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EDITED BY
Noble Lo,
Lancaster University, United Kingdom

REVIEWED BY
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Tarlac State University, Philippines
Kamal Prasad Acharya,
Tribhuvan University, Nepal

*CORRESPONDENCE
Cristian Merino
✉ cristian.merino@pucv.cl

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Continuing professional development in teachers: insights for designing a formative trajectory in scientific education

Cristian Merino[1]*, Gabriela Pacheco[1], Andoni Arenas-Martija[2,3], Rukmini Becerra[4] and Jaime Solís-Pinilla[1]

[1]Laboratory Chemistry Education, Institute of Chemistry, Pontificia Universidad Católica de Valparaíso, Valparaíso, Chile, [2]Laboratory Geography Education, Institute of Geography, Pontificia Universidad Católica de Valparaíso, Valparaíso, Chile, [3]Centro Internacional Cabo de Hornos para Estudios de Cambio Global y Conservación Biocultural CHIC ANID/BASAL FB, Puerto Williams, Chile, [4]Pontificia Universidad Católica de Chile, Campus Villarrica, Villarrica, Chile

This research on Continuing Professional Development (CPD) was conducted through a meticulous and structured systematic review. Initially, four academic databases were explored, merging key terms in both Spanish and English, identifying 1,942 articles. After a preliminary screening, publications were discarded for various reasons: duplication, access restrictions, irrelevance, or exceeding the 10-year age limit, reducing the corpus to 722 articles. A subsequent content review pinpointed only 100 articles directly relevant to CPD studies. A final review assessed thematic depth, research status, and educational relevance, leading to further exclusion and a consolidated set of 81 publications ready for an in-depth review. These articles, selected through a rigorous process, represent current and significant contributions to CPD knowledge in the academic context. All information is organized following the PRISMA 2020 guidelines. The methodology employed ensures the relevance and timeliness of the selected literature, providing a solid foundation for future research in the field and for the design of a Professional Development Program. It is concluded that implementing a CPD program focused on scientific and socially relevant topics requires a strategic combination of pedagogical innovation, expert collaboration, technological integration, and research orientation. These elements prepare teachers to face contemporary challenges and position them as agents of change in their disciplines and communities.

KEYWORDS

continuing professional development, formative trajectory, systematic review, PRISMA 2020, designing curricula, science education

1 Introduction

The scientific community agrees that the world is rapidly moving toward a point of no return, the threshold of which points to a series of profound environmental changes in global ecology (OECD, 2023). As part of this global event, the science teaching community has insisted on promoting understanding, awareness and decision-making that is scientifically informed in related socio-scientific issues (Hestness et al., 2017). However, although this aspect forms part of the intentions and theories that guide science teaching, at the curricular level, the persistent traditional nature of science teaching continues to focus teacher training on highly specific content, with an emphasis on technical and universalist principles of knowledge (Solís-Pinilla et al., 2025). Given this, it is pertinent to move toward new ways of promoting scientific knowledge based on local meanings, worldviews, and cultures, so that

everyday issues become the driving force behind teaching, commitment, and participation (Rivera et al., 2025).

This demand calls for the creation of new spaces for teacher professional development that will support science educators in the transformation of their practices according to the new trends (Mcginnis et al., 2016). Therefore, Continuing Professional Development (CPD) for teachers is not only a necessity, but an imperative to ensure education that promotes scientific communication and engagement (Murphy et al., 2021). However, institutional resistances and the lack of resources limits the implementation of sustainable formative programs, deepening the disconnection between the scientific theory and the educational practice. This situation is aggravated by the lack of formative spaces that promote a holistic understanding of socio-scientific issues, in line with Sustainable Development Goals (SDG) 4 and 13.

This systematic review seeks to offer a clear and deep understanding of the State of the Art on CPD in relation to scientific education. This review focuses on understanding the existing literature related to CPD and highlighting its significance in the contemporary educational context. Through this literature review, the purpose is to (i) understand how CPD impacts teaching practices, teachers' perceptions, and student learning; (ii) identify contemporary trends and approaches in CPD and (iii) detect gaps that necessitate the exploration of innovative perspectives in the field.

To carry out this review, a systematic methodology has been adopted under the PRISMA 2020 protocol which guarantees the inclusion of multiple perspectives through 27 steps for the selection, identification, sifting, analysis and discussion of articles (Page et al., 2021). Both theoretical and empirical studies were reviewed, paying special attention to those that represent innovative approaches or proposals for teacher education improvement. Likewise, the main obstacles and challenges faced by teachers in their search for continuous education were identified, as well as the opportunities and available resources to overcome them.

This present systematic review is formulated from the main question: What are the trends, characteristics and challenges in CPD design for scientific education? The central objective is to analyze and summarize the existing literature to identify effective practices, challenges and opportunities in CPD for science teachers, looking to strengthen teaching and learning. This article is structured in three main sections: in the first section, the theoretical framework that supports the analysis is presented; in the second, the PRISMA 2020 methodology used to guarantee a rigorous address is described in detail; and in the third, key findings are discussed, including trends, innovative approaches and areas that need further research. With this, the purpose is to offer a comprehensive guide that will serve as a foundation for designing and implementing future teacher professional development programs.

2 Frameworks

The 2030 agenda (United Nations, 2015) for sustainable development considers 17 Sustainable Development Goals (SDG), thought to fight against various global issues and ensure economic development, social wellbeing and the protection of the environment for future generations urgency of integrating climate change into educational policy, focusing on communities and its possible SDG 4 aims for an integral and equal education, and the promotion of an active and critical citizenship, capable of participating in the transformation toward a more just and resilient society (Unterhalter, 2019).

2.1 Challenges of scientific education and teacher education

This context demands a situated teaching approach, enriched with practices promoting critical reflection on locally relevant topics including opportunities to explore the territorial and social implications of human activity.

One of the main gaps in scientific education, lies in the limited adaptation of the curricular and teacher training programs with interdisciplinary and contextual approaches. This deficit results from the persistence of standardized educational models that cannot effectively integrate the intersection between natural sciences, ethics and culture. The educational materials, frequently out of context, do not consider cultural and environmental specificities of the different locations, which hinders situated, relevant teaching for students (Wang and Liu, 2024).

To address this gap, a deep transformation in teacher professional development models is required. CPD programs must prioritize the incorporation of interdisciplinary and contextual approaches, creating pedagogical practices that connect scientific knowledge to the local and global reality. This change in paradigm will allow to train an active citizenship that is committed to the challenges of climate change, ensuring that teachers not only receive information but also develop competences to apply and transmit this knowledge to their educational communities.

Another tension emerges between the standardized educational material and the territorial nature of the teaching of sciences under a perspective of epistemic justice. Resources are often decontextualized from the reality of remote locations, without a cultural mark that will appeal to a local teaching of content and its environmental implications (Wang and Liu, 2024). In accordance with this, institutional resistances can prevent the distribution of resources and actions that, due to financial or ideological reasons can become an obstacle to the development of local sustainable development projects that can influence school communities (UNESCO, 2016).

In light of these obstacles, it is important to create a change of paradigm about the traditional teaching models, for the sake of promoting an education capable of developing a citizenship that is empowered and aware in the face of socio-scientific issues. Continuing Professional Development programs (CPD) are a main element to transform schools, given the leading role assigned to in-service teachers and their transference of practices to pre-service teachers (Redman et al., 2018), as both are encouraged to continue to develop competences, knowledge and attitudes that are up to date with scientific evolution.

Regarding these challenges and in preliminary fashion, it becomes necessary to consider a series of key elements that should be present in CPD programs, with the goal of achieving transformation of the educational paradigm in natural science and its intersectionality with SDGs 4 and 13. The integration of interdisciplinary approaches promotes an integral vision that connects natural, philosophical, cultural and social systems. It is fundamental then, to create practices with interaction that will lead to get to know the reality of the student (Solís-Pinilla et al.,

TABLE 1 Key concepts for search.

Professional development	Educational context
- Continuing Professional Development: Refers to education and training that professionals receive throughout their career.	- Scientific Education: Refers to the teaching and learning of sciences in general.
- Permanent Training Programs: Refers to educational programs designed to provide learning throughout their work life.	- Scientific Learning: Focused on the process by which students acquire knowledge and abilities in sciences.
- Continuous Training Programs: Similar to the above, but often referring to shorter or specific programs.	- Science Education: This term is often used to describe specific proposals related to the teaching of sciences.
- Disciplinary Integration: This concept is related to the combination of various disciplines or areas of knowledge with an educational approach.	

2024), which will allow the development of a holistic and integral thought about the complexity of the current environmental phenomena.

Practical experiences are a powerful tool to establish connections to real, local and global issues. In regard to science teacher education, communities of practice should allow to establish links with other teachers, researchers and experts in various topics of socio-scientific interest. It is fundamental for communities to have spaces to reflect on the reach of interdisciplinary knowledge and the strategies used at the local context (Admiraal et al., 2021). Regarding this last point, reflective spaces should allow the exploration of new methodologies, evaluate the effectiveness of different pedagogical approaches and contribute to the development of scientific education.

Because of the presented background, this present work aims to identify the available evidence in the theoretical-empirical research of the last 10 years about design principles and results on CPD in scientific teaching, considering its main areas of development from this basis, this work seeks to establish clear guidelines for future research, educational proposals and specific programs oriented toward CPD in scientific education. In a global context of accelerated transformations and complex challenges, ensuring continuing education of teachers is essential to promote a critical and active citizenship. As a society we have the responsibility to equip teachers with the necessary tools, knowledge and strategies to face the demands of the 21st century, addressing both the opportunities and the gaps passed on from traditional educational systems.

With all this background information, the question guiding this review is: What is the state of research on Teacher Training Programs (CPD) in Science Education? The proposed objective is to determine the state of development of this topic based on the available research, shedding light on the work carried out in the area and establishing guidelines for future teacher training processes.

3 Methodology

The adoption of a rigorous methodology is essential to guarantee the reliability and validity of any investigation. In this study, a systematic review was conducted, which is known for its ability to offer a complete and reliable summary of the existing literature on a particular topic, minimizing the bias through the transparency and reproducibility of the used methods (Table 1).

The systematic review presented in this manuscript focuses on the critical area of Continuing Professional Development (CPD) for teachers, particularly within the context of scientific education. This study aims to provide a comprehensive overview of the current state of CPD programs and their impact on teaching practices, teacher perceptions, and student learning. By adopting the PRISMA 2020 guidelines, the review ensures a rigorous and transparent methodology, allowing for the identification of key trends, challenges, and opportunities in the field. The research specifically examines how CPD programs can be designed to meet the evolving demands of contemporary educational contexts, emphasizing the importance of adapting to global challenges such as climate change and technological advancements (Table 2).

TABLE 2 Boolean operators used for search in databases.

Database	Boolean operator
WOS	((((((ALL = ("Continuous professional development")) OR ALL = ("Permanent training programs")) OR ALL = ("continuing training programs")) OR ALL = ("disciplinary integration")) AND ALL = ("Science education")) OR ALL = ("scientific learning")) OR ALL = ("scientific education"
SCOPUS	("Continuous professional development" OR "Permanent training programs" OR "continuing training programs" OR "disciplinary integration") AND ("Science education" OR "scientific learning" OR "scientific education")
ERIC	("Continuous professional development" OR "Permanent training programs" OR "continuing training programs" OR "disciplinary integration") AND ("Science education" OR "scientific learning" OR "scientific education")
Scielo	(Continuous professional development) OR (Permanent training programs) OR (continuing training programs) OR (disciplinary integration) AND (Science education) OR (scientific learning) OR (scientific education)

(a) Database Selection. The election of adequate databases is a crucial step in a systematic review. For this research we selected four widely known academic databases: Scopus, Web of Science (WoS), ERIC and Scielo. The first two were selected for their widespread prestige and rigorous indexing worldwide, ensuring global coverage of the subject matter. Eric was selected for its recognition as a specialized database in the field of education. Scielo is included in this review in search of territorially contextualized research, which allows for an approach to Latin American contributions. In this way, it is hoped to achieve broad access to research, considering factors of rigor and breadth to be covered. These databases are well

known for containing a vast amount of high-quality academic literature in various disciplines and fields of study.

(b) Inclusion criteria. To maintain the relevance and timeliness of the review, several criteria have been established for the inclusion of articles. Publications from the last 10 years have been considered, ensuring that the review reflects trends and advances in the field of study, responding to the need to address current debates in a reality that is undergoing rapid change (pandemic, new technologies, global warming, among others). In addition, priority was given to publications that made advances in the field of study, responding to the need to address current debates in a reality that is undergoing rapid change (pandemic, new technologies, global warming, among others). In addition, open access publications were prioritized to ensure that the results are accessible to a wide audience, in line with the key principles of verifiability, replicability, and transparency. Finally, only documents classified as "articles" were considered, excluding theses, books, conferences, and other types of publications. This was done to ensure the methodological rigor of the proposed review, avoiding problems of traceability and systematization when comparing studies.

(c) Systematization Methodology: PRISMA 2020. To ensure a systematic and coherent review process, the PRISMA 2020 model was used. Figure 1 provides a visual representation of this process. PRISMA, which stands for "Preferred Reporting Items for Systematic Reviews and Meta-Analyses," is an essential tool for researchers performing systematic reviews. According to Page et al. (2021), this model favors transparent documentation, allowing researchers to clarify the reasons for the review, provide details of their actions and present findings in a coherent fashion.

(d) Key Concepts for Search. The terms or concepts selected for the search are crucial, since they determine the pertinence and focus of the recovered articles. In this review, two main concept categories were identified.

The selection of databases, the clear definition of inclusion criteria and the adoption of a systematization methodology, such as PRISMA 2020, are essential to ensure quality and pertinence and allowing a more directed and relevant review. This methodology guarantees a literary review that is both thorough and coherent, capable of offering a solid basis for future research in the field. In regard to the inclusion and exclusion criteria that guided this search, they are presented in Table 3, which were applied to all 4 databases.

Given the amplitude of the databases and the extensive number of available publications, it is essential to carry out an efficient and coherent strategy to filter and select those articles that are really pertinent to the study. In this case, the research about Continuing Professional Development (CPD), the process was carried out in various stages according to the PRISMA 2020 protocol, described below.

3.1 Search strategy

Searches in four Academic databases were performed, combining two key concept families related to CPD, both in spanish and english. The goal of the search strategy used was to maximize the identification of relevant articles. This initial search resulted in the identification of 1942 articles.

3.2 Preliminary sifting

The next step involved a preliminary sifting process to exclude those articles that did not meet the basic criteria established for the review:

(a) Duplicates: A total of 41 documents are repeated in more than one database and therefore, were eliminated.

(b) Access type: 680 documents were excluded due to access restrictions, whether they were protected by copyright, required a subscription, or any other reason that will prevent its full review.

(c) Nature of the publication: It was determined that 268 of the documents were not research in the strict sense. This includes opinions, essays, commentaries, among others, that do not offer concrete research findings.

(d) Date of publication: A time limit of 10 years to ensure relevance and currency of the studies. As a result, 95 documents that are over this time limit were disregarded.

After this preliminary sifting, the analysis corpus was reduced to 722 articles that met the initial criteria.

3.3 Content evaluation sifting

With 722 articles in hand, a content review was carried out to determine thematic relevance. Key textual research summaries were searched for textual references that pointed to the relevance of the writings within the proposed objectives, the focus being to trace explicit links between CPD and science education that account for the influence of these training spaces. The objective was to identify and exclude those articles that, although initially looked relevant, did not directly address the topic of CPD or moved away from the context of interest of this research.

To ensure a high level of rigor and minimize bias during the selection and classification of articles, the researchers implemented a methodical approach in accordance with the criteria proposed by Solís-Pinilla et al. (2024). Initially, a random sample of works was subjected to detailed analysis by three researchers. Then, an in-depth discussion was held on the consistency, sensitivity, and accuracy of the classification criteria, which were applied independently and following an inductive methodology. This rigorous process culminated in the selection of a total of 100 articles that met the previously defined criteria.

3.4 Final review sifting

In the final stage, an in-depth review of the 100 articles was performed. The objective was to identify those articles that, although about CPD, did not offer the adequate detail or would derail from the main context of the research:

(a) Thematic depth: 5 documents that addressed CPD only superficially or tangentially were excluded. That is, articles that mention the implementation of CPD processes without it being the focus or object of study.

(b) Research Status: A study that was still under development, and therefore offered partial results. Studies that present incomplete and/or preliminary results, which is stated by the researchers themselves.

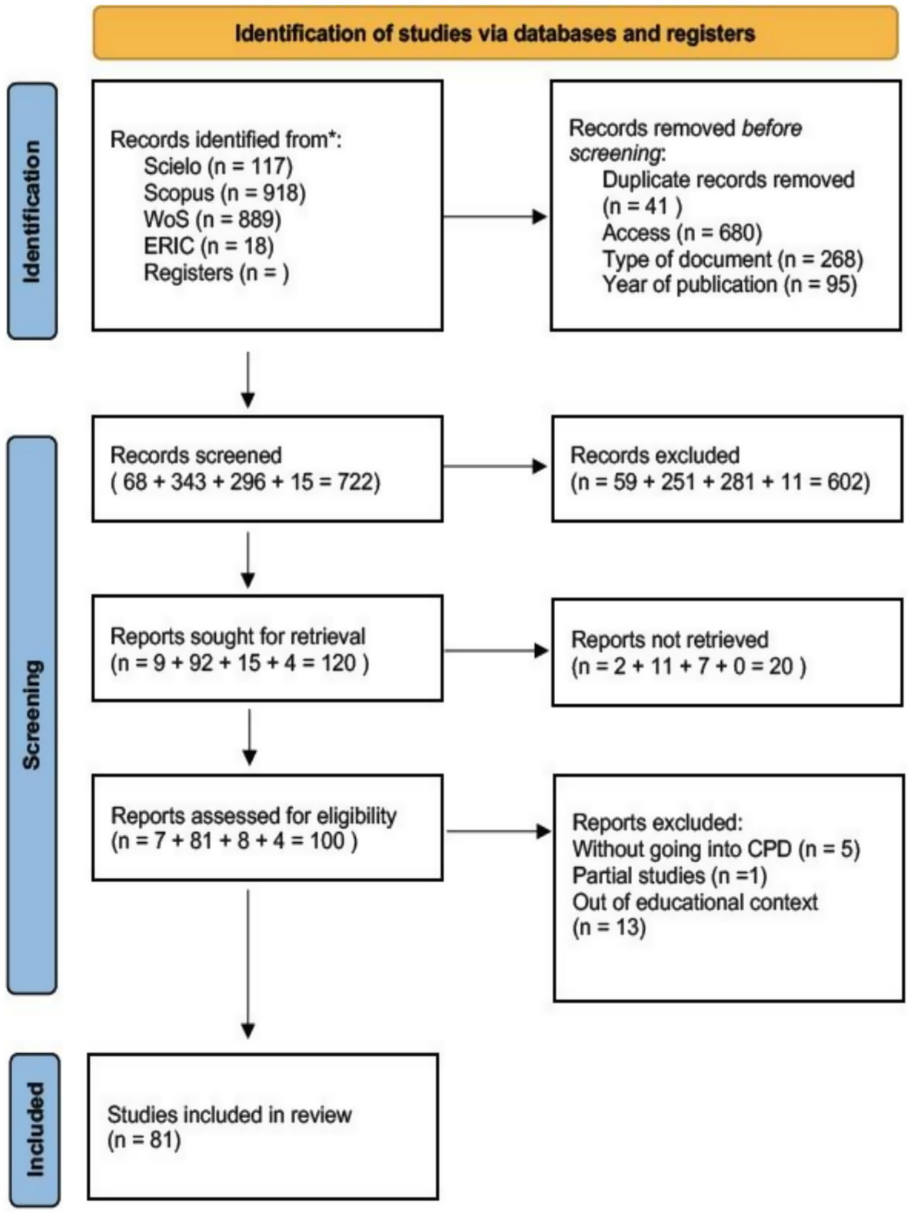

FIGURE 1
PRISMA 2020 on CPD diagram.

TABLE 3 Inclusion and exclusion search criteria.

Criteria	Inclusion criteria	Exclusion criteria
Year of publication	Between 2013 and 2023	Published before 2013
Document type	Articles	Editorials, conferences, theses, reviews, dissertations
Language	English and Spanish	Other Languages (Portuguese, Russian, German…)
Access type	Open Access	Subscription journals
Context	Teaching in different scenarios	Professional training in non-education areas

(c) Educational relevance: 13 documents, although addressing formative processes related to teaching, were not directly related to the formal education field, and therefore, were excluded. This responds to the proposed objectives, which aim to visualize what happens with CPD programs for teachers within the education system, whether K-12 or higher education.

Upon finalizing this methodic and structured review process, a final group of 81 articles on CPD was consolidated and ready for an exhaustive and detailed review. This methodology guarantees that only articles that are pertinent and offer a significant contribution to the area of interest are included.

In the case of Continuing Professional Training, the process resulted in a consolidated group of 81 articles that represent the more relevant and current contributions about the topic in the academic field.

4 Results

From the 81 articles included in the main review, several categories were established to understand how they are distributed and how they reflect various research criteria. An upward trend in research on teacher continuous professional development (CPD) can be observed over time. Table 3 presents the distribution of these publications from 2013 to 2023. Figure 2 illustrates this trend graphically, highlighting the marked increase in recent years. Specifically, 38.5% of the total publications have been produced in the last 3 years (2021–2023), indicating growing academic interest in this topic.

Regarding the geographic origin of the selected articles, a wide diversity is evident. For analytical purposes, the countries of origin were grouped by continent. As shown in Figure 3, Asia and Europe lead in contributions, accounting together for 48 out of the 81 publications, which represents nearly 60% of the total. North America and Africa follow with 10 publications each. South America is represented by only two publications, both originating from Chilean research. An additional point of interest is that, when disaggregated by country, the United States emerges as the leading contributor with 7 publications, followed by Indonesia with 6.

Eight documents lack a clearly defined geographical origin. Three of them belong to the "Online" category (Feldman-Maggor et al., 2022; Jocius et al., 2022; Bedford, 2019), as their research was conducted in virtual environments without specifying a physical location. Another three studies do not declare where the research was carried out (Sálica et al., 2020; Kennedy, 2014; Yerushalmi and Eylon, 2013). Two further articles fall into the "Not Applicable" category (Pečiuliauskienė et al., 2023; Pečiuliauskienė and Kaminskienė, 2022), as they are theoretical or conceptual reviews where geographical context is not relevant.

The selected articles were also categorized according to their application context. As shown in Table 4, the majority of CPD programs and associated reflections are situated within the school system. The "schoolteacher" category accounts for 51 out of the 81 publications, encompassing research in primary, secondary, or both educational levels. The second most common context is "higher education," comprising 10 articles focused on CPD programs implemented in universities. "Cross-sectoral" studies (5 publications) involve training activities shared between school and university educators.

Four publications fall under the "theoretical framework" category, which includes studies analyzing the characteristics and implications of CPD programs. Additionally, there are two publications on CPD initiatives with preschool teachers and four that explore collaborative professional development efforts involving both teachers and other educational professionals, such as principals or support staff. The category "English teachers" includes five studies, which were grouped separately due to their distinct disciplinary focus and to facilitate comparative analysis within CPD research.

When observed in percentage terms (see Figure 4), school-based research represents 63% of the selected studies, while higher education-focused investigations constitute 12%.

Although the literature search was primarily oriented toward natural sciences education, not all selected studies belong exclusively to this field. This inclusive approach allowed for a broader understanding of CPD experiences with interdisciplinary dimensions. Of the 81 educational studies reviewed, 49 focus specifically on science teaching, STEM education, or science-related instructional contexts (see Table 4). The remaining 32 publications relate to other areas within education, such as English language instruction, educational

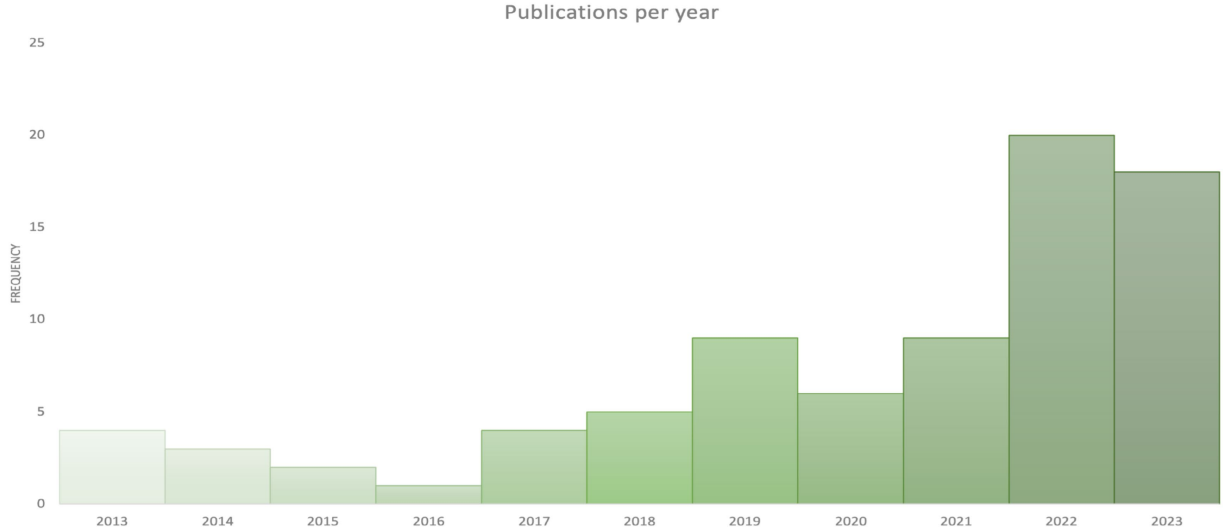

FIGURE 2
Publications per year.

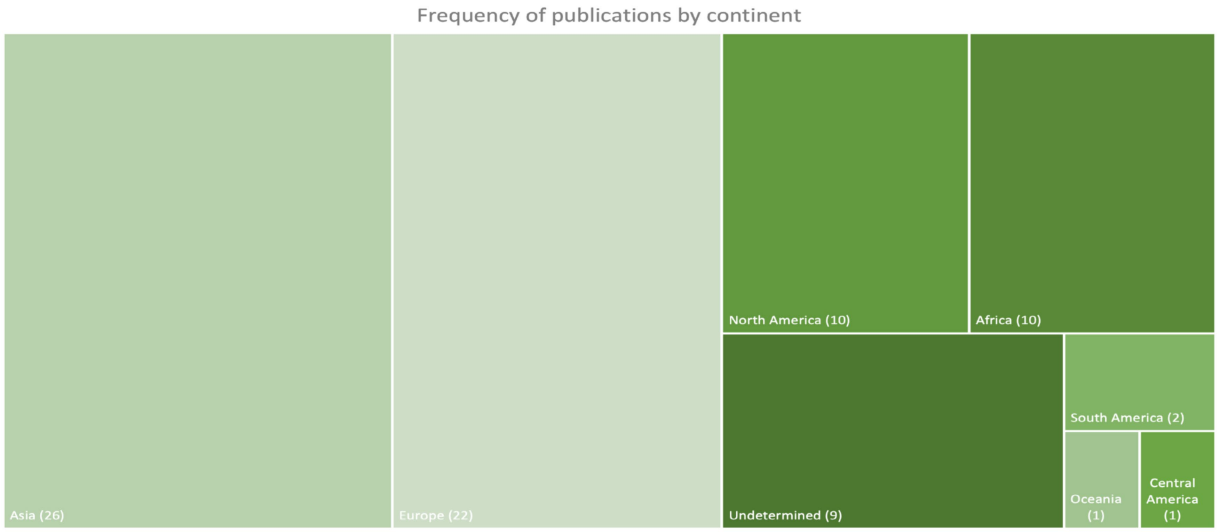

FIGURE 3
Frequency of publications by continent.

TABLE 4 Distribution of investigations in the scientific education field.

Research context	Frequency	Natural sciences investigations
Higher education	10	5
Cross-sectoral	5	5
Theoretical Framework	4	3
School teachers	51	36
English teachers	5	0
Preschool teachers	2	0
Teachers and Education Professionals	4	0

management, teaching methodologies, or general pedagogical innovations.

Table 4 reveals an evident imbalance in the distribution of research efforts, with a predominant focus on school and higher education contexts. This trend may reflect a perception that these levels have the most direct influence on students' scientific education. Conversely, the limited research on preschool and English teachers suggests a gap that represents a valuable opportunity for future exploration. The dominance of studies centered on natural sciences in diverse contexts reinforces the centrality of this discipline in science education. However, the absence of natural sciences research in certain categories (e.g., English and preschool teachers) may limit the integration of interdisciplinary or cross-curricular approaches. Notably, cross-sectoral research shows a strong emphasis on natural sciences, which may indicate a preference for applying scientific knowledge to real-world problems that transcend formal educational boundaries (Table 5).

In conclusion, scientific education research is primarily concentrated in formal educational levels—namely, school and higher education. While the prominence of natural sciences underscores their transversal relevance, the identified gaps in underexplored contexts (e.g., preschool and English education) highlight the need to diversify research efforts. Expanding the scope of CPD studies to include these less-represented areas, as well as theoretical or general professional contexts, would contribute significantly to enriching the landscape of science education research.

5 Analysis and discussion

Following a detailed analysis of the 81 documents selected through the PRISMA 2020 protocol, this section provides a state-of-the-art account of Continuous Professional Development (CPD) for teachers, considering the contexts in which the studies were conducted. A comprehensive content analysis was carried out to identify key themes, recurrent patterns, and emergent challenges. This discussion presents the most salient characteristics of CPD initiatives, their shared features, and the main difficulties encountered in implementation.

5.1 Common characteristics of continuous professional development

From the corpus of 81 documents, several core features emerge as critical for the success of CPD initiatives. These features are discussed in the following subsections.

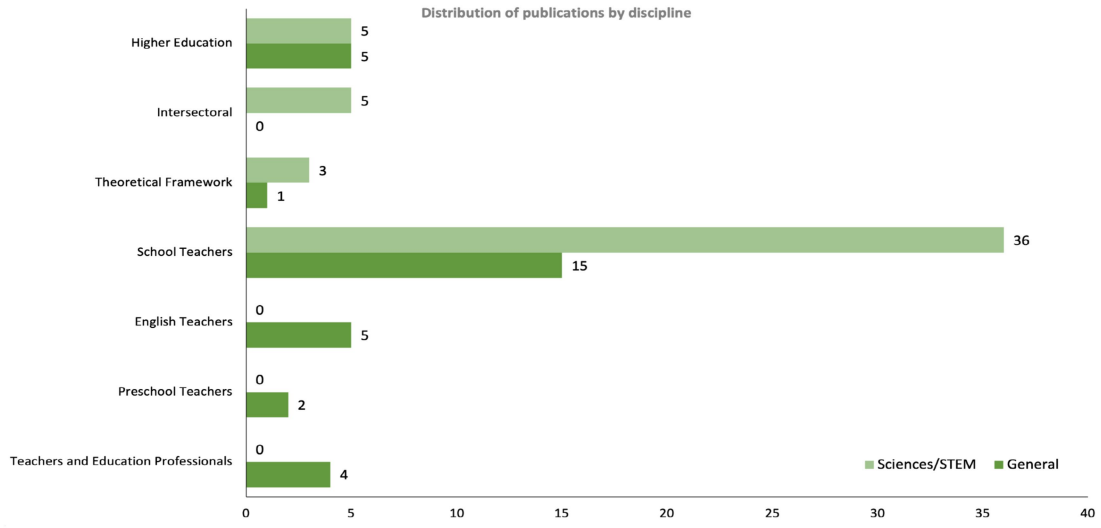

FIGURE 4
Distribution of publication according to disciplinary context.

5.1.1 The teacher as a learner

A recurring theme is the conceptualization of the teacher as a lifelong learner. Teachers must actively engage in learning processes to improve their teaching practices and better support student learning (Hardré et al., 2013; Qazi and Mtenzi, 2023; Murphy et al., 2015). This includes experimenting with new resources (Pombo and Marques, 2021) and assuming learner roles in playful, computational, or game-based environments (Gravel et al., 2022). Teachers benefit from intellectual exchanges with colleagues in communities of practice, as documented in Martins-Loução et al. (2019), which foster a reflective and collaborative culture.

5.1.2 Contextualized CPD programs

Effective CPD programs are tailored to the specific needs of participating teachers (Abakah et al., 2022; Brouwer et al., 2022; Mohammadi and Moradi, 2017). A deep understanding of the teachers' contexts—including school culture, student characteristics, and administrative barriers—is essential for relevance and impact (Tang et al., 2022; Harron et al., 2022). Needs assessment tools such as surveys, interviews, and classroom observations are frequently employed to identify these contextual elements (Zúñiga-Meléndez et al., 2020; Qablan, 2019).

5.1.3 Collaborative work

Collaboration is consistently recognized as a foundational element of effective CPD. Collaborative dynamics improve pedagogical practice, enhance professional capacity, and foster knowledge sharing (Ghani et al., 2022; Dinh and Huong, 2023). Collaboration can take multiple forms, including peer interaction, school-university partnerships (González-Weil et al., 2013), virtual communities (Alrubian, 2022), and interdisciplinary teams (Perl-Nussbaum et al., 2023). Facilitating such collaboration requires intentional program design, including structured group discussions and shared reflection activities (Philander and Botha, 2021; Alzhrani, 2023).

5.1.4 Long-term engagement

Sustained participation over time is a key factor in effective CPD (Brouwer et al., 2022; Haagen-Schützenhöfer and Joham, 2018). Programs that extend beyond short-term interventions—such as follow-up sessions and embedded support—are more likely to impact teaching practices (Heppt et al., 2022; Bernard and Dudek-Różycki, 2020).

5.1.5 Reflective practice

Reflection is a critical dimension of CPD success (Murphy et al., 2015; Dinh and Huong, 2023; Alzhrani, 2023). Programs should foster structured opportunities for self-assessment and critical thinking. Both individual and collective reflections have been shown to enhance professional learning and agency (Pischetola et al., 2023; Gericke and Torbjörnsson, 2022; Heppt et al., 2022).

5.1.6 Heterogeneous participation

Inclusion of diverse actors—across educational levels, disciplines, and roles—strengthens CPD outcomes (Robbins et al., 2021; Finch et al., 2021). External mentors can mitigate teacher anxiety, promote trust, and foster professional confidence (Hobson and McIntyre, 2013; Bentall and Hunt, 2022). Collaborative learning across institutional boundaries encourages interdisciplinary integration and mutual growth (Sharp et al., 2022).

5.1.7 Cross-sectoral coordination

Institutional support is fundamental for the success of CPD programs. Active involvement of school leaders and the alignment of CPD goals with school priorities contribute to program sustainability (Uzorka et al., 2023; Körkkö et al., 2022). A culture that values teacher expertise and promotes organizational learning is key (McChesney and Aldridge, 2021; Gutierez, 2019).

5.1.8 Updated and relevant content

CPD must incorporate up-to-date content aligned with current educational demands, such as technological integration and sustainable

TABLE 5 Search results in SCOPUS, WOS, ERIC and Scielo databases.

No.	Authors and Year	Title	Context
1	Loughlin et al. (2023)	Barriers and levers driving change in a STEM science subject in the Australian higher education sector: a focused study.	Change in a STEM science subject to higher education professors, with a focus on joint work.
2	Bravo González and Galdames (2023)	Peeking behind the curtain: unboxing science teacher educators' subjectivities in continuous professional development programs.	Experiences of 12 teacher educators in a continuing training program in higher education
3	Mena et al., 2020	Una nueva mirada: sistema para el trabajo metodológico en disciplinas docentes complejas [A new perspective: a system for the methodological work in complex teaching disciplines].	Participation of 33 teachers that teach complex disciplines in the context of higher education.
4	Biswas et al., 2022	Institutionalizing evidence-based STEM reform through faculty professional development and support structures.	Training of 41 STEM university professors and support in the context of a reform process.
5	Negassa and Engdasew, 2017	The impacts and challenges of pedagogical skills improvement program at Adama Science and Technology University.	Pedagogical abilities improvement program for 496 university professors from various areas.
6	Pischetola et al. (2023)	Enhancing teacher collaboration in higher education: the potential of activity-oriented design for professional development.	Sixty-four higher education teachers in a technology-use program with a design oriented toward the activity.
7	Delgado et al. (2021)	Lessons in the Use of Technology for Science Education during COVID-19 Age under a Teachers' Collaboration Cluster.	Experiences of university STEM teachers, implementing online courses during the pandemic.
8	Bedford (2019)	Using social media as a platform for a virtual professional learning community.	Twenty-two mentors in doctoral program in a CPD experience using a social network platform for interaction.
9	Brouwer et al. (2022)	Effect of a person-centered, tailor-made, teaching practice-oriented training program on continuous professional development of STEM lecturers.	Sixty-one university lecturers training in STEM areas with a focus on student-centered teaching, and evaluation to 5 of them 5 years later.
10	Uzorka et al. (2023)	Modern technology adoption and professional development of lecturers.	Experiences of 89 university lecturers in CPD with a focus on the use of technology in teaching.
11	Robbins et al. (2021)	The NHGRI Short Course in Genomics: energizing genetics and genomics education in classrooms through direct engagement between educators and scientists.	Educators from different levels participating in a short course that seeks to close the gaps in the teaching of genetics. Follow up for 5 years.
12	Marques et al. (2015)	Science teaching strategies developed in an online community of practice: A case study.	Five teachers and three researchers working in an online community on science teaching.
13	Ralls et al. (2020)	'Across the Divide': Developing Professional Learning Ecosystems in STEM Education.	Focus on the university-school relationship, with 8 participants from both parts for the cooperation and creation of links in STEM education.
14	González-Weil et al. (2013)	Building encounter domains to problematize secondary science teachers' practice: Incorporating the action-research model as a continuous development plan.	Seventeen teachers and a university team in a teacher project that conform, together with a group of university researchers, a space of encounter around scientific education.
15	Hardré et al. (2013)	Teachers in an Interdisciplinary Learning Community: Engaging, Integrating, and Strengthening K-12 Education.	Eleven school teachers and six university mentors in a learning and practice community at the university.
16	Tang et al. (2022)	The impact of teachers' professional development in science pedagogy on students' achievement: evidence from TIMSS 2019.	Review of standardized test to students in 142 schools to analyze the importance of CPD.
17	Pečiuliauskienė and Kaminskienė (2022)	The Implementation of Cognitively Challenging Tasks: The Role of Science Teachers' Professional Development and Teaching Experience.	Review of TIMSS results in students and a questionnaire to TIMSS teachers in relation to the CPD content.

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TABLE 5 (Continued)

No.	Authors and Year	Title	Context
18	Pečiuliauskienė et al. (2023)	Science teachers' collaborative innovative activities: the role of professional development and professional experience.	Review of TIMSS results in students and a questionnaire to TIMSS teachers in relation to the CPD content.
19	Kennedy (2014)	Understanding continuing professional development: the need for theory to impact on policy and practice.	Theoretical framework proposal for the model analysis of CPD.
20	Zúñiga-Meléndez et al. (2020)	Diagnosis of Training Needs of Teachers of Biology, Chemistry, Physics, and Mathematics, in Disciplinary, Pedagogical Areas, and Use of Technologies to Promote Scientific Thinking Skills	Teachers of different Levels: 72 mathematics teachers and 88 science teachers answer a survey on formative needs.
21	Finch et al. (2021)	Luminous Science: Teachers Designing for and Developing Transdisciplinary Thinking and Learning	Six teachers and two engineers in educational technology in a co-design workshop about curricular integration.
22	Harron et al. (2022)	Maker Math: Exploring Mathematics through Digitally Fabricated Tools with K–12 In-Service Teachers	Nine mathematics teachers in CPD about the use of digital manufacture tools and its application.
23	Sharp et al. (2022)	Creative Science Through Inquiry: Improving Teacher Self-efficacy and Outcome Expectancy Through Adaptable, Mystery-based Professional Development	Thirty-nine science and mathematics teachers, mainly secondary: participation in laboratory activities workshop.
24	McChesney and Aldridge (2021)	What gets in the way? A new conceptual model for the trajectory from teacher professional development to impact	Review of models that relate professional training with the impact it has on students.
25	Gutierez, 2019	Teacher-practitioner research inquiry and sense making of their reflections on scaffolded collaborative lesson planning experience	Primary STEAM teachers in CPD about scaffolding and collaborative planning.
26	Sormunen et al. (2014)	Finnish Science Teachers' Views on the Three Stage Model	Thirty secondary science teachers participating of PROFILE meetings offer their opinion on continuing education.
27	Abakah (2023)	Teacher learning from continuing professional development (CPD) participation: A sociocultural perspective	Sixteen senior secondary teachers in general about CPD and challenges in its implementation.
28	Abakah et al. (2022)	Continuing Professional Development (CPD) Practices Among Basic School Teachers in the Central Region of Ghana	Secondary school teachers (456) participating of a CPD and its learning needs.
29	Tzovla et al. (2021)	Investigating In-service Elementary School Teachers' Satisfaction with Participating in MOOC for Teaching Biological Concepts	Primary school teachers (127) in a course about biological concepts in the midst of the pandemic's second wave.
30	Julia et al. (2023)	Developing Elementary School Teacher's Professional Competence in Composing Traditional Songs: An Action Research in Indonesia	Fifteen Primary music teachers in training for the teaching of traditional music and its consequences.
31	Jusuf et al. (2019)	Strengthening teacher competency through ICARE approach to improve literacy assessment of science creative thinking	Twenty-one primary teachers in a program for the strengthening of creative thinking abilities.
32	Murphy et al. (2015)	Changing practice: An evaluation of the impact of a nature of science inquiry-based professional development program on primary teachers	Seventeen Primary school teachers in a program on science inquiry: 2-year CPD program.
33	Qablan, 2019	Effective professional development and change in practice: The case of Queen Rania Teacher Academy science network	Eighteen science teachers for grades 6 through 8, participating from a CPD experience for 3 years.
34	Kariyev et al. (2022)	Development of primary school teachers' skills to accompany pupils in projects and research	Fifty-seven primary teachers participating in courses with a focus on supporting research and projects.

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TABLE 5 (Continued)

No.	Authors and Year	Title	Context
35	Fernández-Limón et al. (2018)	The role of non-formal contexts in teacher education for STEM: the case of horno3 science and technology interactive center	Forty-nine various level teachers to improve the quality of STEM education with a focus on the use of the museum.
36	Sálica et al. (2020)	"Modelos de conocimiento didáctico del contenido científico y tecnológico en docentes de Química y Física" [Didactic knowledge models of scientific and technological content in Chemistry and Physics] "Tecné, Episteme y Didaxis: TED	Six Pre-service and in-service teachers in didactics training workshop for the curricular integration of ICTs in science teaching.
37	Jocius et al. (2022)	Building a Virtual Community of Practice: Teacher Learning for Computational Thinking Infusion	Primary and secondary teachers (151) in a project for the integration of computational thinking.
38	Qazi and Mtenzi, 2023	The conceptual framing, design, and development of mobile-mediated professional development for primary mathematics teachers	Mathematics teachers (328) in primary levels in a continuing training experience mediated by mobile devices (pilot study).
39	Ghani et al. (2022)	Developing Teaching Practice in Computational Thinking in Palestine	Thirty-eight teachers in a CPD on computational thinking with a focus on the classroom and challenges encountered.
40	Pombo and Marques, 2021	Guidelines for Teacher Training in Mobile Augmented Reality Games: Hearing the Teachers' Voices	Fourteen teachers of different subjects in CPD about mobile augmented reality games for teaching.
41	Bentall and Hunt, 2022	The value of third sector organizations' provision of global learning CPD in English schools	Eight leader teachers in global learning CPD program given by a third sector organization.
42	Enache et al. (2019)	Present and Perspectives in the Teachers' Continuous Professional Training in Romania	One hundred school teachers speak and reflect about CPD experiences.
43	Ige and Jita, 2020	Instructional practices of science teachers in rural learning ecologies	Five rural school teachers in a CPD program developed by themselves with a focus on teacher collaboration.
44	Joubert and Kenny, 2018	Exploring the Perspectives of Participants of Two Mathematics Professional Development Courses in South Africa: Personal, Professional and Community Outcomes	Four mathematics teachers evaluate their perceptions about CPD of mathematical thinking after 2 years.
45	Philander and Botha, 2021	Natural sciences teachers' continuous professional development through a Community of Practice	Ten Natural Science teachers in a rural school participating from a learning community.
46	Gericke and Torbjörnsson (2022)	Supporting local school reform toward education for sustainable development: The need for creating and continuously negotiating a shared vision and building trust	Fifteen School teachers in a school reform program on sustainable development. Information is gathered about intervention.
47	Walan and Gericke (2023)	Transferring makerspace activities to the classroom: a tension between	Eleven STEM school teachers in a CPD program on
	Gericke and Torbjörnsson (2022)	two learning cultures	makerspace and its transference into the classroom.
48	Unver et al. (2023)	The Readiness of Stakeholders in the Scientific Inquiry-Supported Mentoring Project	Twenty teachers and six mentors in CPD with online mentorship on scientific research.
49	Dinh and Huong (2023)	Teacher-practitioner inquiry in professional development: a case of adaptation and resistance to genre-based systemic functional linguistic as a new writing instruction.	School and university teachers (120) in an education program on instruction of linguistic writing in a teacher-professional research.
50	Budiastra et al. (2020)	The effectiveness of video-based interaction on professional science teachers to improve elementary school students' achievements.	Thirty-six teachers and 432 students in a CPD for science teachers with a focus on video-based interaction.
51	Alrubian (2022)	Adopting BuddyPress Platform as an Online Community of Practice for Professional Development.	Twelve computer teachers form a learning community (COP) online and share their work.
52	Haagen-Schützenhöfer and Joham (2018)	Professionalizing physics teachers in doing experimental work.	Thirty-nine Science and Mathematics teachers participating in a program. Students are surveyed about the use of experiments in the classroom.

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TABLE 5 (Continued)

No.	Authors and Year	Title	Context
53	Wang and Zhang, 2023	Understanding teachers' online professional learning: A "community of inquiry" perspective on the role of Chinese middle school teachers' sense of self-efficacy, and online learning achievement.	Teachers (439) in an online learning experience through a research community. Their perceptions are analyzed and related to auto-efficacy.
54	Gravel et al. (2022)	"Weebles wobble but they also commit to lifelong relationships": teachers' transdisciplinary learning in computational play.	Twelve STEM teachers in CPD program with a focus on Computer games with the participation of students and workshops.
55	Holbrook et al. (2014)	Identifying Teacher Needs for Promoting Education through Science as a Paradigm Shift in Science Education.	Twenty-seven teachers in science areas in the process of building and validating an instrument that will bring to light the needs of teachers.
56	Chan and Erduran (2023)	The Impact of Collaboration Between Science and Religious Education Teachers on Their Understanding and Views of Argumentation.	Three pairs of Science and Religion teachers in the context of a research project promoting collaboration: CPD of five argumentation workshops with Interdisciplinary application strategies.
57	Hobson and McIntyre (2013)	Teacher fabrication as an impediment to professional learning and development: the external mentor antidote.	Forty-seven teachers and nineteen mentors in external tutoring program linked to the science teaching in secondary education.
58	Peleg et al. (2017)	Teachers' views on implementing storytelling as a way to motivate inquiry learning in high-school chemistry teaching.	Fourteen chemistry teachers in CPD focused on including drama and performance in teaching.
59	Perl-Nussbaum et al. (2023)	Interdisciplinary dialogic argumentation among out-of-field and in-field physics teachers.	Three Physics teachers from inside and outside the field working together to build knowledge through interdisciplinary argumentation.
60	Lunde et al. (2016)	Exploring the Negotiation of the Meaning of Laboratory Work in a Continuous Professional Development Program for Lower Secondary Teachers.	Fifteen secondary teachers in CPD program about laboratory work with a focus on meaning negotiation.
61	Yerushalmi and Eylon, 2013	Supporting teachers who introduce curricular innovations into their classrooms: A problem-solving perspective.	Three groups of Physics teachers in workshops about cooperative personalization in classroom innovations.
62	Feldman-Maggor et al. (2022)	Development and evaluation of an online course on nanotechnology for the professional development of chemistry teachers.	Ninety-five Chemistry professors participating in an online nanotechnology course.
63	Dolfing et al. (2021)	Strategies to support teachers' professional development regarding sense-making in context-based science curricula	Six Science teachers in a collaboration environment to design science units based on context.
64	Bernard and Dudek-Różycki, 2020	The impact of professional development in inquiry-based methods on science teachers' classroom practice	Ninety-five Science teachers in secondary schools that participated in a IBSE course about inquiry. Their practices are evaluated in time.
65	Martins-Loução et al. (2019)	Inquiry-based science learning in the context of a continuing professional development program for biology teachers	Thirty-four science teachers in secondary schools in CPD for scientific education with a focus on IBSE.
66	Köksal and Southerland (2018)	What is Value of Reform-oriented in-service Teacher Development Attempts on Inquiry Teaching for Pedagogically Discontented Science Teachers? An Expectancy-value Perspective	Three Science teachers with Levels of pedagogical dissatisfaction in a CPD teaching program based on research. Their views are gathered.
67	Kucuk et al. (2023)	Expressed Willingness of STEM Teachers to Teach Engineering	STEM teachers (434) in a study about the disposition to offer engineering courses and the reasons within the framework of the beginning of a STEM CPD online program.
68	Arslan et al. (2022)	The Effects of Group Mentoring on Teachers' Classroom Activities: An Instrumental Case Study	Three Chemistry teachers at the secondary level, in a group. Tutoring program.
69	Asiyah et al. (2021)	The effect of professional development, innovative work and work commitment on quality of teacher learning in elementary schools of Indonesia.	One hundred Primary school teachers that participated in CPD experiences answer survey and review concepts around a CPD in primary education.

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TABLE 5 (Continued)

No.	Authors and Year	Title	Context
70	Heppt et al. (2022)	Professional development for language support in science classrooms: Evaluating effects for elementary school teachers.	Thirty-two Primary teachers working on development of linguistic abilities for the teaching of science.
71	Alzhrani, 2023	Liberating an EFL teacher as an activist teacher professional identity in MA TESOL classrooms.	Ten English teachers studying a masters, encouraged to design their own CPD course and evaluate others.
72	Drajati et al. (2023)	Exploring the Impact of TPACK-based Teacher Professional Development (TPD) Program on EFL Teachers' TPACK Confidence and Beliefs.	Ten English teachers in a program to improve the inclusion of technology in the classroom (TPACK): measurement of beliefs and trust.
73	Utami et al. (2019)	Continuing Professional Development and teachers' perceptions and practices - A tenable relationship.	Six English teachers participating in a CPD, the aligning of their perceptions and practices is measured. Each one represents a different type of participation in CPD.
74	Mohammadi and Moradi, 2017	Exploring Change in EFL Teachers' Perceptions of Professional Development.	Eighty-six non-native english teachers in CPD course. The experience is evaluated through their opinions.
75	Msamba et al. (2023)	The Impact of In-Service Education and Training on Teachers' Learning: Perspectives from English Foreign Language Teachers in Tanzania.	Twenty-one English teachers in a program to strengthen their teaching within a competence-based study plan.
76	Saxena and Chiu, 2022	Developing Preschool Teachers' Computational Thinking Knowledge, Attitudes, Beliefs, and Teaching Self-Efficacies: A Curriculum-Based Professional Development Program.	Twenty-five Preschool teachers in CPD with a focus on computational thinking.
77	Wang et al. (2024)	Creating conditions for Chinese kindergarten Teacher's professional development in play-based setting.	Two educators and their students in CPD in an educational experiment mode: the use of the imaginary game to teach scientific concepts in the same preschool.
78	Körkkö et al. (2022)	Developing teacher in-service education through a professional development plan: modeling the process.	Sixteen teachers and ten school principals. Professional development plans where everyone participates in the design are analyzed.
79	Damkuviene et al. (2023)	Education Professionals' Cooperative Learning for the Development of Professional Capital.	Schools (189) in relation to the results of a cooperative learning program in a long-term continuing training program.
80	Wolde, 2021	The role of continuous professional development in improving secondary school teachers' teaching and learning competencies to deliver quality education in Ethiopia: A case of secondary school.	One School in CPD with a focus on three areas: continuous evaluation of students, active learning, dialog between professionals. The process is evaluated.
81	Akinyemi et al. (2019)	Allocation of time in communities of practice: A strategy to enhance continuing professional teachers' development of high school teachers.	Ten schools in a study about the amount of time dedicated to CPD.

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development (Uzorka et al., 2023; Gericke and Torbjörnsson, 2022). Teachers are more likely to engage when content is perceived as relevant and applicable (Abakah et al., 2022; Kariyev et al., 2022).

5.1.9 Trust and empowerment

Trust among participants, and between teachers and facilitators, is essential for meaningful engagement (Drajati et al., 2023; Ige and Jita, 2020). Trust enhances collaboration, reduces resistance to change, and increases confidence in implementing innovative practices (Martins-Loução et al., 2019; Joubert and Kenny, 2018).

5.1.10 Methodological diversity

CPD initiatives benefit from a wide variety of formats, such as modular content, synchronous/asynchronous sessions, hands-on workshops, and collaborative projects (Pischetola et al., 2023; Murphy et al., 2015). Mixed-method evaluations highlight the effectiveness of combining diverse instructional strategies (Biswas et al., 2022; Kariyev et al., 2022).

5.1.11 Application to practice

Successful CPD must translate into improved classroom practice. Action research, co-design methodologies, and embedded support systems have proven effective in enabling teachers to adapt innovations to their unique contexts (Chan and Erduran, 2023; Wang et al., 2024; Sharp et al., 2022). Applicability also requires sustained reflection and teacher autonomy (Kennedy, 2014; Damkuviene et al., 2023).

5.2 Difficulties and gaps in the implementation of continuous professional development

Despite the numerous benefits reported in the literature, various barriers hinder the development, implementation, and sustainability of CPD initiatives. The following subsections summarize the most recurrent obstacles.

5.2.1 Lack of time

Time constraints are among the most frequently cited barriers to CPD (Pischetola et al., 2023; Bernard and Dudek-Różycki, 2020; Bedford, 2019). Teachers report difficulty in balancing instructional duties, administrative tasks, and professional development (Alzhrani, 2023; Ghani et al., 2022). These constraints impact the organization of collaborative meetings, reflective discussions (Bravo González and Galdames, 2023), and the implementation of changes (Loughlin et al., 2023). The issue is exacerbated in low-and middle-income countries, where work overload is more prevalent (Qazi and Mtenzi, 2023). Suggested solutions include offering flexible scheduling, workload reduction, and financial support to enable participation, such as subsidies or covering substitute teacher costs (Biswas et al., 2022; Ralls et al., 2020).

5.2.2 Lack of resources

Limited access to pedagogical materials, technology, infrastructure, and technical support is a persistent barrier (Philander and Botha, 2021; Saxena and Chiu, 2022). Programs requiring significant technological input face higher implementation costs (Walan and Gericke, 2023), and schools often lack the financial means to support such initiatives (Qablan, 2019). In some cases, external data sources (e.g., TIMSS) are unavailable or insufficient for measuring long-term CPD impacts (Tang et al., 2022). Mobile technologies and low-cost interventions have been proposed to reach teachers in resource-constrained environments (Qazi and Mtenzi, 2023).

5.2.3 Limited commitment and disposition

Teachers may exhibit resistance to CPD when they feel detached from its relevance or when participation is perceived as imposed (Bedford, 2019). Factors such as diminished professional prestige (González-Weil et al., 2013), low self-efficacy, and cultural attitudes toward innovation can undermine engagement (Perl-Nussbaum et al., 2023; Hobson and McIntyre, 2013). Resistance may stem from discomfort with unfamiliar methodologies or lack of confidence in adopting new practices (Walan and Gericke, 2023; Haagen-Schützenhöfer and Joham, 2018). To address this, CPD programs must align with teachers' needs and foster trust, transparency, and teacher agency (Körkkö et al., 2022; McChesney and Aldridge, 2021).

5.2.4 Coordination and institutional support

Institutional support is often inadequate, limiting the effectiveness of CPD initiatives (Enache et al., 2019; Pischetola et al., 2023). A lack of administrative coordination and school-level leadership can result in high dropout rates and restricted implementation of learned practices (Jocius et al., 2022; Heppt et al., 2022). Support from colleagues, school leaders, and parents is also essential for fostering a CPD culture (Saxena and Chiu, 2022; Drajati et al., 2023). Schools must promote a professional culture that values teacher expertise, provides methodological support, and facilitates collaboration (Martins-Loução et al., 2019).

5.2.5 Work overload

High workloads are a major obstacle to CPD engagement. Teachers often struggle to find time and energy to participate in professional development due to dense curricula, administrative burdens, and complex technologies (Zúñiga-Meléndez et al., 2020; Chan and Erduran, 2023). Language barriers, particularly in multilingual settings, add to the cognitive load (McChesney and Aldridge, 2021). Institutional actions such as reducing teaching loads and providing structured time for CPD are critical (Biswas et al., 2022).

5.2.6 Limited applicability and contextualization

CPD programs may not always translate into effective classroom practices if they lack contextual relevance. Factors such as class size, inadequate follow-up, and limited resources hinder applicability (Negassa and Engdasew, 2017; Abakah, 2023). Teachers may also perceive new methodologies as incompatible with student needs (Drajati et al., 2023; Ralls et al., 2020). Effective CPD should incorporate contextual variables, provide ongoing support, and align content with the teaching environment (McChesney and Aldridge, 2021).

5.2.7 Insufficient understanding of CPD content

Barriers can also be intrinsic, arising from misunderstandings of CPD goals or poor communication regarding program structure

(Murphy et al., 2015; Abakah et al., 2022). Top-down approaches that exclude teacher input often result in disengagement and limited impact (Pischetola et al., 2023). Programs must be clearly structured, adequately explained, and co-designed with educators to ensure their relevance and effectiveness.

5.2.8 Lack of recognition and incentives

The absence of formal or informal recognition, as well as limited financial or career-related incentives, can demotivate participation (Utami et al., 2019; Qazi and Mtenzi, 2023). Teachers often report that CPD is undervalued by their institutions or society at large (González-Weil et al., 2013; McChesney and Aldridge, 2021). Recognition mechanisms—monetary or symbolic—should be embedded in CPD design to reinforce participation and professional growth.

5.2.9 Lack of recognition and incentives

Continuing with intrinsic barriers, the lack of recognition and incentives is an obstacle in continuous training (Pischetola et al., 2023; Utami et al., 2019; Mohammadi and Moradi, 2017). Some teachers may not be motivated to participate in CPD due to precisely the lack of incentives and the relevance of the programs (Qazi and Mtenzi, 2023). A way of encouraging teachers is through economical aspects since the lack of financial motivation makes continuous training difficult (Negassa and Engdasew, 2017). Recognition is not only financial. For example, González-Weil et al. (2013) noted that some teachers proposed as a limiting factor the discreditation of the teaching role at the society level, which accounts for other ways in which teachers wish to be recognized, and that has to do with the respect to the teaching figure as an education professional (McChesney and Aldridge, 2021).

5.3 Continuing professional development in the school context

Of the 81 articles reviewed, 51 focus specifically on CPD for schoolteachers, making this the most prominent category in the corpus. These studies address both primary and secondary education settings. School-based CPD is consistently highlighted as essential for improving student learning outcomes, with effective programs sharing identifiable characteristics (Abakah, 2023; Hobson and McIntyre, 2013; Köksal and Southerland, 2018; McChesney and Aldridge, 2021; Murphy et al., 2015; Tzovla et al., 2021). However, several studies caution that even well-structured programs may fall short due to the complex interplay of contextual and systemic factors influencing educational quality (Asiyah et al., 2021).

An illustrative example is the study by Zúñiga-Meléndez et al. (2020), which investigates the professional development needs of STEM teachers. The results reveal a strong commitment among educators to engage in ongoing training as a means of strengthening their professional profiles and improving pedagogical practices. Teachers' expressed willingness and expectation to pursue further development is a critical factor in the sustainability of CPD efforts.

Effective CPD enhances teachers' confidence in applying new tools and methodologies (Joubert and Kenny, 2018; Qablan, 2019). It also promotes collaborative learning, not only among peers but also through mentorship models that foster openness and reflection (Hobson and McIntyre, 2013; Yerushalmi and Eylon, 2013). These trusted environments encourage professional dialog and growth.

CPD programs that facilitate collaborative, in-depth reflection on teaching practices are consistently associated with improved outcomes (Finch et al., 2021; Pombo and Marques, 2021; Sharp et al., 2022). This is evident in both face-to-face and virtual learning communities (Jocius et al., 2022; Wang and Zhang, 2023). Moreover, such programs should not be limited to methodological training but must also promote critical and reflective practices in and beyond the classroom (Martins-Loução et al., 2019).

Interdisciplinary approaches in CPD enable teachers to transcend disciplinary boundaries and develop broader pedagogical insights (Finch et al., 2021; Chan and Erduran, 2023). These collaborations—e.g., between science and religion teachers—foster shared expertise and joint professional growth. Similarly, studies with physics teachers have revealed differing epistemic cognitions, highlighting the value of interdisciplinary dialog (Perl-Nussbaum et al., 2023).

An emphasis on learning how to learn is central to CPD. Programs must not only address teaching strategies but also challenge teachers' conceptions about pedagogy and learning (Dolfing et al., 2021; Lunde et al., 2016). Techniques such as role-play have proven effective in helping teachers adopt student perspectives and improve pedagogical reflexivity (Gravel et al., 2022; Bernard and Dudek-Różycki, 2020).

Community and institutional support is another enabling factor. Involving families, school leaders, and other stakeholders contributes to the formation of support networks and enhances program relevance (Ghani et al., 2022; Harron et al., 2022).

Despite these strengths, barriers persist. CPD implementation is challenged by financial, environmental, and logistical constraints (Akinyemi et al., 2019; Qablan, 2019). A recurring issue is the misalignment between program content and teachers' specific learning needs (Gutierez, 2019; Wolde, 2021). Effective CPD requires genuine teacher involvement in program design and decision-making (Sormunen et al., 2014; Bentall and Hunt, 2022). Teacher agency must be prioritized to ensure meaningful engagement and long-term impact.

Programs that are attractive but imposed without consultation often fail to resonate with teachers' realities. Instead, CPD should be developed through participatory mechanisms that value the expertise of in-service educators and reflect a shared professional vision (Gericke and Torbjörnsson, 2022).

5.4 Continuing professional development in higher education

Of the 81 publications reviewed, 10 focus exclusively on CPD experiences in higher education contexts. These studies consistently emphasize that improving teaching and learning processes at the tertiary level requires the implementation of innovative CPD strategies (Biswas et al., 2022; Negassa and Engdasew, 2017).

Collaborative learning environments are identified as particularly valuable in this context. Initiatives such as virtual CPD communities (Bedford, 2019) provide platforms for sharing experiences, fostering peer exchange, and co-constructing pedagogical knowledge (Delgado et al., 2021; Solís-Pinilla et al., 2025). Future CPD designs should

integrate collaborative activities and dialogic practices aimed at building sustained academic communities.

Nevertheless, structural challenges limit the success of CPD in higher education. Time constraints, lack of infrastructure, and insufficient institutional support are frequently mentioned barriers, contributing to increased workload perceptions among faculty (Loughlin et al., 2023; Uzorka et al., 2023). CPD programs must therefore consider how to embed professional development within teachers' working hours and institutional responsibilities.

The level of participant commitment is another critical factor. As reported by Loughlin et al. (2023), initiatives aimed at fostering interdisciplinary teaching may falter when participants' engagement varies. This aligns with critiques of the competitive and individualistic culture of academia, which can hinder collaborative professional learning (Bravo González and Galdames, 2023).

Effective CPD in higher education requires not only motivation but also multifaceted support systems. These include mentorship, peer collaboration, financial resources, and institutional policies that promote pedagogical development (Biswas et al., 2022). Factors such as dedicated time, reflective opportunities, and learner-centered approaches are widely acknowledged as conditions for success (Brouwer et al., 2022; Pischetola et al., 2023).

A "safe" and trusting environment is also essential for productive CPD, especially when addressing complex or controversial educational issues (Bedford, 2019; Pischetola et al., 2023). Facilitating open dialog among colleagues supports innovation and professional agency.

Case studies reinforce these findings. For instance, a Cuban initiative on methodological workshops stresses that success depends on participant engagement and intrinsic motivation (Mena et al., 2020; Biswas et al., 2022). A Finnish study similarly highlights the importance of collaborative practices, while Mexican experiences during the COVID-19 pandemic show that faculty collaboration enabled the rapid development of new teaching approaches (Delgado et al., 2021).

Altogether, the reviewed studies suggest that clearly defined learning goals, aligned with participants' expectations and institutional objectives, are key success factors in higher education CPD (Brouwer et al., 2022).

5.5 Continuing professional development: work, university and school

There are other 5 investigations, which have been denominated "cross-sectoral" (Robbins et al., 2021; Ralls et al., 2020; Marques et al., 2015; González-Weil et al., 2013; Hardré et al., 2013). These studies highlight the importance of collaborative efforts between secondary and university educators to enhance teaching practices and student learning outcomes in STEM fields. They demonstrate that by bridging the gap between these educational sectors, educators can co-develop innovative teaching strategies, share expertise, and create professional learning communities that foster continuous improvement and innovation in education.

One of them is a short course on genetics for teachers at all levels, and the study that evaluates 5 years impact of this initiative (Robbins et al., 2021). This study provides valuable insights into how the course has influenced educators and, by extension, their students. The impact was measured through a combination of comparing publicly available participant data from 2015 to 2019 to data from the National Center for Education Statistics, as well as through course agendas and interviews with participants and instructors. The study highlights the importance of bidirectional learning and the creation of a collaborative atmosphere, which are key factors in enhancing teacher motivation and student learning.

The experience of Ralls et al. (2020) explores university-school partnerships in STEM education through qualitative methods, including interviews and an immersion day. It highlights the importance of trust and collaboration in improving teaching practices. By fostering relational, cross-sector professional development, the research shows that educators can enhance their practices and better meet the needs of students. The findings emphasize the role of change agents in brokering these relationships and creating effective learning ecosystems.

Another experience has Chile as the context and the conformation of a joint workspace on action-research with university professors and secondary education science teachers (González-Weil et al., 2013). In this space "teachers were able to share their good experiences in teaching science, listen to good practices and good results of other colleagues, as well as failure experiences that allowed to consolidate learnings" (p.142), highlighting the importance of building collaborative spaces for improvement. This agrees with a group of teachers that went through an immersive experience, which allowed them to learn now abilities in a new cultural space, as is the university, in order to transmit these learnings to their classroom, but with a whole interdisciplinary learning community as support (Hardré et al., 2013). In the online community of practice studied by Marques et al. (2015), improvement in science practices was measured through the development of a curriculum-integrated field trip that combined diverse teaching strategies. Content analysis and data triangulation were used to assess collaborative and reflective practices, highlighting the evolution from teacher-centered to student-centered strategies. This happens beyond the specific content of training, between teachers that take the courses and the instructors or researchers.

5.6 Teacher continuous training: common ideas in diverse contexts

Five articles in this review focus on specific educational contexts, particularly English teaching. These studies contribute to the broader discourse on teacher development by reinforcing key principles previously identified. They highlight essential characteristics of effective CPD, such as reflective practice and collaborative engagement among teachers (Alzhrani, 2023; Mohammadi and Moradi, 2017). Additionally, they emphasize the necessity for training programs to be tailored to educators' specific needs and contextual realities (Mohammadi and Moradi, 2017), reinforcing the idea that teacher development should ultimately serve student learning (Alzhrani, 2023; Msamba et al., 2023).

Despite these strengths, common limitations are identified. These include the practical challenges teachers face during implementation and a lack of institutional or peer support (Drajati et al., 2023). Excessive teaching hours and unsupportive environments are frequently cited as impediments to sustained professional growth

(Mohammadi and Moradi, 2017). An illustrative finding from Utami et al. (2019) shows that teachers with strong professional enthusiasm are better able to overcome contextual barriers, suggesting that personal motivation is a critical driver for enacting pedagogical change.

Preschool education contexts also reinforce these findings. One study underscore how teacher collaboration fosters supportive classroom dynamics that enhance student learning (Wang et al., 2024). Another, focusing on computational thinking, highlights how a positive school culture—characterized by teamwork and resource availability—enhances teachers' self-efficacy (Saxena and Chiu, 2022). These examples affirm that individual commitment is insufficient without supportive structural and cultural conditions. Moreover, four additional studies discuss CPD in school contexts where broader educational communities are involved. These programs integrate teachers and other stakeholders in decision-making processes.

Körkkö et al. (2022) emphasize the role of school principals in shaping CPD outcomes, providing strategic guidance, and fostering shared understanding among staff. Similarly, Damkuviene et al. (2023) argue that professional capital develops through cooperative engagement across multiple organizational levels, enhancing collective feedback and decision-making capacity. Other studies identify barriers to CPD effectiveness, such as the persistent gap between theoretical content and practical implementation (Wolde, 2021), and the limited time available for participating in professional communities due to heavy workloads (Akinyemi et al., 2019). Although these studies do not focus on science education, they offer valuable cross-disciplinary insights into teacher development.

5.7 Theoretical frameworks in CPD research

This category comprises studies that address the conceptual, methodological, and theoretical underpinnings of CPD. Four key articles are included, three of which draw on analyses of TIMSS data across different countries (Pečiuliauskienė et al., 2023; Pečiuliauskienė and Kaminskienė, 2022; Tang et al., 2022), while the fourth examines CPD models more broadly (Kennedy, 2014).

These frameworks highlight the centrality of CPD in shaping teacher practices and student outcomes (Tang et al., 2022). CPD is identified as a critical intervention for enhancing teaching quality (Pečiuliauskienė and Kaminskienė, 2022).

Tang et al. (2022) point to the prevalence of low-quality programs globally and argue that "adequate development" must account for both the duration and structure of CPD activities, as well as the relevance of content (Pečiuliauskienė et al., 2023).

Kennedy (2014), through a longitudinal review of CPD models, introduces the concept of agency, stressing that teachers require autonomy and opportunities for self-directed, meaningful engagement in CPD. Notably, she revisits earlier findings from 2005 and observes that persistent structural challenges remain unaddressed almost a decade later.

Together, these studies invite reflection on the duration, content, and design of CPD initiatives. They suggest that effective programs should move beyond traditional frameworks, embracing innovative pedagogical strategies that are grounded in theory and responsive to contextual needs.

6 Discussion

This systematic review aimed to synthesize evidence from diverse indexed sources concerning the characteristics and trends of Continuing Professional Development (CPD) in science education. Guided by the PRISMA 2020 framework, 81 articles were analyzed, yielding critical insights for the design of CPD programs tailored to science teachers. Figure 5 illustrates key mobilizing questions for CPD program design, informed by the reviewed literature.

Regarding CPD characteristics, it is essential to prioritize teacher-centered approaches that foster active learning. Effective programs—whether conducted in-person or virtually—promote collaboration and reflective practice within trusting environments, thereby enabling the transfer of acquired knowledge to classroom practice.

Across the educational spectrum, CPD programs show consistent positive effects. In school contexts, CPD enhances teacher confidence and peer collaboration, with documented improvements in student learning outcomes. In higher education, CPD fosters structural reform in teaching practices and contributes to meaningful pedagogical transformation.

Nonetheless, several limitations continue to challenge CPD implementation. These include teachers' high workloads, rigid institutional schedules, and insufficient technological and infrastructural resources, all of which impact program execution. Teachers' commitment and disposition, shaped by contextual and institutional factors, are critical to their engagement in CPD. A lack of institutional backing and a school culture that undervalues professional development can further undermine participation and continuity. Lo and To (2023b) reveal that, in response to these school factors and in order to reduce their workload and increase their participation, teachers prefer to develop CPD activities linked to the development of independent work and research.

One of the main challenges for teachers regarding CPD programs is their rigid curriculum, which leaves out learning tailored to interests and needs (Lo and To, 2023a). Therefore, CPD programs must be responsive to teachers' specific needs, equipping them with tools to design contextualized learning activities aligned with the scientific content relevant to their classrooms. Additionally, involving other community members in these initiatives strengthens educational ecosystems and fosters a shared vision of professional learning.

The reinforcement of teacher agency also emerges as a critical dimension. Granting autonomy and participatory roles in the design of CPD programs has a demonstrable impact on teaching effectiveness and contributes to shifts away from traditional paradigms in science education. The role of facilitators is central to promoting collaborative reflection, while interdisciplinary CPD designs support enduring, meaningful learning. Going beyond the disciplinary framework is an interesting but real challenge, where the exchange of materials, experiences, and meanings with other professionals through communities of practice has had successful results on classroom decision-making (Lo and To, 2023a).

Several challenges require sustained attention. CPD programs must exhibit pedagogical and administrative flexibility, with resources allocated to ensure their long-term sustainability. These resources should safeguard spaces for collaboration, reflection, and territorial relevance, enabling broader community engagement and collective

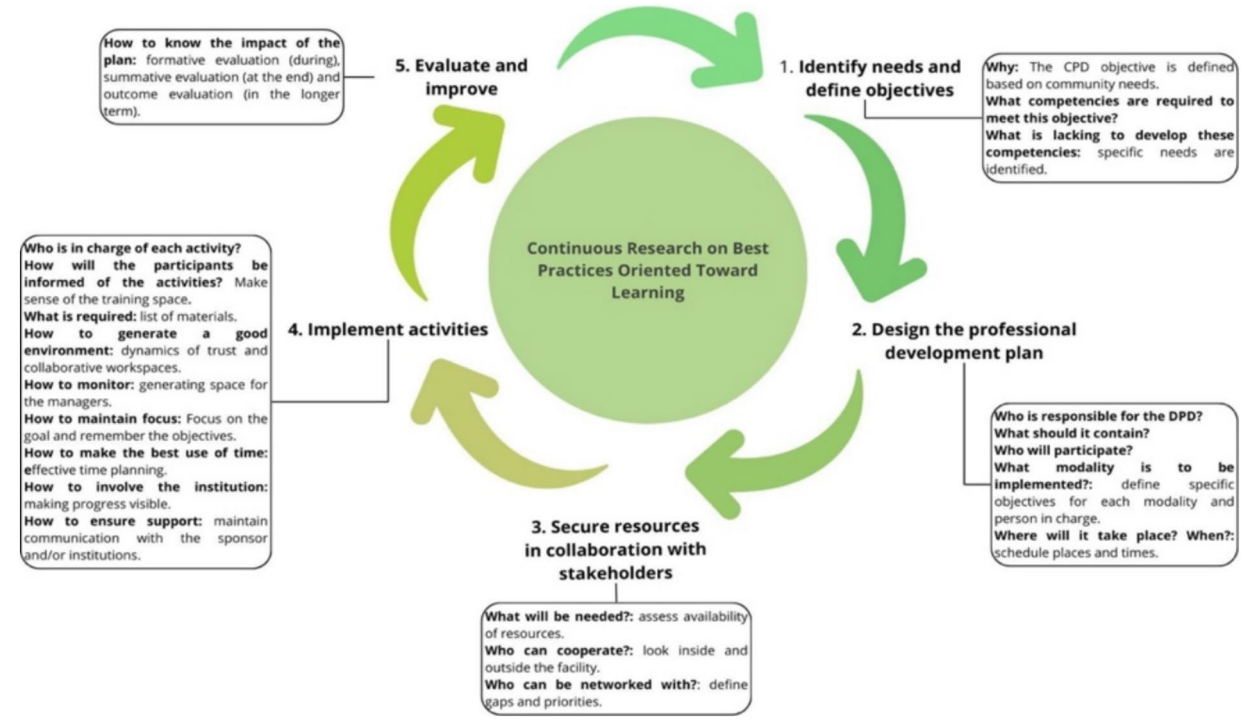

FIGURE 5
Mobilizing elements for CPD design [Adapted from Hassel, 1999].

agency. Such a model positions science teaching as a vehicle for social justice, empowering students to act as informed citizens in shaping their environments.

7 Conclusion

In conclusion, implementing a CPD program focused on scientifically and socially relevant topics demands a strategic blend of pedagogical innovation, expert collaboration, technological integration, and research orientation. These elements prepare teachers to address contemporary challenges while positioning them as transformative agents in their disciplines and communities. A concrete example of this approach is the MICA project,[1] which offers a structured formative trajectory to support teachers in addressing climate change education through interdisciplinary resources, sustained mentoring, and localized implementation strategies. This initiative exemplifies how CPD can align scientific literacy with civic engagement, fostering teacher empowerment and territorial relevance.

From this perspective, it is hoped that this type of analysis of literature on CPD programs will lay the foundations for advancing toward a comprehensive understanding of teachers' careers. Thus, the findings of this review seek to raise new research questions, the impact of which will be directly relevant to the design of training curricula at the initial and continuing development levels.

8 Limitations and future research

The main limitation of this systematic review is that it searched for articles in the main global and Latin American databases, excluding journals, whether indexed or not, in local databases specific to each geographical region of interest. This review aims to lay the foundations for future CPD programs in Chile and Latin America, as well as future meta-analyses that weigh the impact of implementations on teacher development. A key factor that is expected but not explored in depth in the corpus of articles is understanding how sociocultural and economic factors affect CPD design, an aspect that should be strengthened in future experiences and literature reviews.

Author contributions

CM: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Writing – original draft. GP: Investigation, Writing – review & editing. AA-M: Formal analysis, Supervision, Writing – review & editing. RB: Supervision, Validation, Writing – review & editing. JS-P: Validation, Writing – review & editing.

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1 https://www.etecc.cl/

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that Gen AI was used in the creation of this manuscript. Generative AI was used to structure the summary.

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Reference

Abakah, E. (2023). Teacher learning from continuing professional development (CPD) participation: a sociocultural perspective. *Int. J. Educ. Res. Open* 4:100242. doi: 10.1016/j.ijedro.2023.100242

Abakah, E., Widin, J., and Ameyaw, E. K. (2022). Continuing professional development (CPD) practices among basic school teachers in the central region of Ghana. *SAGE Open* 12:597. doi: 10.1177/21582440221094597

Admiraal, W., Schenke, W., De Jong, L., Emmelot, Y., and Sligte, H. (2021). Schools as professional learning communities: what can schools do to support professional development of their teachers?*Prof. Dev. Educ.* 47, 684–698. doi: 10.1080/19415257.2019.1665573

Akinyemi, A. F., Rembe, S., Shumba, J., and Adewumi, T. M. (2019). Allocation of time in communities of practice: a strategy to enhance continuing professional teachers' development of high school teachers. *Cogent Soc. Sci.* 5:1583629. doi: 10.1080/23311886.2019.1583629

Alrubian, A. M. (2022). Adopting BuddyPress platform as an online community of practice for professional development. *Educ. Res. Int.* 2022, 1–11. doi: 10.1155/2022/4395048

Alzhrani, N. (2023). Liberating an EFL teacher as an activist teacher professional identity in MA TESOL classrooms. *Asia-Pac. J. Second Foreign Lang. Educ.* 8, 1–15. doi: 10.1186/s40862-022-00172-3

Arslan, A. S., Karatas, F. O., Unal, S., and Aslan, A. (2022). The effects of group mentoring on teachers' classroom activities: an instrumental case study. *Particip. Educ. Res.* 9, 390–413. doi: 10.17275/per.22.120.9.5

Asiyah, S., Wiyono, B. B., Hidayah, N., and Supriyanto, A. (2021). The effect of professional development, innovative work and work commitment on quality of teacher learning in elementary schools of Indonesia. *Eurasian J. Educ. Res.* 2021, 227–246. doi: 10.14689/ejer.2021.95.13

Bedford, L. (2019). Using social media as a platform for a virtual professional learning community. *Online Learn. J.* 23, 120–136. doi: 10.24059/olj.v23i3.1538

Bentall, C., and Hunt, F. (2022). The value of third sector organisations' provision of global learning CPD in English schools. *Prof. Dev. Educ.* 51, 184–198. doi: 10.1080/19415257.2022.2038656

Bernard, P., and Dudek-Różycki, K. (2020). The impact of professional development in inquiry-based methods on science teachers' classroom practice. *J. Balt. Sci. Educ.* 19, 201–219. doi: 10.33225/jbse/20.19.201

Biswas, S., Benabentos, R., Brewe, E., Potvin, G., Edward, J., Kravec, M., et al. (2022). Institutionalizing evidence-based STEM reform through faculty professional development and support structures. International journal of STEM. *Education* 9:53. doi: 10.1186/s40594-022-00353-z

Bravo González, P. D., and Galdames, S. I. (2023). Peeking behind the curtain: unboxing science teacher educators' subjectivities in continuous professional development programmes. *Perspect. Educ.* 62, 92–112. doi: 10.4151/07189729-VOL.62-ISS.1-ART.1410

Brouwer, N., Joling, E., and Kaper, W. (2022). Effect of a person-centered, tailor-made, teaching practice-oriented training programme on continuous professional development of STEM lecturers. *Teach. Teach. Educ.* 119:103848. doi: 10.1016/j.tate.2022.103848

Budiastra, A. A. K., Wicaksono, I., and Erlina, N. (2020). The effectiveness of video-based interaction on professional science teachers to improve elementary school students' achievements. *J. Educ. Gifted Young Sci.* 8, 1291–1304. doi: 10.17478/JEGYS.715139

Chan, J., and Erduran, S. (2023). The impact of collaboration between science and religious education teachers on their understanding and views of argumentation. *Res. Sci. Educ.* 53, 121–137. doi: 10.1007/s11165-022-10041-1

Damkuviene, M., Valuckiene, J., Balciunas, S., and Petukiene, E. (2023). Education professionals' cooperative learning for the development of professional capital. *Sustain. For.* 15:10972. doi: 10.3390/su151410972

Delgado, F., Enríquez-Flores, M., Jaimes-Nájera, A., Sofianidis, A., Stylianidou, N., and Konstantinou-Katzi, P. (2021). Lessons in the use of technology for science education during COVID-19 age under a teachers' collaboration cluster. *Educ. Sci.* 11:390. doi: 10.3390/educsci11090543

Dinh, H., and Huong, L. N. T. (2023). Teacher-practitioner inquiry in professional development a case of adaptation and resistance to genre-based systemic functional linguistic as a new writing instruction: a case of adaptation and resistance to genre-based systemic functional linguistic as a new writing instruction. *J. Effic. Responsibility Educ. Sci.* 16, 65–80. doi: 10.7160/eriesj.2023.160107

Dolfing, R., Prins, G. T., Bulte, A. M. W., Pilot, A., and Vermunt, J. D. (2021). Strategies to support teachers' professional development regarding sense-making in context-based science curricula. *Sci. Educ.* 105, 127–165. doi: 10.1002/sce.21603

Drajati, N. A., So, H.-J., Rakerda, H., Ilmi, M., and Sulistyawati, H. (2023). Exploring the impact of TPACK-based teacher professional development (TPD) program on EFL teachers' TPACK confidence and beliefs. *J. AsiaTEFL* 20, 300–315. doi: 10.18823/asiatefl.2023.20.2.5.300

Enache, R. C., Petrescu, A.-M. A., Gorghiu, G., and Drăghicescu, L. M. (2019). Present and perspectives in the teachers' continuous professional training in Romania. *Rev. Romaneasca Pentru Educ. Multidimensionala* 11, 20–33. doi: 10.18662/rrem/136

Feldman-Maggor, Y., Tuvi-Arad, I., and Blonder, R. (2022). Development and evaluation of an online course on nanotechnology for the professional development of chemistry teachers. *Int. J. Sci. Educ.* 44, 2465–2484. doi: 10.1080/09500693.2022.2128930

Fernández-Limón, C., Fernández-Cárdenas, J. M., and Galindo, A. A. G. (2018). The role of non-formal contexts in teacher education for STEM: the case of horno3science and technology interactive Centre. *J. Educ. Teach.* 44, 71–89. doi: 10.1080/02607476.2018.1422623

Finch, L., Moreno, C., and Shapiro, R. B. (2021). Luminous science: teachers designing for and developing transdisciplinary thinking and learning. *Cogn. Instr.* 39, 512–560. doi: 10.1080/07370008.2021.1945064

Gericke, N., and Torbjörnsson, T. (2022). Supporting local school reform toward education for sustainable development: the need for creating and continuously negotiating a shared vision and building trust. *J. Environ. Educ.* 53, 231–249. doi: 10.1080/00958964.2022.2102565

Ghani, A., Griffiths, D., Salha, S., Affouneh, S., Khalili, F., Khlaif, Z. N., et al. (2022). Developing teaching practice in computational thinking in Palestine. *Front. Psychol.* 13:870090. doi: 10.3389/fpsyg.2022.870090

González-Weil, C., Muñoz, M. C., Flores, J. L. P., González, P. B., and Guerra, Y. I. (2013). Building encounter domains to problematize secondary science teachers' practice: Incorporating the action-research model as a continuous development plan. *Estud. Pedag. (Valdivia)* 39, 129–146. doi: 10.4067/S0718-07052013000200009

Gravel, B. E., Millner, A., Tucker-Raymond, E., Olivares, M. C., and Wagh, A. (2022). "Weebles wobble but they also commit to lifelong relationships": teachers' transdisciplinary learning in computational play. International journal of STEM. *Education* 9:73. doi: 10.1186/s40594-022-00373-9

Gutierez, S. B. (2019). Teacher-practitioner research inquiry and sense making of their reflections on scaffolded collaborative lesson planning experience. *Asia Pac. Sci. Educ.* 5:8. doi: 10.1186/s41029-019-0043-x

Haagen-Schützenhöfer, C., and Joham, B. (2018). Professionalising physics teachers in doing experimental work. *Center Educ. Policy Stud. J.* 8, 9–34. doi: 10.26529/cepsj.333

Hardré, P. L., Ling, C., Shehab, R. L., Nanny, M. A., Nollert, M. U., Refai, H., et al. (2013). Teachers in an interdisciplinary learning community: engaging, integrating, and strengthening K-12 education. *J. Teach. Educ.* 64, 409–425. doi: 10.1177/0022487113496640

Harron, J. R., Jin, Y., Hillen, A., Mason, L., and Siegel, L. (2022). Maker math: exploring mathematics through digitally fabricated tools with K–12 in-service teachers. *Mathematics* 10:3069. doi: 10.3390/math10173069

Hassel, E. (1999). *Professional development: Learning from the best. A toolkit for schools and districts based on the national awards program for model professional development*. North Central Regional Educational Laboratory. Available online at: http://www.ncrel.org.

Heppt, B., Henschel, S., Hardy, I., Hettmannsperger-Lippolt, R., Gabler, K., Sontag, C., et al. (2022). Professional development for language support in science classrooms: evaluating effects for elementary school teachers. *Teach. Teach. Educ.* 109:103518. doi: 10.1016/j.tate.2021.103518

Hestness, E., McGinnis, J. R., Breslyn, W., McDonald, R. C., and Mouza, C. (2017). Examining science educators' perspectives on learning progressions in a climate change education professional development program. *J. Sci. Teach. Educ.* 28, 250–274. doi: 10.1080/1046560X.2017.1302728

Hobson, A. J., and McIntyre, J. (2013). Teacher fabrication as an impediment to professional learning and development: the external mentor antidote. *Oxf. Rev. Educ.* 39, 345–365. doi: 10.1080/03054985.2013.808618

Holbrook, J., Rannikmäe, M., and Valdmann, A. (2014). Identifying teacher needs for promoting education through science as a paradigm shift in science education. *Sci. Educ. Int.* 25, 4–42.

Ige, O. A., and Jita, L. C. (2020). Instructional practices of science teachers in rural learning ecologies. *J. Balt. Sci. Educ.* 19, 780–803. doi: 10.33225/jbse/20.19.780

Jocius, R., O'Byrne, W. I., Albert, J., Joshi, D., Blanton, M., Robinson, R., et al. (2022). Building a virtual community of practice: teacher learning for computational thinking infusion. *Tech Trends* 66, 547–559. doi: 10.1007/s11528-022-00729-6

Joubert, M., and Kenny, S. (2018). Exploring the perspectives of participants of two mathematics professional development courses in South Africa: personal, professional and community outcomes. *Afr. J. Res. Math., Sci. Technol. Educ.* 22, 319–328. doi: 10.1080/18117295.2018.1525093

Julia, J., Supriyadi, T., Ali, E. Y., Agustian, E., and Fadlilah, A. (2023). Developing elementary school teacher's professional competence in composing traditional songs: an action research in Indonesia. *Int. J. Learn. Teach. Educ. Res.* 22, 435–458. doi: 10.26803/ijlter.22.6.23

Jusuf, R., Sopandi, W., Wulan, A. R., and Sa'ud, U. S. (2019). Strengthening teacher competency through ICARE approach to improve literacy assessment of science creative thinking. *Int. J. Learn. Teach. Educ. Res.* 18, 70–83. doi: 10.26803/ijlter.18.7.5

Kariyev, A. D., Fishman, B. E., Agranovich, Y. N., Fokina, O. A., Ageyeva, L. Y., and Krezhevskikh, O. V. (2022). Development of primary school teachers' skills to accompany pupils in projects and research. *Perspekt. Nauki Obrazovania* 56, 591–607. doi: 10.32744/pse.2022.2.35

Kennedy, A. (2014). Understanding continuing professional development: the need for theory to impact on policy and practice. *Prof. Dev. Educ.* 40, 688–697. doi: 10.1080/19415257.2014.955122

Köksal, M. S., and Southerland, S. (2018). What is value of reform-oriented in-service teacher development attempts on inquiry teaching for pedagogically discontented science teachers? An expectancy-value perspective. *Egitim Bilim* 43, 157–184. doi: 10.15390/EB.2018.7203

Körkkö, M., Kotilainen, M. R., Toljamo, S., and Turunen, T. (2022). Developing teacher in-service education through a professional development plan: modelling the process. *Eur. J. Teach. Educ.* 45, 320–337. doi: 10.1080/02619768.2020.1827393

Kucuk, Z. D., Genek, S. E., Bozoglu, H. S., and Corlu, M. S. (2023). Expressed willingness of STEM teachers to teach engineering. *J. Precoll. Eng. Educ. Res.* 13, 55–69. doi: 10.7771/2157-9288.1358

Lo, N. P. K., and To, B. K. H. (2023a). The transformation of identity of secondary school teachers: professional development and English language education strategies in Hong Kong during the COVID-19 pandemic. *Cogent Educ.* 10:790. doi: 10.1080/2331186x.2022.2163790

Lo, N. P. K., and To, B. K. H. (2023b). To learn or not to learn: perceptions towards continuing professional development (CPD) and self-identity among English language teachers during the COVID-19 pandemic. *SN Comput. Sci.* 4:317. doi: 10.1007/s42979-023-01779-0

Loughlin, W. A., Whiteford, C. M., Geelan, D. R., and Brown, R. A. J. (2023). Barriers and levers driving change in a STEM science subject in the Australian higher education sector: a focused study. *Res. Sci. Technol. Educ.* 41, 1–21. doi: 10.1080/02635143.2020.1830271

Lunde, T., Rundgren, S.-N. C., and Drechsler, M. (2016). Exploring the negotiation of the meaning of laboratory work in a continuous professional development program for lower secondary teachers. *Electron. J. Sci. Educ.* 20, 27–40.

Marques, M. M., Loureiro, M. J., and Marques, L. (2015). Science teaching strategies developed in an online community of practice: a case study. *Int. J. Web Based Commun.* 11, 305–321. doi: 10.1504/IJWBC.2015.072134

Martins-Loução, M. A., Gaio-Oliveira, G., Barata, R., and Carvalho, N. (2019). Inquiry-based science learning in the context of a continuing professional development programme for biology teachers. *J. Biol. Educ.* 54, 497–513. doi: 10.1080/00219266.2019.1609566

McChesney, K., and Aldridge, J. M. (2021). What gets in the way? A new conceptual model for the trajectory from teacher professional development to impact. *Prof. Dev. Educ.* 47, 834–852. doi: 10.1080/19415257.2019.1667412

Mcginnis, J. R., Mcdonald, C., Hestness, E., and Breslyn, W. (2016). An Investigation of Science Educators' View of Roles and Responsibilities for Climate Change Education. *Sci. Educ. Int.* 27, 179–193.

Mena, T., López, E., and Silva, L. (2020). A new perspective: a system for the methodological work in complex teaching disciplines. *Mendive* 18, 923–939.

Mohammadi, M., and Moradi, K. (2017). Exploring change in EFL teachers' perceptions of professional development. *J. Teach. Educ. Sustain.* 19, 22–42. doi: 10.1515/jtes-2017-0002

Msamba, E. M., Msuya, E. A., and Anangisye, W. A. L. (2023). The impact of in-service education and training on teachers' learning: perspectives from English foreign language teachers in Tanzania. *Educ. Res. Int.* 2023:6135444. doi: 10.1155/2023/6135444

Murphy, C., Mallon, B., Smith, G., Kelly, O., Pitsia, V., and Martinez Sainz, G. (2021). The influence of a teachers' professional development programme on primary school pupils' understanding of and attitudes towards sustainability. *Environ. Educ. Res.* 27, 1011–1036. doi: 10.1080/13504622.2021.1889470

Murphy, C., Smith, G., Varley, J., and Razı, Ö. (2015). Changing practice: an evaluation of the impact of a nature of science inquiry-based professional development programme on primary teachers. Cogent. *Education* 2:692. doi: 10.1080/2331186X.2015.1077692

Negassa, T., and Engdasew, Z. (2017). The impacts and challenges of pedagogical skills improvement program at Adama science and technology university. *Int. J. Instr.* 10, 19–38. doi: 10.12973/iji.2017.1042a

OECD (2023). *A comprehensive overview of global biodiversity finance*. Paris, France: OECD.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., et al. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Int. J. Surg.* 88:105906. doi: 10.1016/J.IJSU.2021.105906

Pečiuliauskienė, P., and Kaminskienė, L. (2022). The implementation of cognitively challenging tasks: the role of science teachers' professional development and teaching experience. *Educ. Sci.* 12:439. doi: 10.3390/educsci12070439

Pečiuliauskienė, P., Kaminskienė, L., and Lehtinen, E. (2023). Science teachers' collaborative innovative activities: the role of professional development and professional experience. *Hum. Soc. Sci. Commun.* 10:183. doi: 10.1057/s41599-023-01833-5

Peleg, R., Yayon, M., Katchevich, D., Mamlok-Naaman, R., Fortus, D., Eilks, I., et al. (2017). Teachers' views on implementing storytelling as a way to motivate inquiry learning in high-school chemistry teaching. *Chem. Educ. Res. Pract.* 18, 304–309. doi: 10.1039/c6rp00215c

Perl-Nussbaum, D., Schwarz, B. B., and Yerushalmi, E. (2023). Interdisciplinary dialogic argumentation among out-of-field and in-field physics teachers. *Sci. Educ.* 107, 1457–1484. doi: 10.1002/sce.21811

Philander, C. J., and Botha, M. L. (2021). Natural sciences teachers' continuous professional development through a community of practice. *S. Afr. J. Educ.* 41:1918. doi: 10.15700/saje.v41n4a1918

Pischetola, M., Møller, J. K., and Malmborg, L. (2023). Enhancing teacher collaboration in higher education: the potential of activity-oriented design for professional development. *Educ. Inf. Technol.* 28, 7571–7600. doi: 10.1007/s10639-022-11490-x

Pombo, L., and Marques, M. M. (2021). Guidelines for teacher training in mobile augmented reality games: hearing the teachers' voices. *Educ. Sci.* 11:597. doi: 10.3390/educsci11100597

Qablan, A. M. (2019). Effective professional development and change in practice: the case of queen Rania teacher academy science network. *Eur. J. Math. Sci. Technol. Educ.* 15:9016. doi: 10.29333/ejmste/109016

Qazi, A. G., and Mtenzi, F. J. (2023). The conceptual framing, design, and development of mobile-mediated professional development for primary mathematics teachers. *Int. J. Mob. Blend. Learn.* 15, 1–19. doi: 10.4018/IJMBL.319022

Ralls, D., Bianchi, L., and Choudry, S. (2020). 'Across the divide': developing professional learning ecosystems in STEM education. *Res. Sci. Educ.* 50, 2463–2481. doi: 10.1007/s11165-018-9789-5

Redman, E., Wiek, A., and Redman, A. (2018). Continuing professional development in sustainability education for K-12 teachers: principles, programme, applications, outlook. *J. Educ. Sustain. Dev.* 12, 59–80. doi: 10.1177/2455133318777182

Rivera, M., Cortés, W., Pino, S., Meza, M., Solis, J., and Merino, C. (2025). Climate change perceptions among Andean schoolchildren in Chile. *Front Educ*, 10. doi: 10.3389/feduc.2025.1536271

Robbins, S. M., Daulton, C. R., Hurle, B., and Easter, C. (2021). The NHGRI short course in genomics: energizing genetics and genomics education in classrooms through direct engagement between educators and scientists. *Genet. Med.* 23, 222–229. doi: 10.1038/s41436-020-00962-5

Sálica, M., Almirón, M., and Porro, S. (2020). Modelos de conocimiento didáctico del contenido científico y tecnológico en docentes de Química y Física [Didactic knowledge models of scientific and technological content in Chemistry and Physics]. *Tecné Episteme Didaxis* 127–141, 27–41. doi: 10.7440/res64.2018.03

Saxena, A., and Chiu, M. M. (2022). Developing preschool teachers' computational thinking knowledge, attitudes, beliefs, and teaching self-efficacies: a curriculum-based professional development program. *Front. Educ.* 7:116. doi: 10.3389/feduc.2022.889116

Sharp, S. R., Rutherford, G. L., and Echols, K. I. (2022). Creative science through inquiry: improving teacher self-efficacy and outcome expectancy through adaptable, mystery-based professional development. *Int. J. Innov. Sci. Math. Educ.* 30, 57–69. doi: 10.30722/IJISME.30.01.005

Solís-Pinilla, J., Merino Rubilar, C., Aroca-Toloza, C., Bravo-González, P., and Miranda-Jaña, C. (2025). Reflexión en las Interacciones Educativas: análisis de prácticas de indagación científica desde el modelo ALACT. Revista Eureka Sobre Enseñanza y Divulgación de Las. *Ciencias* 22:1602. doi: 10.25267/rev_eureka_ensen_divulg_cienc.2025.v22.i1.1602

Solís-Pinilla, J., Miranda-Jaña, C., Merino-Rubilar, C., and Medina Andrade, J. M. (2024). Educational interactions in school contexts: a systematic review. *Rev. Complut. Educ.* 35, 575–586. doi: 10.5209/rced.85981

Sormunen, K., Keinonen, T., and Holbrook, J. (2014). Finnish science teachers' views on the three stage model. *Sci. Educ. Int.* 25, 43–56.

Tang, A., Li, W., and Liu, D. (2022). The impact of teachers' professional development in science pedagogy on students' achievement: evidence from TIMSS 2019. *J. Balt. Sci. Educ.* 21, 258–274. doi: 10.33225/jbse/22.21.258

Tzovla, E., Kedraka, K., and Kaltsidis, C. (2021). Investigating in-service elementary school teachers' satisfaction with participating in MOOC for teaching biological concepts. *Eur. J. Math. Sci. Technol. Educ.* 17, 1–11. doi: 10.29333/ejmste/9729

UNESCO. (2016). *Education for people and planet: Creating sustainable futures for all, Global education monitoring report, 2016*. Paris, France: UNESCO.

United Nations (2015). *Transforming our world: The 2030 agenda for sustainable development*. New York: United Nations.

Unterhalter, E. (2019). The many meanings of quality education: politics of targets and indicators in SDG. *Global Pol.* 10, 39–51. doi: 10.1111/1758-5899.12591

Unver, A. O., Okulu, H. Z., Muslu, N., Yilmaz, Y. O., Senler, B., Arabacioglu, S., et al. (2023). The readiness of stakeholders in the scientific inquiry-supported mentoring project. *Int. J. Educ. Math. Sci. Technol.* 11, 37–55. doi: 10.46328/ijemst.2651

Utami, I. G. A. L. P., Prestridge, S., Saukah, A., and Hamied, F. A. (2019). Continuing professional development and teachers' perceptions and practices - a tenable relationship. *Indones. J. Appl. Linguist.* 9, 108–118. doi: 10.17509/ijal.v9i1.12463

Uzorka, A., Namara, S., and Olaniyan, A. O. (2023). Modern technology adoption and professional development of lecturers. *Educ. Inf. Technol.* 28, 14693–14719. doi: 10.1007/s10639-023-11790-w

Walan, S., and Gericke, N. (2023). Transferring makerspace activities to the classroom: a tension between two learning cultures. *Int. J. Technol. Des. Educ.* 33, 1755–1772. doi: 10.1007/s10798-022-09799-2

Wang, J., and Liu, J. (2024). The visual stories in addressing climate change that a petroleum business tells and lives by: a multimodal critical ecolinguistic perspective. *Energy Res. Soc. Sci.* 111:103483. doi: 10.1016/j.erss.2024.103483

Wang, M., and Zhang, L. J. (2023). Understanding teachers' online professional learning: a "community of inquiry" perspective on the role of Chinese middle school teachers' sense of self-efficacy, and online learning achievement. *Heliyon* 9:932. doi: 10.1016/j.heliyon.2023.e16932

Wang, Y., Li, L., Fleer, M., and Ma, Y. (2024). Creating conditions for Chinese kindergarten teachers' professional development in a play-based setting. *Early Years* 44, 665–681. doi: 10.1080/09575146.2023.2205055

Wolde, B. D. (2021). The role of continuous professional development in improving secondary school teachers' teaching and learning competencies to deliver quality education in Ethiopia: a case of secondary school. *Qual. Rep.* 26, 1345–1363. doi: 10.46743/2160-3715/2021.3650

Yerushalmi, E., and Eylon, B. S. (2013). Supporting teachers who introduce curricular innovations into their classrooms: a problem-solving perspective. *Phys. Rev. Spec. Top.* 9:010121. doi: 10.1103/PhysRevSTPER.9.010121

Zúñiga-Meléndez, A., Durán-Apuy, A., Chavarría-Vásquez, J., Gamboa-Araya, R., Carballo-Arce, A. F., Vargas-González, X., et al. (2020). Diagnosis of training needs of teachers of biology, chemistry, physics, and mathematics, in disciplinary, pedagogical areas, and use of technologies to promote scientific thinking skills. *Rev. Electron. Educ.* 24, 1–29. doi: 10.15359/REE.24-3.23