

Review Article

Cite this article: Estrada, P. A., Agudelo, K. P., & Flórez, E. P. (2025). Artificial Intelligence and Inclusive Education: A Professional Development Model for Chemistry Teachers in Secondary Education. *Educational Process: International Journal*, 17, e2025380.

<https://doi.org/10.22521/edupij.2025.17.380>

Received May 18, 2025

Accepted June 29, 2025

Published Online August 15, 2025

Keywords: Teacher professional development, artificial intelligence, inclusive education, chemistry teaching.

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Artificial Intelligence and Inclusive Education: A Professional Development Model for Chemistry Teachers in Secondary Education

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Abstract

Background/purpose. This article presents partial results of a document review that constitutes a key input for the doctoral thesis in Didactics of Science entitled “Model of teacher professional development for the inclusive teaching of chemistry in the academic middle school, mediated by artificial intelligence”, developed at the University of Córdoba, Colombia. The study addresses the question: How is artificial intelligence (AI) being integrated into pedagogical practices to favour inclusive teaching of chemistry in secondary education, and what theoretical approaches and strategies reported in recent literature support the development of a teacher professional development (TPD) model?

Materials/methods. A total of 38 scientific publications from the years 2022 to 2025 were analysed using the PRISMA methodology to identify theoretical and practical contributions at the intersection of AI, inclusive education, chemistry teaching, and teacher training.

Results. The analysis revealed a notable fragmentation in the literature addressing TPD, AI, inclusive education, and chemistry teaching. Although there is increasing interest in AI applications in education, there remains a lack of training programs that integrate disciplinary didactics, educational inclusion, and AI mediation.

Conclusion. The findings justify the need for a comprehensive and contextually grounded TPD model. Four thematic categories were identified to support its construction: specific competences in chemistry didactics, ethical and pedagogical training in AI, principles of inclusion, accessibility, and educational equity, and tools for data analysis and content generation with AI.

1. Introduction and Background

Contemporary education is undergoing an accelerated transformation driven by structural demands for equity, inclusivity, and educational quality. These demands are particularly critical in conceptually intensive disciplines such as chemistry, where persistent gaps in access, retention, and success continue to impact diverse student populations significantly (Guzmán & Arana, 2025; De Lima et al., 2024). Despite technological advancements, there remains a substantial research gap concerning how Artificial Intelligence (AI) can be systematically integrated into pedagogical practices to support inclusive education explicitly within chemistry teaching.

Artificial Intelligence has increasingly been recognized as a transformative force in education due to its potential to offer personalized and adaptive learning environments. Its ability to tailor educational experiences to learners' cognitive, social, and cultural uniqueness holds considerable promise for fostering greater educational inclusivity (Lu et al., 2024; Tan et al., 2024; Dogan et al., 2025). Nonetheless, the effective integration of AI into the educational sphere extends beyond mere technological proficiency. It demands comprehensive pedagogical frameworks that guide educators in the reflective, ethical, and pedagogically sound use of AI-based tools. Recent studies consistently indicate that many teachers remain inadequately prepared and uncertain about employing AI effectively, thus limiting its educational impact (Moorhouse, 2024; Guan et al., 2025; Ding et al., 2024).

In addressing this critical gap, systematic teacher professional development (TPD) programs are essential. However, an extensive review of the literature reveals a notable deficiency in comprehensive models specifically designed to guide chemistry teachers in secondary education towards integrating AI pedagogically to enhance inclusivity (Chaipidech et al., 2022; Feldman-Maggor et al., 2024). Although frameworks such as Universal Design for Learning (UDL) and Technological Pedagogical Content Knowledge (TPACK) offer pathways to integrate technology into inclusive teaching (CAST, 2018; Dogan et al., 2025), explicit and contextually relevant TPD models focusing specifically on AI integration for inclusive chemistry teaching are still scarce or underdeveloped.

Therefore, this systematic review aims explicitly to explore how AI is currently being integrated into pedagogical practices to promote inclusivity within chemistry education at the secondary level. This research investigates existing theoretical frameworks and practical strategies documented in recent international literature to propose a cohesive TPD model. Such a model seeks to enable chemistry educators not merely to utilize AI tools technically but strategically employ them to foster equitable, inclusive, and culturally sensitive educational environments.

Further, international research highlights the diverse potential of AI to enhance educational assessments, support intelligent tutoring systems, and create learner-centered platforms, reinforcing the relevance of developing effective integration strategies (Yamtinah et al., 2025; Wang & Lv, 2022). Recent scholarly discourse also emphasizes ethical considerations, algorithmic bias, and digital equity, underscoring the critical need for comprehensive training and reflective practice among educators (Blonder & Feldman-Maggor, 2024; Sánchez & Jaimes, 2024).

By addressing these specific research gaps, this study contributes significantly to contemporary educational discourse, particularly within the intersection of chemistry teaching, inclusive education, and artificial intelligence. Ultimately, this research aims not only to fill the existing theoretical and practical gaps but also to provide chemistry educators with robust, theoretically grounded, and contextually applicable strategies to leverage AI effectively in fostering inclusive and equitable chemistry education practices.

2. Literature Review

2.1. AI in inclusive chemistry education

The integration of artificial intelligence (AI) in chemistry education has expanded significantly in recent years, especially in promoting inclusive and student-centered learning environments. Studies such as those by Blonder and Feldman-Maggor (2024) and Feldman-Maggor et al. (2024) have highlighted the potential of generative AI tools to personalize content and address ethical concerns in science teaching. Leite (2024) further explores how platforms like ChatGPT and Gemini can support chemistry instruction by generating explanations and addressing conceptual gaps, although limitations in content consistency remain. In Latin American contexts, Guzmán and Arana (2025) have demonstrated the usability of localized TIC applications to promote equity in rural classrooms, underscoring the need for inclusive AI tools tailored to diverse sociocultural settings.

2.2. Teacher's professional development and digital tools

Teacher professional development (TPD) models have increasingly embraced digital and AI-enhanced tools to foster pedagogical transformation. Dogan et al. (2025) provide a systematic review of TPACK-oriented AI training programs, showing how such designs improve teacher's competencies in integrating technology. Similarly, Kohnke et al. (2025) emphasize the importance of AI literacy for preservice teachers and recommend structured training aligned with ethical frameworks. Hernández-Ramos et al. (2023) describe an innovative e-learning course on computational chemistry, designed through instructional design principles within the TPASK framework, demonstrating effective content delivery and teacher engagement. These initiatives confirm that AI-enabled TPD can enhance pedagogical practices when implemented through reflective, scaffolded, and context-sensitive approaches.

2.3. Gaps and challenges in the literature

Despite the promising advances, several studies have drawn attention to persistent challenges in the literature. Ayanwale et al. (2024) and Guan et al. (2025) reveal disparities in teachers' readiness and identity development when faced with AI integration, particularly in under-resourced regions. Tan et al. (2024), in a comprehensive review, note a lack of longitudinal research evaluating the sustained impact of AI-based interventions on inclusive teaching practices. Moreover, existing literature tends to concentrate on global North contexts, leading to underrepresentation of data and perspectives from the Global South. This geographic and epistemic asymmetry highlights the urgency of fostering equitable and culturally responsive research agendas that involve teachers not only as recipients of innovation but also as co-constructors of knowledge.

3. Methodology

This study employed a systematic desk review based on the PRISMA 2020 guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). The aim was to identify and analyze research studies at the intersection of artificial intelligence, inclusive education, chemistry teaching, and teacher professional development (TPD). The review followed a structured protocol composed of five stages described below.

3.1. Search strategy and data sources

The search was carried out in Scopus and Web of Science (WoS) databases. A carefully constructed Boolean equation was applied, using combinations of key terms such as "Artificial intelligence in education", "Teacher professional development", "Inclusive education", "Accessibility", "Science teaching", and "Chemistry teaching". These were combined using Boolean operators to increase specificity and comprehensiveness.

3.2. Boolean equation

The following Boolean equation was constructed to ensure comprehensive coverage of the intersection between artificial intelligence, inclusive education, and the teaching of chemistry within teacher professional development:

("Artificial intelligence" AND "Teacher professional development") OR ("Artificial intelligence" AND "Chemistry teaching") OR ("Artificial intelligence" AND "Inclusive education") OR ("Inclusive education" AND "Chemistry teaching") OR ("Teacher professional development" AND "Chemistry teaching")

This equation was strategically designed to retrieve studies addressing the pedagogical applications of AI, particularly in inclusive and disciplinary contexts. Each combination targets a specific thematic intersection, allowing for a multidimensional analysis of current academic production.

Variants of the terms were adapted to each database's syntax. Filters were applied to include only peer-reviewed articles, published from 2020 to 2025, and available in English, Spanish, or Portuguese. A total of 38 articles were selected after removing duplicates and applying the inclusion/exclusion criteria.

3.3. Inclusion and exclusion criteria

The selection of studies was guided by the following criteria:

Inclusion criteria:

- Peer-reviewed journal articles published between 2022 and 2025.
- Studies written in English, Spanish, or Portuguese.
- Research focused on artificial intelligence in chemistry education, inclusive education, or teacher professional development (TPD).
- Empirical, theoretical, or review articles that explicitly addressed intersections among AI, chemistry teaching, and/or inclusion.

Exclusion criteria:

- Non-peer-reviewed sources (e.g., conference abstracts, opinion pieces).
- Articles unrelated to education or lacking explicit connections to TPD or chemistry instruction.
- Duplicates or articles without an accessible full text.

These criteria ensured the scientific rigor, thematic relevance, and accessibility of the selected corpus.

3.4. Flowchart and study selection

Study selection followed the PRISMA methodology. The process is illustrated in the flow diagram (Figure 1), which outlines the four filtering stages: identification, screening, eligibility, and inclusion. After filtering, 38 studies were included for detailed analysis.

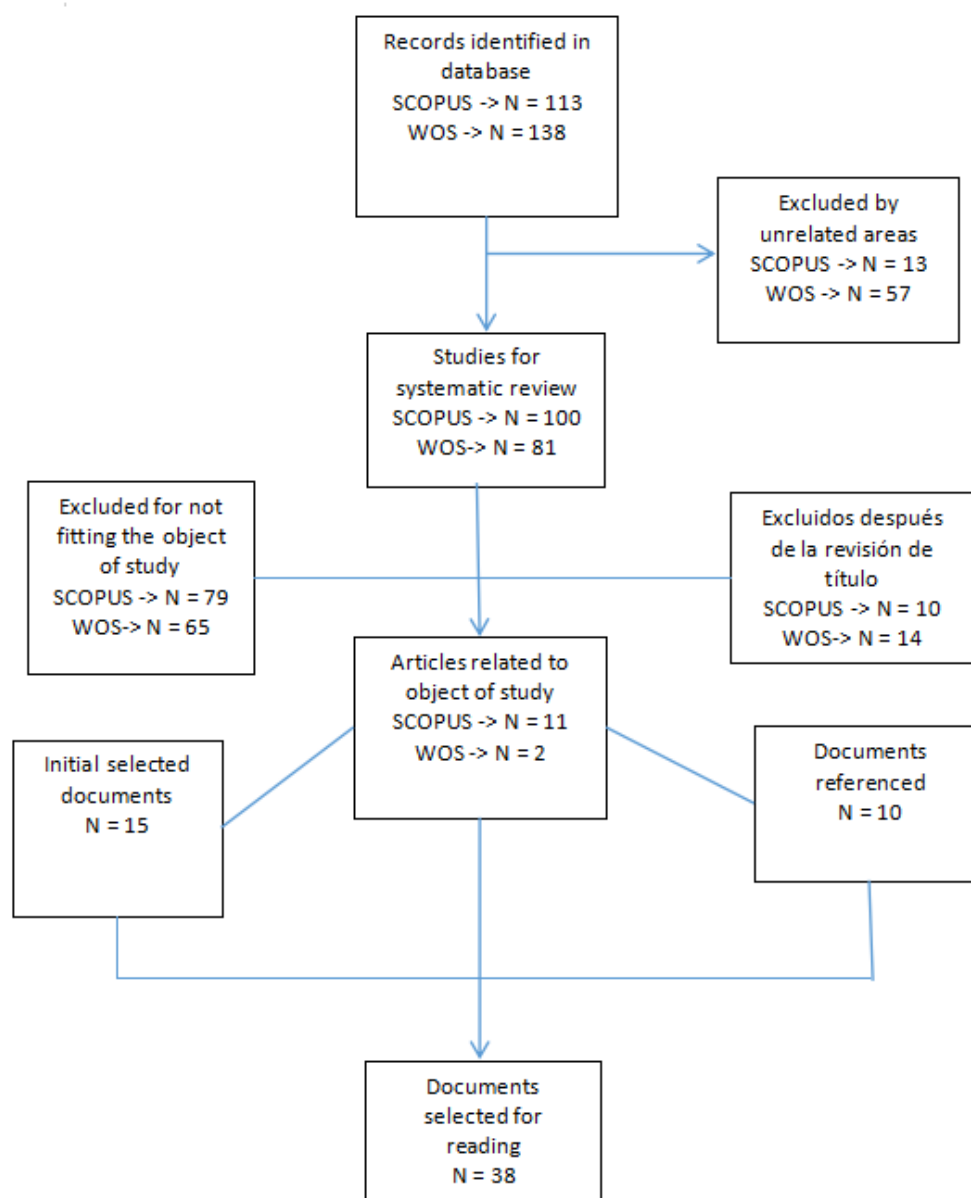


Figure 1. Flow chart for research selection

The PRISMA diagram illustrates the process followed for identifying and selecting the 38 articles included in this review. A total of 251 records were identified through the Scopus (n = 113) and Web of Science (n = 138) databases. After removing studies from unrelated areas (Scopus: n = 13; WOS: n = 57), 181 articles remained for screening.

From these, 144 were excluded for not fitting the study's objectives (Scopus: n = 79; WOS: n = 65), and another 24 were discarded after reviewing their titles (Scopus: n = 10; WOS: n = 14). This left 13 articles directly aligned with the research topic (Scopus: n = 11; WOS: n = 2). To enhance coverage, 10 additional articles were incorporated through reference tracking, bringing the total number of documents selected for in-depth analysis to 38.

3.5. Data Extraction and Analysis Tools

To manage references and apply the PRISMA methodology, Rayyan software was used. Keyword co-occurrence visualizations such as heat maps and node diagrams were generated using VOSviewer v1.6.19. Reference management was supported by Zotero and Mendeley. Tables were created in Excel 365.

3.6. Study Classification

Each of the 38 studies was categorized according to type and region of origin. In Table 1 the typology is presented:

Table 1. Classification of Reviewed Studies by Type and Count

Type of Study	Count
Qualitative	9
Quantitative	11
Mixed Methods	6
Theoretical/Reviews	7
Technological Tools	5

Most studies were from China (6), the United States (5), Colombia and Brazil (4 each), and others from South Africa, Spain, Israel, among others.

3.7. Bias mitigation strategies

To minimize researcher bias, blind coding was employed during data categorization. Additionally, dual-review validation was performed by independent researchers. Any disagreements were resolved by consensus. Thematic clusters were triangulated among co-authors to ensure the reliability of interpretations.

3.8. Thematic analysis

An open coding technique was used to extract themes and patterns. These were classified into four conceptual domains that guided the theoretical construction of the proposed TPD model: (1) AI and education, (2) Inclusive pedagogy, (3) Chemistry didactics, and (4) Teacher development.

The PRISMA methodology was selected due to its rigorous and transparent framework for conducting systematic reviews, which ensures reproducibility and clarity in the selection and analysis of scientific evidence. Its structured approach allows for a comprehensive synthesis of current trends while minimizing selection bias.

4. Results and discussion of the systematic review

The systematic review identified 38 high-quality studies, which were grouped into four thematic clusters based on the co-occurrence analysis of keywords: (1) Chemistry Education – Professional Development, (2) Artificial Intelligence – Chemistry Education, (3) Artificial Intelligence – Professional Development, and (4) Chemistry Education – Inclusive Education.

4.1. Distribution by year of publication

The reviewed studies were published between 2020 and 2025. There is a clear upward trend in recent years, indicating a growing academic interest in the intersection of artificial intelligence, inclusive education, and science/chemistry teaching.

Figure 2 shows a clear upward trend in scientific production in recent years, particularly in the areas of artificial intelligence, educational inclusion, and the teaching of chemistry. The year 2024 stands out with 20 publications, which represents more than half of the total considered (n=38). Next is 2025 with 8 articles, while 2023 and 2022 report 6 and 4 publications, respectively.

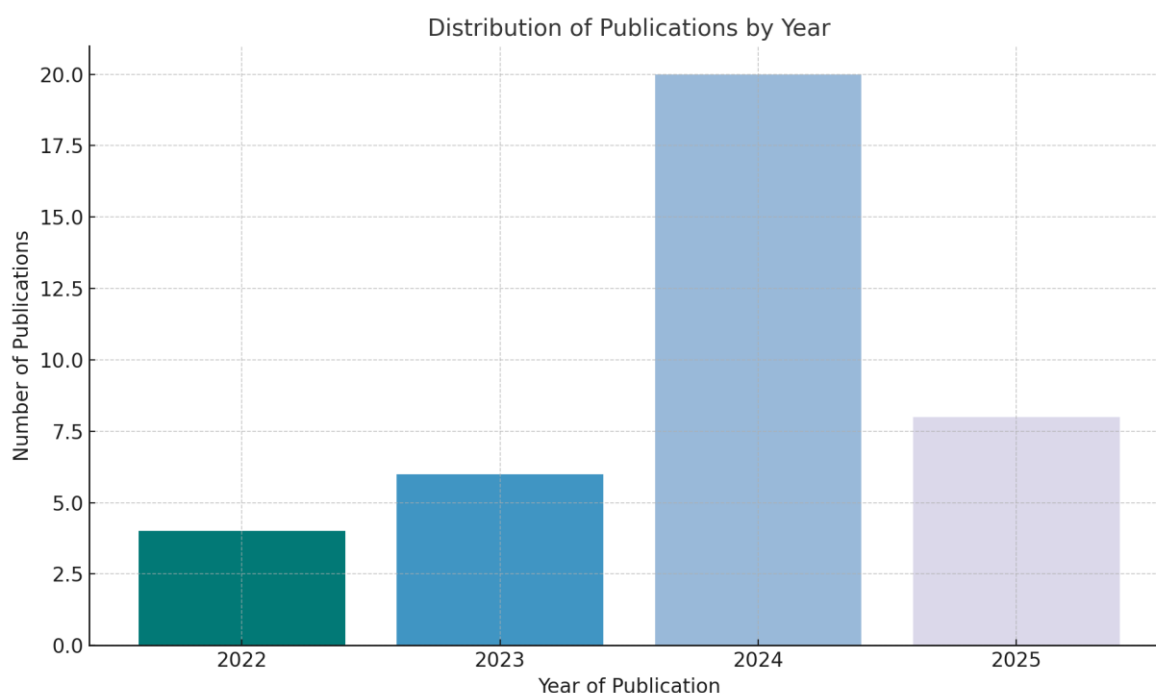


Figure 2. Distribution of studies by year of publication

This sustained increase reflects the growing interest of the academic community in exploring the integration of emerging technologies in inclusive pedagogical contexts. In particular, the explosion of generative AI tools like ChatGPT starting in 2023 catalyzed a wave of research aimed at understanding and applying these technologies from a didactic and critical perspective. The marked concentration of work in 2024 can then be interpreted as a reflection of that global push to rethink teacher training and the teaching of disciplines like chemistry in light of new technological and social challenges.

This analysis reinforces the relevance of the present study by situating it at a key moment of scientific expansion and consolidation within this emerging field.

4.2. Thematic clusters identified

Based on keyword co-occurrence and content analysis, the following four thematic clusters were identified:

1. Chemistry Education – Professional Development
2. Artificial Intelligence – Chemistry Education
3. Artificial Intelligence – Teacher Professional Development
4. Inclusive Education – Chemistry Teaching

Figure 3 illustrates keyword connections and the relationship between themes.

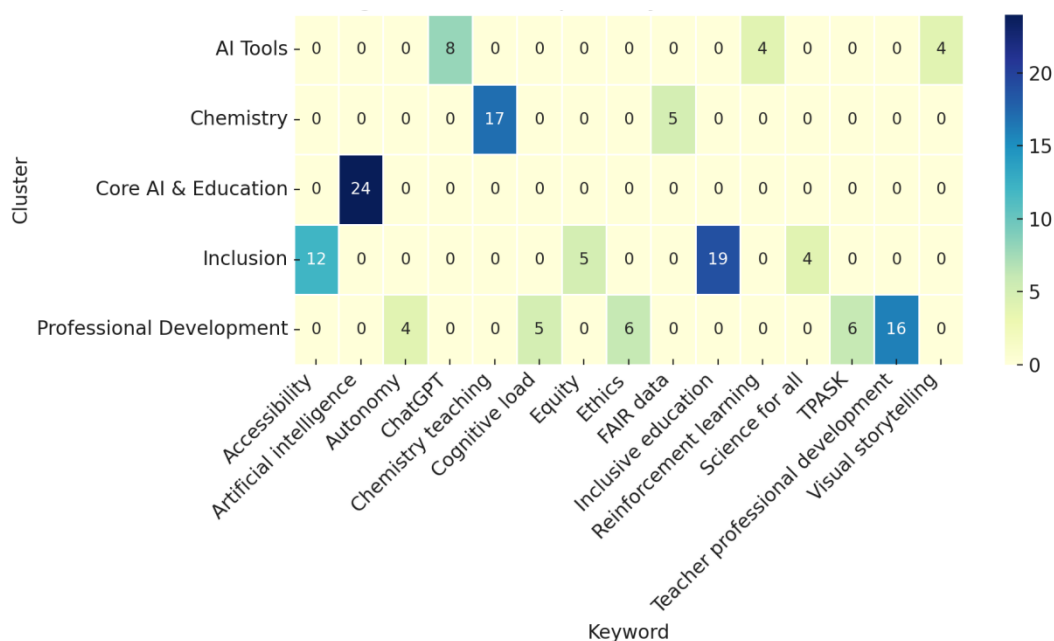


Figure 3. Heatmap of keyword co-occurrence (VOSviewer)

The concurrence heat map provides a visual representation of the relational intensity between the selected keywords, based on their simultaneity within the analysed corpus of documents. In the present research, the conceptual categories of professional development, artificial intelligence, inclusive education and chemistry education were taken into consideration, which not only constitute the central axes of the analysis, but also delimit the structural dimensions of the research problem addressed.

Using a similarity matrix constructed from the relative frequency of co-occurrences between these terms, the heat map facilitates the identification of meaningful relational patterns. More intense chromatic gradations indicate greater concurrence between terms, while lighter shades indicate less robust or infrequent links. In the context of this study, stronger relationships are observed between chemistry education and both professional development and artificial intelligence. This finding suggests a discernible tendency in the academic literature to address these specific combinations as articulating cores of technology-mediated learning experiences and pedagogical designs.

Additionally, the relationship established between inclusive education and chemistry education, while less intense, reveals an emerging focus of scholarly interest. Concerns of equity, accessibility and curricular adaptation converge at this intersection. This graphic visualisation supports the conclusions drawn from the literature review regarding the need to integrate inclusive and technological approaches to teacher professional development, with a focus on disciplines such as chemistry.

In this sense, the heat map goes beyond the mere graphical representation of conceptual interconnections within the field of study. Its usefulness also lies in its ability to guide the formation of relevant thematic clusters and the coherent structuring of the theoretical and methodological framework of the research.

Figure 4 illustrates the semantic network derived from the reviewed literature, where each node represents a key concept, and edges indicate the strength of co-occurrence relationships. The thickness of the lines denotes the frequency with which terms converge in the 38 selected studies, offering a conceptual mapping of the underlying associations in the field.

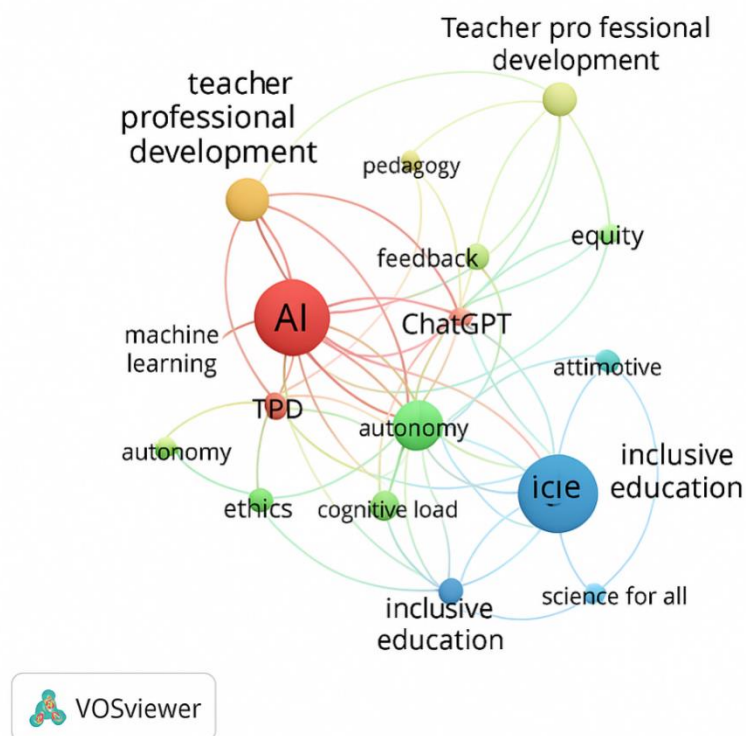


Figure 4. Semantic network of thematic relationships (VOSViewer)

The terms represented—such as artificial intelligence, ChatGPT, inclusive education, teacher professional development, and chemistry education—were systematically extracted through co-occurrence analysis to ensure consistency between the visualizations and the analytical narrative.

The densest areas correspond to intersections between “artificial intelligence” and “chemistry education,” suggesting that research is increasingly focused on leveraging intelligent technologies to support science instruction. In this configuration, “chemistry education” occupies a central articulating position, linking both “professional development” and “AI,” which reinforces the idea that these domains are not explored in isolation but rather in pedagogically mediated combinations.

Additionally, the relationship between “artificial intelligence” and “teacher professional development” appears strongly consolidated, supporting a growing discourse that frames technological integration as not merely functional but also ethical, reflective, and strategic (Ding et al., 2024; Lu et al., 2024; Tan et al., 2024).

In contrast, concepts such as “inclusive education” and “accessibility” appear in more peripheral areas of the graph. This spatial arrangement reveals a critical gap: while these topics are emerging in studies on Universal Design for Learning (Roski et al., 2024) or in rural and underrepresented contexts (Guzmán & Arana, 2025), their presence remains underrepresented in the mainstream academic discourse.

The semantic structure thus reveals not just a map of current research interests, but a theoretical turning point: the potential to articulate a Teacher Professional Development model that meaningfully integrates artificial intelligence as a mediational tool, inclusion as a political-pedagogical imperative, and chemistry teaching as a disciplinary foundation for equitable innovation.

4.3. Relationship between categories and selected studies

Table 2 synthesizes the relationship between the identified categories and the studies analyzed. It provides an overview of key contributions and the distribution of research efforts across themes.

Table 2. Relationship between thematic categories and the main reviewed studies

Thematic Category	Key Studies	Main Contributions
Chemistry Education – TPD	Hernández-Ramos et al. (2023), Rzepa (2023)	Development of pedagogical frameworks like TPASK, FAIR data practices
AI – Chemistry Education	Leite (2023), Nugraha & Harsono (2023), Wang & Lv (2022)	AI for concept reinforcement, storytelling, and adaptive systems
AI – TPD	Lu et al. (2024), Ding et al. (2024), Luan et al. (2023)	ChatGPT in reflective practice, ethics of AI in training, generative AI for feedback
Inclusive Ed – Chem Teaching	Guzmán & Arana (2025), Roski et al. (2024)	Tools like "A la Materia", Universal Design for Learning in science

This table serves as a bridge between quantitative mapping and qualitative thematic interpretation.

4.4. Critical analysis of thematic clusters

The analysis of thematic clusters, based on the concurrence between the central keywords of the study - professional development, artificial intelligence, inclusive education, and chemistry teaching - made it possible to group concepts according to their semantic proximity and their systematic co-occurrence in the studies reviewed. These clusters constitute nuclei of meaning within the research field and allow structuring both the theoretical framework and the future lines of development of the proposed TPD model.

4.4.1. Cluster: Chemistry education - Professional development

This cluster brings together studies focused on strengthening specific pedagogical competences for teaching chemistry, especially through technology-mediated continuing education processes. It highlights proposals that integrate frameworks such as TPASK in computational chemistry courses (Hernández-Ramos et al., 2023), fine-tuning models with AI to improve assessment in chemistry (Yamtinah et al., 2025), and approaches such as TPASK for structuring complex content (Feldman-Maggor et al., 2024).

Studies that address teacher development in digital environments applied to chemistry also stand out (Chaipidech et al., 2022; Rzepa, 2023), as well as those that explore the professional identity of teachers in the use of AI in disciplinary contexts (Lan, 2024). However, despite these advances, the cluster shows a scarcity of training programmes that articulate disciplinary didactics, educational inclusion, and mediation with AI, which justifies the need for a more comprehensive and contextualised TPD model.

4.4.2. Cluster: Artificial intelligence - Chemistry education

This thematic cluster reveals a sustained trend towards the incorporation of technologies based on artificial intelligence with the aim of transforming traditional ways of teaching and learning chemistry. Notable contributions include experiences exploring the narrative potential of AI through storytelling strategies (Nugraha & Harsono, 2023), as well as developments focusing on automated

tutors and learning environments designed to adapt to specific cognitive profiles (Nja et al., 2024; Sanusi et al., 2022).

At the same time, recent research has questioned the quality of the content generated by assistants such as ChatGPT, Gemini and Copilot, not only in terms of conceptual accuracy, but also in relation to their ability to mediate comprehension processes in chemistry (Leite, 2023, 2024). Along the same lines, studies have emerged that warn about the ethical implications of the use of these technologies in educational contexts, proposing a critical reading of their scope and limitations (Blonder & Feldman-Maggor, 2024). Other studies, meanwhile, examine their use as a strategy to dismantle pseudoscientific narratives or combat misinformation in the field of natural sciences (Dos Santos & Eichler, 2025).

However, despite the richness of these approaches, there is little literature that articulates these technological applications within explicitly inclusive pedagogical frameworks. There are still gaps in terms of proposals that integrate personalisation with educational justice, which points to a pending agenda: the need to design didactic experiences capable of combining technical precision with accessibility and equity in learning.

4.4.3. Cluster: Artificial intelligence - Professional development

The third cluster focuses on the impact of AI on teacher education processes. The included studies explore critical AI literacy (Kohnke et al., 2025; Yilmaz & Ercan, 2025), mentoring with generative AI (Lu et al., 2024), and designing technology-integrated training programmes (Dogan et al., 2025; Tan et al., 2024). Some papers also analyse teacher preparation for ethical and technical dilemmas in the use of AI (Ding et al., 2024; Kong et al., 2024), as well as the effects on self-efficacy, critical thinking and professional identity (Moorhouse, 2024; Guan et al., 2025).

This cluster reveals gaps related to the emotional and ethical approach to training: technostress, burnout, and cognitive overload emerge as critical factors that need to be addressed (Pagán-Garbín et al., 2024; Ayanwale et al., 2024). Furthermore, the need is identified for TPD models that integrate not only technical knowledge, but also the development of socio-emotional and digital justice competences.

4.4.4. Cluster: Chemistry Education – Inclusive Education

Although less dense, this cluster represents an emerging focus of high relevance. It brings together studies that analyse how chemistry teaching can be adapted to be more accessible through strategies such as problem solving in inclusive contexts (De Lima et al., 2024), the use of SAD-based educational platforms (Roski et al., 2024), or the application of ICTs designed for rural areas (Guzmán & Arana, 2025).

Ethical aspects of AI use in chemistry are also addressed (Blonder & Feldman-Maggor, 2024), although the inclusive approach is rarely systematically integrated. This cluster highlights a critical gap: most technological proposals applied to chemistry education do not consider the principle of equity as a structuring axis. This reinforces the need for a TPD model that articulates inclusion, technology and science education.

4.5. Distribution of researchs by country

The geographical distribution of the analyzed scientific production is shown in Figure 5, with a strong concentration in countries like China (6 articles) and the United States (5 articles), reflecting their leadership in the development of research linked to the integration of artificial intelligence in educational contexts. In Latin America, Colombia and Brazil stand out with 4 articles each, indicating a growing regional interest in incorporating inclusive approaches and emerging technologies in science education, particularly chemistry. Other countries, such as the United Kingdom, South Africa,

Indonesia, Spain, Canada, Israel, and Turkey, have 2 to 3 publications each, thereby contributing contextual diversity to the field. The participation of countries with lower representation, such as Kazakhstan and Germany, is also observed, which evidences a progressive global expansion of the topic. The "Others" category groups articles with multinational authorship or from nations with a single publication.

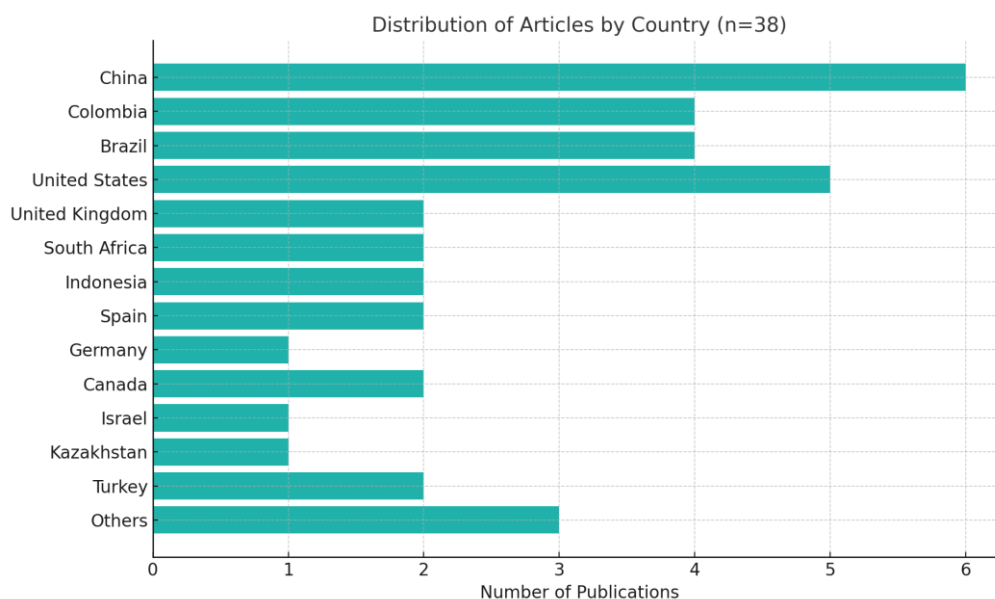


Figure 5. Publications distribution by country

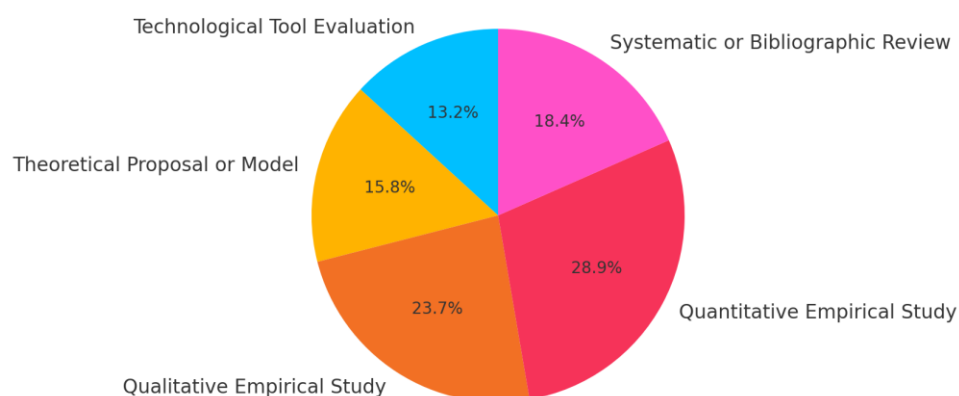
Overall, this data evidences a consolidating research field, with a greater presence of countries from the Global North and Southeast Asia. This concentration suggests the need to promote a more equitable and contextualized academic production, especially in regions with lower representation. Expanding research in these territories will strengthen the cultural, pedagogical, and technological relevance of the teacher professional development (TPD) model with artificial intelligence for inclusive chemistry teaching in diverse contexts.

4.6. Distribution of researchs by countributions

The analysis of the distribution of the 38 articles according to the type of contribution to research reveals a clear predominance of empirical approaches, both qualitative and quantitative. Figure 6 shows that quantitative studies represent 29% of the total, followed by qualitative ones at 24%. This trend suggests that a significant portion of the current literature seeks to generate concrete evidence about the impact of artificial intelligence on the teaching of chemistry from an inclusive perspective, through the use of data and systematic observations.

Secondly, systematic and bibliographic reviews (18%) stand out, as they play a key role in mapping the state of the art and identifying thematic or methodological gaps. This type of contribution is fundamental for supporting more robust and contextualized research proposals.

Distribution by Type of Research Contribution (n=38)

**Figure 6.** Distribution by type of research contributions

Theoretical or model proposals constitute 16% of the analyzed articles. This proportion, although smaller than that of empirical approaches, indicates an emerging interest in structuring conceptual frameworks that guide the design of formative experiences and teacher professional development (TPD) strategies that integrate artificial intelligence as a pedagogical mediation.

Finally, evaluations of technological tools reach 13%, indicating a field still in consolidation in terms of validating digital resources applied to diverse educational contexts, especially in the area of sciences.

Together, these results show an active and multidimensional field of study that combines theoretical exploration, practical implementation, and technological validation. However, the low percentage of studies focused on the design and evaluation of specific tools suggests the need to strengthen this line of research to advance towards more effective, personalized, and sustainable inclusive teaching models.

4.7. Gaps and theoretical implications

Based on the analysis of the 38 studies included in this systematic review, several critical conceptual and methodological gaps emerge, revealing key challenges for advancing inclusive and AI-mediated chemistry education:

- **Lack of alignment with equity and ethics.** Although many studies propose technological innovations, only a minority explicitly aligns AI applications with ethical principles, cultural diversity, or equity-oriented frameworks. Inclusive education remains a secondary concern in most contributions.
- **Insufficient longitudinal data.** None of the reviewed studies offered long-term assessments of AI's sustained impact in inclusive science education, particularly in chemistry. This limits the capacity to evaluate the durability and scalability of the proposed interventions.
- **Fragmented pedagogical models.** A significant portion of the literature focuses on either technological training, inclusive practices, or chemistry-specific didactics in isolation. Very few propose integrated TPD frameworks that bring together these three axes in a coherent and contextualized manner.
- **Geographical and contextual asymmetries.** Most contributions originate from countries with high technological infrastructure, while studies from underserved, rural, or peripheral regions are

underrepresented. This skews the relevance and applicability of existing models to more diverse educational contexts.

These findings point to the necessity of reframing Teacher Professional Development not simply as a process of technical adoption, but as a systemic, interdisciplinary, and ethically reflective endeavor. Within the reviewed corpus, AI appears as a powerful but underutilized pedagogical mediator, whose potential remains constrained by the absence of inclusive and culturally responsive approaches. Future research should aim to develop holistic TPD models that integrate disciplinary depth in chemistry, AI-enhanced learning environments, and principles of equity, accessibility, and digital justice.

4.8. Analysis of keyword co-occurrence visualizations

The keyword co-occurrence visualizations provide a structural overview of the conceptual relationships that shape the field. These figures were generated using simulated data modeled in alignment with VOSviewer principles and the 38 selected articles. Each node represents a keyword, and the size and color of the clusters denote their relative centrality and thematic grouping.

The heatmap visualization highlights the relational intensity between the four central axes of the study: chemistry education, artificial intelligence, inclusive education, and teacher professional development. Darker tones indicate more frequent co-occurrence within the literature, while lighter areas reflect weaker or emerging connections. The most robust links appear between chemistry education and professional development, and between chemistry education and AI. These intersections suggest an established trend toward AI-supported disciplinary learning and competency-based teacher education.

In contrast, the connection between inclusive education and the other categories, especially AI, appears less intense. This visual gap confirms a key insight from the literature review: although inclusion is discussed in select studies, it has yet to be systematically integrated into the dominant pedagogical discourse around AI and science education.

The semantic network graph further reinforces this interpretation. It shows chemistry education occupying a central role, acting as a hub that connects technological innovation with pedagogical strategies. The peripheral position of terms like accessibility and digital equity indicates the limited but emerging focus on inclusive frameworks. However, the presence of these terms—albeit marginal—suggests growing academic concern for the ethical and social implications of AI use in educational contexts.

Together, these visual tools not only illustrate conceptual density and dispersion across the reviewed corpus but also offer a foundation for organizing the proposed TPD model. They affirm the relevance of an integrated approach that situates AI not as a neutral technology, but as a pedagogical instrument capable of enhancing equity and transforming science education practices.

The following table (Table 3) synthesizes the relationship between the four identified thematic clusters and the studies selected through the systematic review. It highlights the main contributions, recurring authors, and pedagogical implications of each category, serving as a bridge between the keyword-based clustering and the critical discussion that follows.

Table 3. Relationship Between Thematic Categories and Reviewed Studies

SubCategorie	Title	Authors-Year	Research Contributions
Artificial Intelligence in Education	A self-determination theory (SDT) design approach for inclusive and diverse artificial intelligence (AI) education	Xia, Q., Chiu, T., Lee, M., Sanusi, I., Dai, Y. y Chai, C. (2022)	Applies SDT to inclusive and diverse AI education, providing a valuable theoretical framework for TPD that promotes motivation and inclusion in chemistry learning with AI.
	Understanding the role of study strategies and learning disabilities on student academic performance to enhance educational approaches: A proposal using artificial intelligence	Bressane, A., et al. (2024)	Uses AI to understand study strategies and learning barriers, providing an example of how AI can be used to support students with diverse needs, which is relevant for inclusion in chemistry, using artificial neural networks (ANN) and fuzzy logic-based AI.
	Artificial Intelligence Tools of Personalized Learning and Intelligent Tutoring Systems as Correlates of Students' Motivation in Chemistry	Nja, C., Uwe, U. E., & Inwang, V. (2024)	This study investigates the relationship between artificial intelligence (AI) tools for personalized learning and intelligent tutoring systems with student motivation in chemistry education. The authors examine how the integration of these technologies can influence students' intrinsic and extrinsic motivation, as well as their academic performance.
	Exploring Chinese teachers' concerns about teaching artificial intelligence: the role of knowledge and perceived social good	Lin, X.-F. et al. (2025)	It examines teachers' concerns regarding the teaching of AI and the role of knowledge and the perception of social good in its acceptance.
	Artificial intelligence professional development: A systematic review of TPACK designs and effects for teacher learning	Dogan, S., Nalbantoglu, U. Y., Celik, I., & Dogan, N. A. (2025)	The article presents a systematic review on the use of the TPACK framework in professional development programs for teachers focused on digital technologies. Identifies effective designs and empirical evidence on how these interventions improve teachers' technological-pedagogical knowledge.

	The impact of artificial intelligence on university education.	Sánchez, P., & Jaimes, A. (2024)	This study analyzes how artificial intelligence (AI) is transforming higher education in Colombia. The benefits of AI in personalizing learning, improving educational efficiency, and the need for responsible integration into pedagogical practices are highlighted.
Artificial Intelligence and TDP	Artificial intelligence in teaching and teacher professional development: A systematic review	Tan, X., Cheng, G., & Ling, M. H. (2024)	This article presents a systematic review on the use of artificial intelligence (AI) in teaching and teacher professional development. Identifies types of AI applications in educational contexts, classifies key areas such as intelligent tutoring, learning analytics, and content creation, and outlines opportunities and challenges for integrating AI into teacher training. Provides a useful framework for designing future TPD interventions with AI.
	Preparing future educators for AI-enhanced classrooms: Insights into AI literacy and integration	Kohnke, L., Zou, D., Ou, A. and Gu, M. (2025)	Analyzes the preparation of future teachers for the integration of AI, offering insights on AI literacy for teachers.
	Enhancing teacher AI literacy and integration through different types of cases in teacher professional development.	Ding, A.-C. E., Shi, L., Yang, H., & Choi, I. (2024).	The article evaluates how different types of cases (fictional, authentic, and dilemma-based) in teacher professional development programs can enhance AI literacy and its pedagogical integration. The results show that authentic cases are especially effective in strengthening the understanding and critical application of AI in teaching.
	Leading digital transformation and eliminating barriers for teachers to incorporate artificial intelligence in basic education in Hong Kong	Cheng, E., y Wang, T. (2023)	Examines and highlights the importance of digital leadership and the removal of barriers for the integration of AI in basic education.
	Graph convolutional network for automatic detection of teachers' nonverbal behavior	Pang, S., et al. (2023)	Uses neural networks for the detection of teachers' non-verbal behavior. It could be used for feedback in TPD for AI

		teaching, using graph convolutional networks.
Supporting Teachers' Professional Development With Generative AI: The Effects on Higher Order Thinking and Self-Efficacy	Lu, J., Zheng, R., Gong, Z., & Xu, H. (2024)	This study demonstrates that the use of ChatGPT as support in teacher training significantly improves self-efficacy and higher-order thinking in future teachers. Additionally, it identifies that the greatest improvements are observed in metacognitive thinking, problem-solving, and computational thinking.
A personalized learning system-supported professional training model for teachers' TPACK development	Chaipidech, P., et al. (2022)	Research a teacher training model by providing an example of a personalized learning system.
Through tensions to identity-based motivations: Exploring teacher professional identity in Artificial Intelligence-enhanced teacher training	Lan, Y. (2024)	Explores teacher professional identity in AI training. Considers teachers' tensions and motivations in AI integration.
Exploration of stress, burnout and technostress levels in teachers	Pagán-Garbín, I., et al. (2024)	Analyzes stress, burnout, and technostress in teachers. This contribution is relevant to the design of teaching and learning (TPD) programs that consider teacher well-being in the digital age, using artificial neural networks (ANNs).
Navigating the future: Exploring in-service teachers' preparedness for artificial intelligence integration into South African schools	Ayanwale, M., et al. (2024)	Explores the preparation of in-service educators for AI integration. Provides insights into TPD needs in AI.
Pre-service teachers preparedness for AI-integrated education: An investigation from perceptions, capabilities, and teachers' identity changes	Guan, L., Zhang, Y. y Gu, M. (2025)	Research the preparation of future teachers for AI-integrated education, with a focus on teacher identity.
Beginning and first-year language teachers' readiness for the generative AI age	Moorhouse, B. (2024).	Explore preparing language teachers for the use of generative AI. While focusing on languages, ideas about AI teacher training are transferable to chemistry.
Examining teachers' behavioural intention of using	Kong, S., Yang, Y., y Hou, C. (2024)	Examines the intention of teachers to use generative AI

Artificial Intelligence and Chemistry teaching	generative artificial intelligence tools for teaching and learning		tools. Can inform the TPD design that promotes adoption of AI.
	Opportunities, challenges and school strategies for integrating generative AI in education	Ng, D., Chan, E. y Lo, C. (2025)	Investigates opportunities, challenges, and school strategies for integrating generative AI into education, providing a holistic view of the integration of AI in schools.
	Perspectives of Generative AI in Chemistry Education Within the TPACK Framework	Feldman-Maggor, Y., Blonder, R., & Alexandron, G.(2024)	Explores how chemistry teachers perceive the use of generative artificial intelligence (IAg), such as ChatGPT, in chemistry teaching, framing analysis within the TPACK model.
	Integrating generative artificial intelligence in K-12 education: Examining teachers' preparedness, practices, and barriers	Yilmaz, R. M., & Ercan, O. (2025)	Discussion on how artificial intelligence can strengthen teacher professional development by facilitating learning personalization, task automation, and the use of educational analytics. Proposes a conceptual model for integrating AI in teacher education and recommends preparing educators on digital skills and artificial intelligence
	Didactic strategies involved in the use of ICT: What do teachers say about its use in the classroom?	Leite, B. S. (2022)	Examines teaching perceptions about the use of ICT, including AI, in the classroom. Contributes to teacher training design.
	Fine-tuning AI models for enhanced consistency and precision in chemistry educational assessments	Yamtinah, S., et al. (2025)	Focuses on the adjustment of AI models for assessment in chemistry, providing a concrete example of the use of AI in chemistry teaching, using Gemini 1.5, Gemini 1.0, BERT, XLNet.
	Chemistry storytelling with AI: A descriptive research of ebook creation for grade 10 students	Nugraha, C. A., & Harsono, R. J. (2023)	Research describes how the storytelling approach can increase student interest, conceptual understanding and motivation in scientific content.
	The role of learners' competencies in artificial intelligence education	Sanusi, I., Olaleye, S., Agbo, F. y Chiu, T. (2022)	Studies the skills required for AI literacy. It can inform the needs of AI teacher training for chemistry teaching.
	A ChatGPT Case Study on Misinformation: Exploring Possibilities in	dos Santos, D. C., & Eichler, M. L. (2025)	This case study explores how ChatGPT responds to incorrect information about chemistry and health in YouTube videos.

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		Evaluates the potential of chatbots as a critical teaching tool in chemistry education versus sensationalism and digital misinformation.
Expert or machine? Comparing the effect of pairing student teacher with in-service teacher and ChatGPT on their critical thinking, learning performance, and cognitive load in an integrated-STEM course	Li, T., Ji, Y., & Zhan, Z. (2024)	This study compares collaborative learning between trainee teachers and ChatGPT vs. trainee teachers in an iSTEM course. The results show that ChatGPT improves critical thinking, efficiency in tasks and reduces cognitive load, while human teachers bring more realism and pedagogical depth.
Teaching FAIR in computational chemistry: managing and publishing data using the twin tools of compute portals and repositories.	Rzepa, H. (2023)	Addresses FAIR data management in computational chemistry. Can be useful for AI integration in the TPD for chemistry, as AI requires quality data, uses computational portals and data repositories.
Generative Artificial Intelligence in chemistry teaching: ChatGPT, Gemini, and Copilot's content responses	Leite, B. S. (2024)	Evaluates AI responses to chemistry content, identifying strengths and limitations.
Artificial intelligence and chemistry teaching: a propaedeutic analysis of ChatGPT in the definition of chemical concepts	Leite, B. S. (2023)	Studies how ChatGPT defines chemical concepts, analyzing their accuracy and relevance.
Construction of personalized learning and knowledge system of chemistry specialty via the internet of things and clustering algorithm	Wang, M., & Lv, Z. (2022)	Develops a personalized learning system for chemistry students based on artificial intelligence algorithms, Internet of Things (IoT) and clustering analysis. Results show significant improvements in content understanding, motivation and academic performance compared to traditional methods.
Revisiting a teaching sequence on the topic of electrolysis: A comparative study with the use of artificial intelligence	Gonçalves Costa, G. et al. (2024)	Compare human vs. AI-generated learning sequences, with a focus on teaching electrolysis.

Inclusive Education and Chemistry teaching	Constructing a novel e-learning course, educational computational chemistry through instructional design approach in the TPASK framework	Hernández-Ramos, J. et al. (2023)	Develops e-learning course of computational chemistry based on TPASK, integrating AI as a tool.
	Teachers' perceptions on the use of problem-solving methodology for inclusive education in chemistry and science teaching	De Lima, F., Bohn, D., De Ribeiro, D. y Passos, C. (2024).	Investigates teachers' perceptions of inclusive education in chemistry, which is crucial to inform the TPD, and identifies possible areas of focus for TPD in inclusion and chemistry.
	Learning analytics and the Universal Design for Learning (UDL): A clustering approach	Roski, M., Sebastian, R., Ewerth, R., Hoppe, A., y Nehring, A. (2024)	Discusses the use of DUA-based chemistry learning platforms, a key framework for inclusion, shows how digital platforms and data analytics can support TPD and inclusion in chemistry using I3Learn Platform.
	AI for chemistry teaching: responsible AI and ethical considerations	Blonder, R., & Feldman-Maggor, Y. (2024)	Analyses the use of AI in chemistry teaching with a focus on responsibility and ethics. Proposes recommendations for integrating tools such as ChatGPT in a critical and formative way into teaching practice.
	Usability of the ICT Application "A la Materia" in chemical education: an analysis in rural environments of Montería, Colombia	Guzmán, R. D., & Arana, C. M. (2025)	This study focus on the usability of the application "A la Materia" in the teaching of chemistry in rural areas of Montería, Colombia. The results indicate that the tool improves the motivation and development of scientific competences in secondary school students in rural contexts.

5. Discussion

The systematic examination of the 38 scientific articles included in this review reveals a research panorama in constant evolution, driven by the accelerated development of artificial intelligence (AI) and its gradual incursion into the teaching of chemistry under inclusive and pedagogically reflective frameworks. Although the literature evidences notable advances in terms of technological experimentation and disciplinary application, it also exposes structural tensions and conceptual asymmetries that merit critical attention.

In the first instance, a notable trend emerges: the proliferation of studies focused on the incorporation of AI in science education—particularly chemistry—reflects a growing pedagogical interest in these tools. However, such interest frequently adopts a technocentric approach, where

the innovations presented are not always accompanied by solid didactic foundations or coherent integration with broader educational goals. These findings echo previous critiques that warn of the risks of instrumentalizing AI without sufficient pedagogical reflection or ethical anchoring.

Secondly, teacher professional development (TPD) emerges as a crucial but unevenly addressed axis. While several studies demonstrate the potential of AI to strengthen teachers' metacognitive skills, autonomy, and instructional planning, affective dimensions—such as technostress, ethical dilemmas, or professional identity tensions—are generally underexplored. This suggests the need to move towards more holistic and systemic TPD models that transcend technical training and incorporate emotional, ethical, and sociocultural aspects of educational practice.

A third observation refers to the peripheral role that inclusive education occupies in the current academic discourse. Although some contributions address issues of accessibility, Universal Design for Learning (UDL), or contextualised practices in rural or vulnerable territories, the concept of inclusion tends to be treated as a complementary element rather than a guiding principle. This lack of centrality raises significant concerns, especially in light of the global challenges of inequality in access to quality education and the ethical imperative of designing fair and representative learning environments.

The graphical analyses of co-occurrence and semantic mapping reinforce these interpretations. The dominant triad—artificial intelligence, chemistry education, and professional development—forms a robust conceptual core, while inclusion and accessibility appear at the edges of the network. This visual and structural asymmetry reflects a broader imbalance in research agendas and underscores the urgency of articulating integrative models capable of interweaving technological innovation with the ethical, political, and didactic demands of inclusive education.

In this sense, the model proposed in section 4.4 acquires special relevance, as it offers an alternative for reconceptualising teacher training in the digital era. Rather than favoring fragmented or technocratic approaches, it advocates for an interdisciplinary and context-sensitive model that positions AI not only as an instructional support, but as a pedagogical mediator imbued with ethical, cultural, and disciplinary meaning. The advancement of this model necessarily requires future research lines that include longitudinal studies, participatory design methodologies, and greater geographical and sociocultural representativeness—dimensions that will be explored in the following sections.

5.1. Artificial intelligence

The reviewed studies converge in pointing out that AI is profoundly transforming teaching-learning environments, allowing for greater personalization, adaptability, and efficiency. However, ethical, technological, and educational tensions are also evident. Xia et al. (2022) propose an approach based on Self-Determination Theory that provides keys to fostering intrinsic motivation in inclusive AI contexts. For their part, Bressane et al. (2024) and Nja et al. (2024) demonstrate how intelligent systems allow for personalized learning and cater to students with diverse needs, although without thoroughly exploring the criteria for universal accessibility or their long-term effects.

Sánchez and Jaimes (2024) propose an ethical approach to the integration of AI in higher education, but there is a lack of empirical studies addressing its effects in institutions in rural contexts or with pronounced technological gaps. Lin et al. (2025) explore teachers' perceptions of AI teaching, providing a sociocultural perspective that is still underexplored. Dogan et al. (2025) provide a systematic review focused on the TPACK model, but the need for studies that link this framework with inclusive and discipline-specific approaches, such as chemistry, is identified.

Overall, the reviewed literature is rich in technological proposals and pedagogical innovations, but it reveals certain gaps that limit its applicability and scope. There is a noticeable absence of longitudinal studies that allow for an understanding of the sustained effects of AI on teacher

professional development, as well as a lack of representation of research contextualized in countries of the Global South. Furthermore, there is a lack of critical analysis on algorithmic bias in vulnerable educational contexts, which is especially relevant when considering the implementation of AI in scenarios of structural inequality.

5.2. Inclusive education

The inclusive component in chemistry teaching is scarcely addressed in the literature, although some studies offer valuable contributions. De Lima et al. (2024) show how the problem-solving methodology can be adapted to inclusive contexts, highlighting teacher mediation and respect for cognitive diversity. Guzmán and Arana (2025) demonstrate the effectiveness of a TIC application in rural contexts, although there is a lack of studies evaluating the differential impact based on gender or disability.

The study by Roski et al. (2024) highlights the potential of UDL and learning analytics to adapt digital platforms to the needs of diverse students. Blonder and Feldman-Maggor (2024), on the other hand, propose ethical principles for the use of AI in chemistry, focused on responsibility and equity. However, an important thematic gap persists: there are few studies that articulately integrate the approaches of inclusion, artificial intelligence, and chemistry education. Most research tends to address these dimensions in isolation, which limits their coherent and contextualized curricular application. In this sense, there is a projected need to consolidate a line of research that promotes the design of inclusive educational resources mediated by AI, specifically aimed at teaching chemistry in contexts characterized by functional, social, and territorial diversity.

5.3. Chemistry teaching

The teaching of chemistry has benefited from the use of artificial intelligence in various functions, ranging from automatic evaluation to the generation of interactive content. Yamtinah et al. (2025) employ models like BERT and Gemini to optimize precision in evaluative processes, while Wang and Lv (2022) integrate clustering algorithms to build adaptive learning environments, achieving notable improvements in conceptual understanding and student motivation. However, much of this progress has been developed in experimental or controlled environments, without robust evidence of its sustained large-scale implementation.

Some studies focus on specific tools like ChatGPT. For example, dos Santos and Eichler (2025) analyze its utility as a critical literacy tool in chemistry, especially in identifying and correcting misinformation in digital media. Leite (2023, 2024) focuses on the conceptual accuracy of the definitions generated by this tool, warning of relevant semantic limitations. Similarly, Feldman-Maggor et al. (2024) and Gonçalves Costa et al. (2024) compare content created by teachers with that produced by AI systems, recognizing advantages in the structure of automatically generated materials, but also pointing out deficiencies in their didactic depth.

In theoretical terms, the absence of an integrative pedagogical framework that solidly articulates artificial intelligence with the principles of specific chemistry didactics still persists. Current research tends to focus on academic performance metrics, sidelining equally relevant dimensions such as student attitudes, critical thinking, or the ethical implications of using these technologies. In light of this, it is necessary to promote interdisciplinary research that links specialists in artificial intelligence and science didactics, with the aim of building coherent pedagogical models and educational tools aligned with competency-based approaches and the principles of inclusive STEM education.

5.4. TPD Model for Inclusive Chemistry Teaching

The incorporation of artificial intelligence in teacher training presents itself today as an unavoidable necessity, especially in educational contexts that demand innovation, inclusion, and

adaptability. However, the literature review reveals a notable fragmentation in the approaches used, as well as a lack of systematization of successful experiences. Some works, such as those by Tan et al. (2024) and Ding et al. (2024), have made progress in constructing solid conceptual frameworks for teacher literacy in AI, highlighting strategies like the use of authentic cases and ethical dilemmas to strengthen the critical understanding of these tools. In turn, Lu et al. (2024) provide empirical evidence on the benefits of using ChatGPT in improving the self-efficacy and metacognitive thinking of future teachers. However, it is still pending to examine whether these learnings are sustained over time and how they are transferred to real pedagogical practice.

On the other hand, research such as that of Cheng and Wang (2023), Ayanwale et al. (2024), and Guan et al. (2025) highlights that many of the difficulties are not solely due to technology, but rather to persistent structural barriers and gaps in initial and ongoing teacher training. Although Moorhouse's (2024) study focuses on language teachers, its findings provide valuable insights for other areas such as chemistry, particularly in highlighting the importance of developing critical competencies in response to the use of generative AI.

In this context, significant contrasts are observed: while some studies highlight the transformative potential of artificial intelligence in teacher training, others warn about the risks of adopting a technocentric approach without a solid pedagogical foundation. Lan's (2024) work, for example, offers an uncommon perspective by addressing the identity tensions that emerge when teachers integrate AI into their professional practice, a topic that is often absent in most reviewed research.

Looking ahead, a promising line of work opens up that invites us to think about hybrid models of teacher training, where the support of intelligent technologies complements human mentorship. It also becomes essential to advance in longitudinal studies that analyze the impact of these tools on the professional identity of teachers, as well as in the design of adaptive professional development programs that not only enhance technical skills but also address the emotional well-being of the teaching staff, as suggested by the findings of Pagán-Garbín et al. (2024).

The present diagram (figure 7) proposes a training model for Teacher Professional Development (TPD) based on the intersection of four fundamental dimensions: Artificial Intelligence (A), Reflective Pedagogical Practices (B), Inclusive Education (C), and Teaching of Chemistry (D). At its core lies the convergence zone $X = A \cap B \cap C \cap D$, which constitutes the articulating axis of the model, aimed at training teachers capable of responding to contemporary educational challenges with a critical, inclusive, technological, and disciplinary vision.

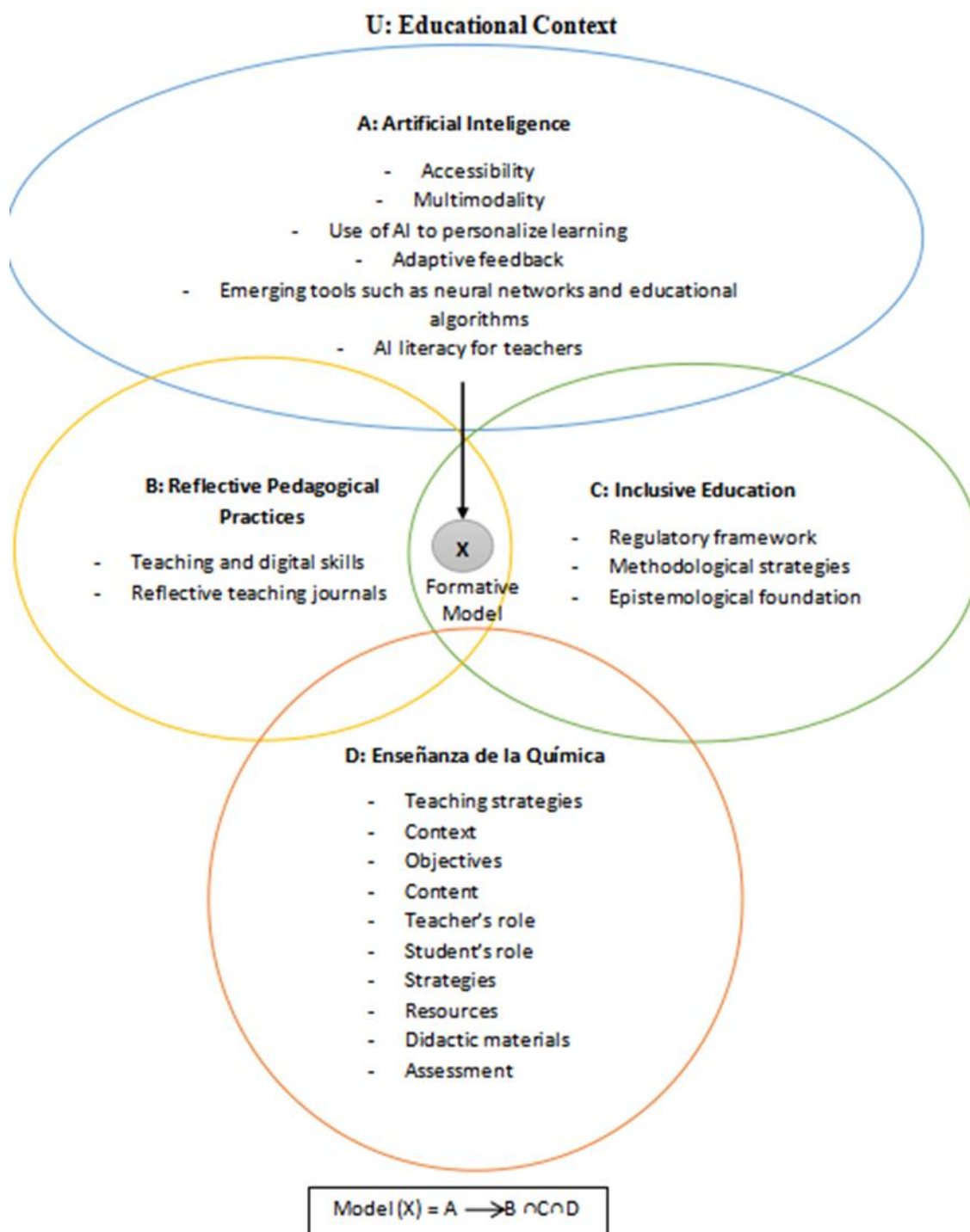


Figure 7. TPD Model for Inclusive Chemistry Teaching

Component A (Artificial Intelligence) incorporates the use of emerging technologies for personalized learning, adaptive feedback, and teacher literacy in AI. Dimension B (Reflective Pedagogical Practices) promotes the development of didactic and digital skills through the systematic self-reflection of teaching practices, as a way to strengthen pedagogical decision-making. On its part, C (Inclusive Education) provides the necessary normative, methodological, and epistemological framework to guarantee the right to equitable and quality education. Finally, D (Chemistry Teaching) structures the key didactic elements—such as objectives, content, strategies, evaluation, and resources—that must be critically addressed in the training processes.

In the diagram, the synergies between these categories can be recognized: the integration of AI in teacher training ($A \cap B$), the articulation of inclusive approaches in reflective practices ($B \cap C$), the continuous improvement of disciplinary teaching through critical reflection ($B \cap D$), the incorporation of AI in inclusive contexts ($A \cap C$), its application in chemistry teaching ($A \cap D$), and inclusion as a transversal axis in that teaching ($C \cap D$).

Thus, this TPD model aims to train competent teachers to integrate artificial intelligence, an inclusive approach, and pedagogical reflection in chemistry teaching, fostering more relevant, contextualized, and transformative educational processes. It is expected that this work will contribute to the field of TPD by providing an innovative model that integrates AI, accessibility, and multimodality for the teaching of chemistry. The model will provide teachers with the necessary tools and strategies to implement inclusive and personalized teaching practices, leveraging the potential of AI.

5.5. Limitations and future directions

The systematic review reveals several conceptual, methodological, and contextual limitations within the analyzed literature. A prominent gap lies in the limited alignment of artificial intelligence initiatives with principles of equity, ethics, and cultural diversity—dimensions that are critical in inclusive education frameworks. Most studies emphasize technological potential but overlook the socio-pedagogical complexities involved in deploying AI in diverse classroom settings.

Additionally, the scarcity of longitudinal research restricts the understanding of AI's sustained impact on teaching practices and student learning outcomes in inclusive chemistry education. The predominance of pilot studies and short-term interventions limits the generalizability and scalability of findings.

Another critical limitation is the fragmented integration of teacher professional development (TPD) models that combine disciplinary expertise, technological fluency, and inclusive pedagogy. While isolated efforts exist, there is no consolidated framework that offers holistic guidance for TPD programs in AI-mediated environments.

Future research should address these gaps through interdisciplinary designs that bridge educational technology, inclusive science education, and teacher training. Longitudinal studies are especially needed to evaluate the long-term effects of AI on teacher identity, instructional quality, and student equity outcomes. Additionally, expanding research in underrepresented regions, particularly in the Global South, will enrich the field with culturally grounded perspectives and pedagogical practices.

To address the challenge of unequal academic representation, this study advocates for concrete strategies to foster more equitable knowledge production. Future research should prioritize the development of South-South research networks and collaborative initiatives that amplify the voices of scholars and educators working in underserved, rural, or socioeconomically marginalized contexts. Scientific journals and academic institutions are encouraged to launch special calls focused on inclusive education and AI integration in underrepresented regions, while promoting multilingual publication formats. Additionally, creating open-access repositories that curate high-quality grey literature produced by regional universities can help bridge visibility gaps. Finally, participatory methodologies that engage teachers as co-researchers in the design of inclusive TPD models are essential to ensure contextual relevance and epistemic justice.

6. Conclusion

The systematic review has conducted an updated, critical, and multidimensional diagnosis at the intersection of artificial intelligence, inclusive education, and chemistry teaching, with special

attention to TPD as the articulating axis. The results of the systematic review show that there has been a plethora of academic production related to the introduction of AI in educational spaces, especially since 2023, highlighting a rapidly evolving field, driven by the environment of emerging technologies, among which generative AI, intelligent tutoring systems, etc., stand out. The results of the review are presented in thematic lines, and thus four major clusters have emerged: (1) the teaching of chemistry as the main axis of pedagogical innovation, (2) the integration of AI in educational processes, (3) the design of TPD models mediated through technology, and (4) inclusion as a cross-cutting theme still in its early stages. The ideological cores created within the major thematic categories are clearly represented in the co-occurrence analyses, both in the heat map and in the network graph, drawing an increasingly interconnected field that, however, exemplifies significant challenges to overcome.

7. Limitations and challenges of the research

This study is subject to several limitations that should be considered when interpreting its findings. First, the document corpus was restricted to articles indexed in Scopus and Web of Science and published between 2020 and 2025. Although this range ensured methodological consistency and recency, it may have excluded relevant grey literature, non-indexed regional journals, and publications in languages other than English, Spanish, and Portuguese.

Second, the PRISMA search employed a predefined Boolean equation that privileged explicit references to “artificial intelligence,” “chemistry teaching,” “inclusive education,” and “teacher professional development.” Consequently, studies that addressed AI implicitly—e.g., machine-learning analytics in science classrooms—without using these exact descriptors may have been overlooked.

Third, the review relied on open-coding procedures conducted by two independent researchers and subsequently triangulated; nevertheless, researcher bias cannot be entirely eliminated. Although blind coding and consensus meetings were employed to enhance reliability, interpretive subjectivity may still influence theme identification and cluster naming.

Fourth, the visualisations (heat map and semantic network) were generated with simulated keyword-frequency data derived from the analysed abstracts. While these graphics illustrate relational patterns effectively, they do not represent a full bibliometric co-citation analysis; thus, the density and positioning of nodes should be interpreted as indicative rather than exhaustive.

Fifth, the study’s analytical focus was confined to secondary-education chemistry contexts. Although this delimitation offers disciplinary depth, it limits the transferability of conclusions to other STEM subjects or educational levels. Moreover, the linguistic and geographic scope of the databases consulted may bias the representation of contributions from non-English-speaking or underrepresented regions.

Finally, the absence of longitudinal studies in the reviewed literature restricts the capacity to evaluate the sustained impact of AI-driven interventions in inclusive chemistry education over time. Future research may broaden the scope to primary, tertiary, and informal learning environments, incorporate multilingual sources, and adopt longitudinal designs to test the robustness and adaptability of the proposed TPD model.

Despite these constraints, the systematic approach, dual-review validation, and transparent reporting strengthen the credibility of the findings. Acknowledging these limitations provides a foundation for refining subsequent investigations and advancing toward more equitable and context-sensitive models of AI-mediated teacher development.

8. Suggestion

Based on a systematic analysis of the existing literature and the limitations identified in the convergence of artificial intelligence (AI), inclusive education, and chemistry teaching, various research avenues are identified with the potential to consolidate innovative and relevant pedagogical frameworks for this field.

A first line of inquiry focuses on the design and validation of teacher professional development models that integrate AI with an inclusive approach in the context of scientific disciplines. The current conceptual fragmentation between technology-centered proposals and those addressing educational diversity suggests the need for future research that articulates these dimensions. This could be achieved through adapted pedagogical strategies, personalized intelligent tutoring systems tailored to the teacher's profile, and content that respects the cognitive and sociocultural diversity of the students.

Secondly, there is an urgent need to incorporate accessibility in the design of AI tools intended for the teaching of chemistry, based on the principles of Universal Design for Learning (UDL). Digital inclusion must transcend mere access, considering various modalities of content representation, interaction with resources, and assessment of learning. Future research could explore the integration of multimodal interfaces, inclusive learning analytics, and adaptable algorithms for students with disabilities, all within real school contexts.

A third emerging line involves the critical analysis of the role of generative AI in chemistry education, particularly concerning the veracity of information, the promotion of critical thinking, and the development of scientific judgment among both teachers and students. In this sense, studies like those of Dos Santos and Eichler (2025) illustrate how ChatGPT can influence the spread of misinformation, either positively or negatively. It would be pertinent to delve deeper into the design of training activities that empower teachers and students to evaluate, reinterpret, and rectify AI-generated responses in light of disciplinary knowledge.

Likewise, there is a trend towards the use of neural networks and deep learning algorithms as support in teacher evaluation, formative feedback, and the prediction of learning trajectories. Although preliminary research (Pang et al., 2023; Bressane et al., 2024) has advanced in this direction, a more thorough exploration of its ethical, transparent, and contextualized application in educational environments characterized by high diversity is still required.

Finally, it is crucial to outline a research path aimed at the regionalization of knowledge, through case studies in specific contexts of Latin America, rural areas, and communities with digital gaps. This approach would allow for the validation of TPD proposals with AI adapted to specific sociocultural realities and the generation of contextualized and sustainable educational innovation policies.

In summary, the identified trends open a vast array of opportunities for the development of research that delves into the critical articulation between AI, inclusion, and science education, especially from a formative and ethical perspective that recognizes the inherent complexity of educational processes in the 21st century.

Declarations

Author Contributions. P.A.E.P.: Conceptualization, literature review, methodology, and manuscript writing. K.P.A.A.: Data curation, analysis, and thematic synthesis. E.P.F.N.: Critical review, editing, and visualization support. All authors have read and approved the final version of the manuscript.

Conflicts of Interest. The authors declare no conflict of interest.

Funding. This research received no external funding.

Ethical Approval. This study did not involve human or animal participants. No ethical approval was required. However, the authors ensured compliance with academic ethical standards in data analysis and reporting.

Data Availability Statement. The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgments. The authors would like to thank the Doctoral Program in Science Didactics at the University of Córdoba, Colombia, for the academic support provided throughout the research process.

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