy (Boucher & Allard, 1998), and the concepts of lifelong learning and free-choice learning (Falk & Dierking, 2002). It also incorporates planning and assessment tools in the field of museums, such as the GLOs tool (Hooper-Greenhill, 2007) and Personal Meaning Mapping (Falk & Dierking, 2003), among others. At the same time, the pre-service teachers participate in a hands-on introduction to the museum, which allows them to become familiar with the institution, its heritage and museography resources, and the role of museum educators. A key aspect of this immersion involves engaging with different audiences, including school audiences. Part of this process of preparing future teachers involves visiting other museums in the city to showcase the diversity of institutions that are classified as museum spaces: botanical gardens, planetariums, interactive centres, and zoos.

As a practical exercise for applying the knowledge acquired in both components (theoretical and experiential), the pre-service teachers have to design an educational route designed for school audiences. For this exercise, pre-service teachers draw on the conceptual and methodological framework of the GLOs tool (Soto-Lombana et al., 2024), which allows

them to formulate the intended learning outcomes that they aim to promote in visitors and the corresponding evaluation strategies.

Focus of the integration

The purpose of the museum internship is to help future teachers acquire the knowledge and practical expertise that characterize educators in non-formal science education institutions. This is reflected in the development of a set of pedagogical content knowledge specific to free-choice science learning environments, also known as ISE-PCK (Busch et al., 2023). As the museum is conceptualized as a "third space" for the professional training of future teachers, it is essential that the internship respects the institution's nature, its approaches to learning, the communication models it employs, its knowledge of different audiences, and its participatory methodologies.

In this case, the researchers' interest lies in determining the contributions the museum internship makes to pre-service teachers' Social Representations regarding museums, education, and pedagogical practice. To this end, we used a reflective practice model consisting of five stages implemented with pre-service teachers (Mazzitelli et al., 2023).

Reflections on tensions, challenges, and learning as teacher educators

The teaching experience is situated within the framework of collaboration between museums and faculties of education. The concept of the museum as a "third space" makes it possible to bring together university professors and researchers with experience and interest in the field of teacher training and museum education. On the one hand, faculties of education broaden their approaches to teacher training by offering future teachers educational experiences that can complement and challenge the traditional education that characterizes formal education. On the other hand, museums and their education staff can draw on these collaborative experiences to provide feedback on the educational role of these institutions.

We consider that the primary challenges and tensions arise within the context of the relationship between museums and faculties of education. These challenges stem from the fact that it represents a different way of conceiving science teacher training, one that incorporates dialogue among equals and is grounded in mutual institutional recognition. At the same time, tensions emerge because it is not easy to break with established paradigms and historically constructed hierarchies. In our case, the relationship between the Faculty of Education and the University Museum, institutions with which we work, has been achieved through the development of a broad collaborative agenda. This agenda includes programs and initiatives across multiple dimensions that extend beyond the scope of science teacher training (Soto-Lombana et al., 2025; Soto-Lombana et al., 2013).

5.1.3 Brazil

Professional trajectories of the authors

Adriana. My engagement with non-formal education began during my undergraduate degree in Biological Sciences and can be traced through three distinct pathways. First, I served as curator of UFRJ's didactic collection, facilitating specimen loans to teachers and students for science fairs and exhibitions. Second, I worked as an educator at a conservation project in Pernambuco, engaging diverse audiences, including school groups, families, elderly visitors, people in social vulnerability, and teachers. Third, I served as a mediator at the National Museum/UFRJ, working with Brazilian and international visitors across educational levels.

After completing my degree, I began teaching at elementary and middle schools, systematically incorporating museum visits into my lesson plans. Throughout my career, I have maintained this practice to position museum education as a field of knowledge in its own right, rather than a mere didactic strategy (Pugliese, 2015). This theoretical stance solidified during my doctoral studies, when the relationship between non-formal education and teacher training became my primary research focus (Pugliese, 2015), supervised by Professor Martha Marandino. This focus has structured my work across teaching, research supervision of scientific initiation, master's, and doctoral projects (Hungaro & Pugliese, 2024; Pugliese & Saleh, 2021).

The course "Pedagogical and formative practices in science museums" consolidates my experience in teacher training within non-formal education. I supervise mandatory curricular internships in non-formal education settings, enabling students to gain direct experience with museum spaces from multiple perspectives. In the context of postgraduate studies, I teach "Non-formal education and scientific communication" to master's and doctoral students. Graduate students typically initially view museums as pedagogical complements to schooling. Through the course's readings and discussions, they come to recognise other possibilities and develop the capacity for research practice in non-formal education, appropriating concepts from this theoretical field, especially those of authors from the Global South. I also lead extension courses of varying durations for teachers in basic education and initial training (Pugliese et al., 2020) that address museum education and learning opportunities in non-formal spaces.

Jessica. My engagement with non-formal education began during my undergraduate degree in Languages, where I interned for 4 years at a centre responsible for building two science museums: an interactive science museum, and an itinerant science museum. That formative experience gave me an early understanding of how museums are built, curated, and connected to public education. I deepened this understanding during a one-year academic exchange in the UK, at King's College London and at the Natural History Museum as a learning

volunteer. There, I engaged directly with school groups and teachers.

My master's research in Brazil examined this gap empirically by studying the scientific culture of pre- and in-service teachers in the interior of Minas Gerais who were enrolled in a distance-education pedagogy program. The study documented a structural reality: current and future teachers in peripheral municipalities had minimal exposure to museums and scientific culture, with access conditioned by income, territory, and educational capital (Norberto Rocha, 2013). My doctoral research (also supervised by Professor Martha Marandino) extended this concern to the museum side, analysing itinerant science museums through the lens of scientific literacy (Norberto Rocha, 2018). This work developed alongside my coordination of a mobile science centre reaching municipalities across Rio de Janeiro and a program that combined interactive exhibitions with teacher training in contexts where inequalities were most acute. Since 2016, I have coordinated the Research Group on Accessible Science Museums and Science Centers (MCCAC – grupomccac.org).

Together, these experiences allowed me to witness firsthand that many teachers were not prepared to explore museum visits as pedagogical tools.

Institutional and programmatic context

Adriana's course, at the centre of this account, is titled Pedagogical and formative practices in science museums, an elective offered within the Bachelor's degree in Biological Sciences at the Federal University of ABC, a public federal university in the metropolitan region of the city of São Paulo. The course comprises 48 hours, with one four-hour class each week. The course has three core objectives: to help students understand the role of science museums and science centres in both initial and continuing teacher education; to identify pedagogical possibilities in non-formal educational spaces within school contexts; and to discuss practicum experiences in museums, positioning these institutions as legitimate professional career pathways (Pugliese et al., in press).

Jessica's course, Special topics in Science Teaching 2 at the Federal Institute of Rio de Janeiro, is held at night and is compulsory for all 15-20 students enrolled in the Specialisation, who are generally graduates and in-service school teachers. The course comprises 30 hours, with one four-hour class each week. In this course, she addresses science communication, inclusion in museums, online museums as didactic tools, and scientific literacy in museum contexts. The challenge is not to introduce future teachers to museum spaces but to equip practising teachers with theoretical and methodological tools for using and researching those spaces, including issues of scientific literacy, inclusion, and accessibility.

Ways of incorporating non-formal learning environments

In Adriana's course, the central pedagogical structure is an iterative cycle of preparatory work, institutional visits, and post-visit activities. The number of sites visited has increased across successive offerings, from three initially to six non-formal spaces per academic term in recent editions. Sites have included natural history museums, science centres, ethnology and archaeology museums, spaces with zoological and botanical collections, parks, planetariums, and school museums. Each visit lasts about 2.5 to 3 hours and is always accompanied by the host institution's educators, enabling students to ask questions, engage in dialogue with museum staff, and understand the museum's educational programming.

Post-visit activities are grounded in theory. Students are asked to: characterize the museum in relation to the literature on museum generations (Cazelli et al., 2003; Pedretti & Iannini, 2020); design educational activities for school groups, spontaneous audiences, socially excluded groups, and visitors with disabilities (Finck et al., 2022); propose interdisciplinary activities; conduct interviews with museum educators or school teachers who regularly incorporate museum visits into their planning (see Pugliese et al., in press); and use frameworks for scientific literacy in museum contexts (Marandino et al., 2018; Norberto Rocha, 2018). The course also includes dialogic lectures with weekly readings and, in at least one session per semester, guest lectures by practicing museum educators.

Jessica's course takes a deliberately different structural approach, reflecting her student population of graduates and in-service teachers. Rather than organizing the course around physical visits, Jessica structures her teaching around three integrated analytical dimensions.

First, scientific literacy as a critical analytical lens. Drawing on frameworks developed by Jessica and colleagues (Marandino et al., 2018), the course examines how museums can foster critical scientific literacy. Rather than treating scientific literacy as knowledge transmission, the course frames it as conscious, critical engagement with how scientific knowledge is positioned and legitimized in institutional spaces and with whose voices are included or silenced. This aligns with the idea that teachers equipped with strong scientific literacy frameworks can more effectively challenge reductive "museum as entertainment" models and position museum work as serious educational practice.

Second, online museums as legitimate sites of analysis (Marinho & Norberto Rocha, 2023; Ribeiro et al., 2024). Teachers examine specific virtual exhibitions, design educational activities that leverage digital affordances, and critically consider how online formats both address and create new access barriers for their own students. This reflects Jessica's theoretical conviction that, given Brazil's deeply unequal geographic distribution of museums, teachers need the capacity to work with digital resources. It also reflects the pragmatic reality of the specialisation program: because it is held at night in Rio de Janeiro, physical museum visits are logistically impossible for many working teachers.

Third, accessibility and inclusion are foundational design principles. Using accessibility frameworks that Jessica coordinated across the region (Norberto Rocha et al., 2020, 2025), the course positions accessibility not as an add-on or special accommodation but as a foundational principle for designing museums from the outset. This approach addresses in-service teachers' primary needs, which is not an introduction to museums but a critical analytical capacity to (re)position how museums can serve their teaching in their own contexts.

Focus of the integration

Although structured differently, three overlapping pedagogical purposes emerge across both courses, with their emphasis varying by institutional context.

Preparation for school visits is central to Adriana's course: students learn to plan, execute, and reflect on visits as pedagogical tools within school contexts using the structured before-during-after cycle. In Jessica's course, this dimension appears in the analytical study of visit planning frameworks and in the design of museum-based activities as course assignments.

Teacher learning in non-formal environments is evident in both courses. In Adriana's course, students engage with scientific and pedagogical practices embedded in museum spaces through direct experience. In Jessica's course, this learning is mediated by science communication and science literacy theories, inclusion frameworks, and the critical examination of online and physical museum resources.

Broadening professional horizons is perhaps the most distinctive feature of Adriana's course: it explicitly positions the museum educator career as a legitimate professional pathway (Pugliese, 2015). In Jessica's course, this dimension manifests as the scholarly legitimization of museum education and science communication as research fields in which teachers can become producers of knowledge. Both courses fundamentally disrupt the assumption that teaching trajectories are confined to school-only careers and position non-formal education spaces as legitimate professional fields deserving serious intellectual engagement and sustained scholarly attention.

Underlying both courses is a shared political commitment that connects directly to the Brazilian context of unequal access to science and culture (Norberto Rocha et al., 2020; Polino et al., 2024). In a country where engagement with museums and science institutions is strongly conditioned by income, territory, and educational capital, the decision to incorporate these spaces into teacher education carries an explicit rights-based dimension (Marandino & Martins, 2016). For both Adriana and Jessica, preparing teachers to use, understand, and critically engage with non-formal environments is not a neutral pedagogical choice: it is part of a broader commitment of expanding access to scientific culture and to forming educators who can challenge the exclusionary patterns that characterize participation in these institutions.

Reflections on tensions, challenges, and learning as teacher educators

Organising a course built around multiple off-campus visits creates significant logistical and institutional tensions. From an equity standpoint, Adriana has explicitly decided to limit visits to free-entry spaces or institutions that offer fee waivers for public university students. A choice that has meant excluding some pedagogically rich sites, but reflects a deliberate democratic positioning consistent with UFABC's public mandate.

The administrative burden is substantial. Without dedicated staff, Adriana manages all logistics personally. Each visit generates about three hours of administrative work outside teaching time. Across five or six visits per semester, this workload becomes a significant drain, falling outside the formal scope of teaching duties. Geographic distance adds another layer: most of São Paulo's major museums are far from UFABC's campus, and round-trips can take up to 6.5 hours, creating real tensions for working students who must negotiate time off from employment.

Because Jessica's course is held at night, most museums are already closed. She therefore chose to work exclusively with online museums and scientific exhibitions, a choice that also underscores the difficulty of access for both teachers and students and offers learning opportunities for those unable to visit a museum due to geographical, economic, or availability constraints.

A shared tension across both courses is the structural invisibility of this kind of pedagogical work within university evaluation systems. The relational and institutional labour involved in integrating non-formal environments is rarely recognised in academic productivity metrics. Yet this labour is real, sustained, and generative of student learning, professional development, and transformative engagement with educational practice.

What we have learned is that every curricular and logistical decision (which museum, which format, which theoretical framework, and who is invited to speak) encodes values about equity, access, and what counts as a legitimate educational experience. Navigating these tensions has deepened our understanding of the structural conditions that shape and often constrain the integration of non-formal learning environments into teacher education programs across institutional levels. It has also reinforced our commitment to this work as central to democratizing access to science and culture in Brazil.

5.2 Co-ethnography – cross-case analysis

Building on the individual narratives presented in Section 5.1, this section develops the cross-case analysis produced through cross-reading, analytical memos, and collaborative discussion among the six authors. The analysis is organised around our two research questions and Table 1 summarises the comparative dimensions.

Table 1. Cross-case comparison of how non-formal learning environments are incorporated into science teacher education

Dimension	Chile (PUC Chile)	Colombia–Argentina (U. de Antioquia)	Brazil (UFABC / IFRJ)	Cross-case reading
Curricular status	Learning modules within two compulsory science education courses (3rd and 5th year); not formally institutionalised.	Final-year immersive internship and associated theoretical course, embedded in the programme's practicum line.	Two stand-alone courses. UFABC: elective; IFRJ: compulsory within a Specialisation.	Integration ranges from an add-on module to a structurally embedded internship.
Participants	Pre-service primary teachers; approximately 45 (Science Education I) and 10 (Science Education III).	Pre-service Natural Science teachers, 8th and 9th semesters.	UFABC: Pre-service Biological Sciences teachers; IFRJ: graduates and in-service teachers, 15–20.	Predominantly Pre-service teachers. Brazil is the only case combining pre-service and in-service teachers and graduates.
Engagement with non-formal institutions	Science Education I: no visits to external institutions, campus-based spaces only; Science Education III: at least five sites, one visit each (science and technology museums, natural history museums, zoos).	Introductory visits to institutions (planetariums, zoos, botanical gardens, interactive centres) and sustained placement in the university museum, working with school audiences.	UFABC: six sites per term, one visit each (natural history museums, science centres, ethnology and archaeology museums, zoological and botanical collections, parks, planetariums, school museums); IFRJ: online museums and virtual exhibitions.	Chile and Brazil favour breadth, many institutions visited once each; only the Colombia–Argentina case sustains depth in a single institution, moving pre-service teachers from observation to designing and delivering activities.
Purpose 1: preparing for school visits	Explicit; teaching sequence with activities before, during and after the visit (Science Education III).	Explicit; design of an educational route for school audiences using the GLOs framework.	Explicit; design of educational activities for school groups, spontaneous audiences, socially excluded groups and visitors with disabilities.	Present in all three cases, enacted through different combinations of planning, observation, design and practice.
Purpose 2: teachers' own learning	Explicit in Science Education III; visits organised around disciplinary themes.	Explicit; conceptual foundation on museums combined with hands-on immersion.	Explicit; engagement with science communication, scientific literacy and accessibility as fields of knowledge.	Present in all three cases; non-formal settings function as contexts for disciplinary and pedagogical learning, not only as objects of study.
Purpose 3: broadening professional horizons	Not an explicit curricular focus; emerges in students' questions following the visits.	Explicit; the museum conceived as a "third space" and as a professional field.	Explicit; museums positioned as legitimate professional career pathways.	Explicit in two of the three cases. Explicit in Colombia–Argentina and Brazil; in Chile it emerges only implicitly, in students' questions after visits.
Tensions & Challenges	Cohort size; no funding for transport; fragmented weekly timetable; non-institutionalisation; invisibility in productivity metrics.	Hierarchies between faculties of education and museums; need for mutual institutional recognition.	Unrecognised administrative load; distance; working students; invisibility in productivity metrics.	Constraints are structural rather than pedagogical. There is a shared invisibility of this labour within academic evaluation systems.

5.2.1 How do teacher educators' professional trajectories influence the incorporation of non-formal learning practices into science teacher education?

Our cross-reading and collaborative discussions suggested a relationship, within these three cases, among professional trajectories, institutional contexts, and pedagogical decisions concerning non-formal learning. The cases make visible two situated pathways through which non-formal education enters teacher education.

In the cases of Brazil and Chile, the four researchers had close relations with non-formal learning in their early professional paths. None of them is a teacher of initial training; rather, they have careers more closely linked to their discipline. However, in their professional practice or in their first jobs, they worked with initiatives in non-formal spaces such as botanical gardens, science museums and science camps.

It was noted that during their training, they all faced challenges related to how teachers engaged with and used non-formal education, identifying early on the need for teacher training. For example, Jessica (Brazil) mentions that the practical experiences in museum settings engaging directly with school groups offer her the opportunity to witness how poorly most teachers are prepared to use museum visits as pedagogical tools. Similarly, Natália (Chile) says that she observed recurring patterns in how teachers engaged with the learning experience: “In many cases, teachers remained on the periphery of the visit, and the educational experience was largely delegated to the mediator”. These experiences contributed to a growing awareness of a gap between the potential of non-formal environments and their integration into school practice.

These challenges, which arose from their own practices, led to lines of research in non-formal education during their graduate studies in every case. Furthermore, as they developed into teacher educators, they incorporated non-formal education into their courses. This was partly to address the identified challenges, but also because their first-hand experience of these contexts had led them to recognise the significant contribution of non-formal settings to science education. They also came to value non-formal education as pedagogical spaces. In Adriana's words (Brazil): “I maintained this practice across all the courses I taught, with the explicit intention of positioning museum education as a field of knowledge in its own right, rather than merely a didactic strategy”.

The Colombia–Argentina case reflects a different pathway. They have training as teachers and their interest in non-formal education emerged later in their careers. In Carlos's case (Colombia), his role as dean of a Faculty of Education enabled him to play a part in a public policy initiative that promoted the construction of museums and library parks in the city of Medellín. This sparked the interest of Carlos' research group, which shifted its focus towards non-formal education. The group began to develop expertise in the field by establishing connections with various international researchers and specialists in this area. They also established ties with Argentina, leading to the joint research project on teacher training in

non-formal education that they are currently conducting. This narrative emphasises the importance of their engagement with museums in helping them to understand these institutions as educational spaces. Carlos stresses this point when he says, “Our prior work with museums enabled us to appreciate the educational and cultural potential of these institutions, as well as their role in training future teachers.”

To complement the narratives, we conducted a review of the national policy and regulatory documents of the four participating countries to provide an additional contextual reference for interpreting these experiences. In Chile and Colombia, framework legislation explicitly defines non-formal education, whereas in the Argentine and Brazilian documents reviewed it is more often mentioned in connection with adult education. Across the teacher education standards and professional teaching frameworks included in the matrix, we did not identify an explicit articulation between non-formal science education and teacher education. These observations are limited to the selected documents and were only used to contextualise the narrative findings.

These cases suggest that prior experiences and professional trajectories may contribute to how teacher educators recognise and incorporate non-formal learning, particularly in domains not yet structurally embedded within teacher education programs. This situated answer to the first research question provides an interpretive pattern for further examination in relation to Latin American teacher education.

At the same time, our cases suggest that access to these forms of training may remain uneven, depending on the presence of faculty with prior experience or interest in non-formal education. This reliance on academic agency raises important challenges for Latin America, because it is neither scalable nor transferable. As a result, opportunities to engage with non-formal learning environments may be limited to specific programs or institutions, reinforcing broader inequalities in access to scientific culture and educational innovation in the region (Polino, 2019; Polino et al., 2024).

5.2.2 How are non-formal learning environments incorporated into science teacher education programs in Latin American contexts?

Across the three cases, non-formal education was incorporated into teacher education in different ways, with a shared concern for connecting schools and other learning environments. The comparison identified variation in depth, scope, duration, institutional embeddedness, and the nature of engagement with non-formal institutions.

Firstly, in terms of the institutional and curricular context, in Chile, the programme is limited to learning modules within two broader courses on science education. These courses total approximately six instructional hours on the topic in the introductory course and 12 hours in the final course, including field trips. In Brazil, the experience extends to a full-semester or quarterly course on the subject at each university (30 and 48 hours respectively).

Finally, the Colombia-Argentina case is more in-depth, with student teachers completing a full professional internship at a science museum for one year, comprising 12 weekly hours in a university museum and four hours in an associated theoretical course. In these cases, the depth and form of integration were associated with programme structures, curricular decisions, and institutional support.

Another distinctive feature relating to the incorporation of non-formal spaces is the number of spaces visited and the depth of connections established with each institution. In Chile, one course does not visit any external institutions due to structural limitations, working instead with spaces within the university campus, while another course visits at least five spaces (including museums, zoos, and parks) per semester, but only once per venue. In Brazil, one course involves visiting only online museums, while the other involves students visiting six venues per four-month academic term (including museums, zoos and aquariums), but only once per venue. In the Colombia-Argentina case, the museum internship programme includes a series of visits to museums in the city to showcase the diversity of institutions (planetariums, zoos, botanical gardens, interactive centres), and at the same time, they must attend the university museum for 12 hours a week over 32 weeks, developing close relationships with the museum's professional staff and carrying out educational activities in the museum, primarily with school groups.

Still regarding the approach to implementation, it is evident that all cases have a strong theoretical focus on non-formal education. However, it differs in each case. In Chile, literature on the design and implementation of educational visits (Allard et al., 1994; Morentin & Guisasola, 2015), the contextual learning model (Falk & Dierking, 2013) and mediation models in museums and science centres (Cândido et al., 2024) is particularly notable. In Colombia, the focus is on the contextual model of learning (Falk & Dierking, 2013), museum pedagogy models (Boucher & Allard, 1998) and planning and evaluation tools in the museum sector (Falk & Dierking, 2003; Hooper-Greenhill, 2007; Soto-Lombana et al., 2024). In Brazil, literature focuses on generations of museums (Pedretti & Iannini, 2020), the design of educational activities (Finck et al., 2022), online museums as didactic tools (Marinho & Norberto Rocha, 2023; Ribeiro et al., 2024), frameworks for scientific literacy in museum contexts (Marandino et al., 2018; Norberto Rocha, 2018) and inclusion and accessibility (Norberto Rocha et al., 2020, 2025; Polino et al., 2024). The choice of theoretical frameworks is closely linked to cultural contexts and professional experiences.

The comparison of the narratives generated three overlapping purposes within these cases. First, preparation for school visits appeared as an explicit concern across the experiences, although it was enacted through different combinations of planning, observation, design, and practice. Second, non-formal environments functioned as contexts for teacher learning, supporting engagement with disciplinary ideas, pedagogical knowledge, and theories of science communication. Third, the experiences opened professional horizons

beyond school teaching, explicitly in the Brazilian and Colombian cases and more implicitly in Chile.

These findings emerged from the collaborative analysis and may serve as provisional points of reference for examining other experiences and provide a situated answer to our second research question.

Challenges and learning across-cases

Across the three cases, the incorporation of non-formal learning environments into teacher education reveals a set of shared challenges and emerging learnings that are shaped by contextual conditions.

From a structural perspective, all cases face constraints related to time, resources, and access to non-formal institutions. Our discussions suggested that making these constraints visible to teachers may be pedagogically useful because similar administrative and material challenges are likely to arise when they organise visits in schools (Behrendt & Franklin, 2014), especially in Latin American countries where access to those institutions is uneven. In the experiences examined, this involved discussing not only the design of educational activities but also the practical decisions required to make them possible.

The narratives also indicated that some pre-service teachers initially struggled to recognise non-formal environments as legitimate educational spaces. The authors associated this uncertainty with limited prior contact with museums, science centres, or similar institutions during their own schooling, an interpretation that is consistent with previous research in the region (Anderson et al., 2006; Bustamante & Vanegas, 2018). In our experience, many future teachers arrive in teacher education programmes having been systematically excluded from the very spaces they are now expected to use pedagogically. The implication is not simply that more preparation is needed, but that the legitimisation of non-formal environments as educational spaces is itself an equity intervention, one that requires teacher educators to address not only how to use these spaces, but why access to them has been, and continues to be, unequally distributed (Marandino et al., 2022).

Finally, our discussions highlighted the importance of connecting theoretical study with opportunities to examine practice. The most immersive case enabled pre-service teachers to design and implement activities directly, whereas other cases relied on observing educators, analysing exhibitions or virtual resources, and engaging in guided reflection. Within these cases, such combinations helped make the possibilities and limitations of educational visits more visible. Further research involving teachers and students would be needed to examine how these approaches influence subsequent professional practice.

6 Discussion

In Latin American contexts, the integration of non-formal learning environments into science teacher education cannot be discussed without considering issues of inequality, access, and the uneven distribution of scientific culture (Polino et al., 2024). As evidenced across the three cases, these inequalities are evident both in the limited prior exposure that many trainee teachers have to such environments and in the structural constraints faced by teacher trainers themselves when attempting to incorporate these experiences into their courses. These findings reinforce that the challenges are not only pedagogical but also deeply structural, shaping both access to and the pedagogical use of non-formal environments. However, there are examples, such as the case of Colombia, which encourage us to continue seeking ways to effectively and systematically integrate teaching practices within non-formal educational contexts. In this sense, the Colombian case suggests that stronger institutional articulation may enable more sustained and immersive forms of integration, highlighting the importance of structural support beyond individual initiatives.

In addition, all three cases are situated in major urban areas, where access to non-formal settings is relatively more feasible (Cândido & Pugliese, 2024). This suggests that the challenges identified here may be even more pronounced in other regions, particularly in smaller cities or peripheral areas, where distance, infrastructure, and resource limitations further restrict access to non-formal learning opportunities (Polino, 2019). When read alongside previous literature, our situated findings suggest that public policies supporting non-formal science education, as well as the material and institutional conditions for its integration into school systems and teacher education programmes, may be relevant in contexts where initiatives depend heavily on individual teacher educators' agency (Hoppers, 2006; Polino, 2019; Polino et al., 2024).

Regarding implications for science teacher education, the cases do not identify a single best model. Instead, they show that different arrangements can create different opportunities for professional learning, depending on institutional conditions and available resources. Three key points emerge from our discussions. First, teacher education may benefit from explicit opportunities to engage with non-formal education, so that teachers can examine these institutions as resources for science teaching and learning (Bustamante & Vanegas, 2018; Mazzitelli et al., 2026; Morentin & Guisasola, 2015). Second, these experiences should be grounded in theory and reflective processes, rather than being reduced to isolated field trips (Falk & Dierking, 2013; Morentin & Guisasola, 2015). Third, the integration of non-formal education should attend to multiple purposes: preparing teachers to design and facilitate school visits, enabling them to learn from these experiences as learners themselves, and open possibilities for broader professional trajectories within science education (Monteiro et al., 2016; Morentin & Guisasola, 2015; Oliveira & Marandino, 2024). Together, these elements point to a more comprehensive understanding of non-formal contexts, in

which disciplinary, pedagogical, and contextual dimensions are intertwined. Only in this way can these institutions' full potential be realised.

Our analysis suggests that, in these three cases, integrating non-formal education into teacher training was a complex, context-dependent process shaped by institutional conditions, the professional trajectories of teacher trainers, and broader socio-educational aspects. The practices examined were sustained through differing combinations of individual commitment and institutional support. The collaborative self-study helped us recognise non-formal settings as legitimate spaces for teacher education and as a field of pedagogical knowledge, while also identifying questions that should guide future reflection and research. Ensuring that similar opportunities extend beyond individual initiatives remains an important challenge for the region, but the forms this may take cannot be determined from these cases alone.

Conclusions

This paper examined how non-formal science learning environments are incorporated into science teacher education across three specific Latin American contexts, and how teacher educators' trajectories shape these pedagogical decisions.

Regarding the first research question, the narratives suggest that professional trajectories and prior engagement with non-formal education were meaningfully connected to pedagogical practice in these cases. The integration of non-formal environments was closely associated with formative experiences in these contexts. In the absence of institutional mandates, biography could operate as a mechanism through which non-formal education enters teacher training, with individual agency shaping both the existence and form of these practices.

Regarding the second research question, integration occurs along a spectrum of depth and institutional embeddedness, from short-term modules to full-year internships. Across this variation, three pedagogical purposes are consistently identified: preparing teachers for school visits, supporting teacher learning in non-formal contexts, and broadening professional horizons. The extent to which these purposes are developed depends on institutional support, with more sustained approaches relying on individual commitment where structural guarantees are absent.

The contribution of the study lies in making six teacher educators' practices public for comparison, and making explicit a pattern of structurally vulnerable pedagogical practice: while effective in specific contexts, the integration of non-formal environments could remain difficult to sustain or scale without institutional support. This discussion extends current understandings of non-formal learning in teacher training by discussing its dependence on biographical and structural conditions in the three cases.

Finally, when read alongside existing literature, our situated analysis point to a possible structural agenda. While pedagogical knowledge in this field is already developed in practice, its broader implementation could be enhanced by policy frameworks, institutional support, and sustained partnerships between teacher education programmes and non-formal science institutions. Future studies should include a broader range of institutions and teacher educators, as well as evidence from course enactment, to examine and extend the interpretations developed here.

Research ethics

Author contributions

N.C.: conceptualization, methodology, data curation, formal analysis, writing—original draft preparation, writing—review and editing

J.N.: investigation, data curation, formal analysis, writing—original draft preparation, writing—review and editing

E.G.: investigation, data curation, formal analysis, writing—original draft preparation, writing—review and editing

A.P.: investigation, data curation, formal analysis, writing—original draft preparation

C.M.: investigation, data curation, formal analysis, writing—original draft preparation

C.S.: investigation, data curation, formal analysis, writing—original draft preparation

All authors have read and agreed to the published version of the manuscript.

Artificial intelligence

While preparing this paper, the authors used ChatGPT and Grammarly to help translate some parts of it into English, improve its readability and grammar, and summarise parts of the text. Having used these tools, the authors reviewed and edited the content as necessary, taking final responsibility for the publication's content.

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Institutional review board statement

All participants are co-authors of the study and voluntarily contributed their narratives and reflections. Given the self-study nature of the research, ethical considerations focused on: ensuring transparency in the representation of experiences; maintaining respect for institutional contexts and collectively negotiating how practices and tensions are presented.

Informed consent statement

Informed consent was waived due to the self-study nature of the research.

Data availability statement

Given the nature of the study, the narratives constitute our primary source of data and are reported in full in the results section.

Conflicts of Interest

The authors declare no conflicts of interest.

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