Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Artificial Intelligence in Science Teaching: An Inductive Typology of Teacher Use and Its Alignment with Artificial Intelligence Literacy Frameworks

Konstantinos Karampelas

kkarampelas@aegean.gr

University of the Aegean

Research Article

Keywords: Artificial intelligence in education, Science education, Teacher practices, AI literacy, OECD AI literacy framework, Pedagogical integration, Document-based analysis, Educational technology, Instructional design, Assessment and feedback

Posted Date: March 10th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9062130/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Artificial intelligence (AI) is increasingly recognized as a transformative force in education; however, limited attention has been given to systematically examining how teachers represent AI use within subject-specific contexts. This study therefore aims to develop an empirically grounded classification of AI use in science education on the basis of an analysis of 795 Scopus-indexed journal articles. Using a qualitative document-based approach, the article abstracts were inductively analyzed to identify recurring pedagogical functions attributed to AI in science teaching. Six nonexclusive categories emerged: instructional delivery and pedagogy, assessment and feedback, lesson planning and curriculum design, interactive agents, simulations and virtual environments, and teacher professional development and support. In a second analytical stage, these categories were interpreted through the Organization for Economic Cooperation and Development (OECD) AI literacy framework to examine how documented practices align with broader domains of AI engagement. The findings indicate that AI is predominantly framed as a support resource for classroom interaction and assessment processes, with strong alignment with engagement-oriented and design-mediated modes of AI use. Overall, the literature positions teachers as pedagogical integrators who interpret and structure AI within existing instructional practices rather than as technical developers. The study therefore offers a large-scale, practice-oriented typology of AI use in science education and provides an analytically grounded bridge between empirical representations and AI literacy discourse.

1. Introduction

Over the years, artificial intelligence (AI) has rapidly transitioned from a speculative technological horizon to an increasingly embedded presence within educational discourse and practice. Across policy documents, research publications, and institutional strategies, AI is frequently portrayed as a transformative force that can reshape teaching, learning, and assessment. However, despite the proliferation of AI-related tools and the intensification of the debate concerning their implications, considerable ambiguity persists regarding how AI is integrated into everyday educational practice, particularly at the subject level. Discussions often emphasize potential, innovation, or systemic reform, while comparatively less attention is given to understanding how teachers operationalize AI within their pedagogical routines (UNESCO, 2021; U.S. Department of Education, 2023; Garzón et al., 2025).

This ambiguity is especially salient in science education, a domain characterized by distinctive epistemic practices such as inquiry, modeling, experimentation, and evidence-based reasoning. The integration of new technologies into science teaching is rarely a neutral practice, as it interacts with disciplinary content, representational forms, and pedagogical traditions. AI, with its capacity for adaptive feedback, generative content production, simulation, and data-driven decision support, introduces additional layers of complexity. Whether AI reinforces established instructional structures or enables new modes of disciplinary engagement largely depends on how it is interpreted and enacted by teachers within specific educational contexts (Lee et al., 2025; Petko et al., 2025).

Concurrently, the expanding body of literature on AI in education presents a paradox: on the one hand, bibliometric analyses and systematic reviews document a rapidly growing research landscape, while on the other hand, much of this literature remains fragmented across tool-specific studies, intervention-based reports, or normative discussions of future-oriented AI integration. Consequently, obtaining a coherent, practice-oriented overview of how teachers' use of AI is currently conceptualized in science education research is challenging. Without such an overview, both theoretical discussions of AI literacy and practical debates about teacher education risk proceeding without a clear understanding of the patterns already emerging in published scholarship (Biagini, 2025; Nikolinakos, 2023).

Moreover, while AI literacy frameworks and policy models provide valuable conceptual vocabularies for describing engagement with AI, they do not clarify how AI is positioned within disciplinary teaching practice. Frameworks articulate domains of engagement, competence, or responsibility, but the empirical question of how teachers use AI within science classrooms and preparatory work remains insufficiently systematized. Given this, bridging this gap requires an approach grounded in the analysis of documented practice yet capable of connecting such analysis to broader conceptual structures without imposing them prematurely (Chee et al., 2025; OECD, 2025).

Against this backdrop, the present study sought to provide a systematic and empirically grounded classification of how AI is represented as being used by teachers in science education. Drawing on a large corpus of Scopus-indexed publications, the study developed an inductive typology of AI use on the basis of recurring pedagogical functions described in the literature. In the second analytical stage, these empirically derived categories were interpreted through the lens of an established AI literacy framework, allowing for a structured examination of how documented practices align with broader modes of AI-related engagement. Thus, by separating category development from conceptual alignment, the study aimed to contribute both descriptive clarity and theoretical integration.

By clarifying how AI use is currently framed within science education research, this study contributes to ongoing discussions concerning teacher agency, pedagogical design, and AI literacy in subject-specific contexts. Rather than asking whether AI should be integrated into education, this study addresses a more fundamental question: how is AI already being positioned within science teaching, as represented in academic discourse? Answering this question is essential for informing future research, guiding teacher education initiatives, and grounding policy discussions in a more comprehensive understanding of the existing research landscape (Petko et al., 2025; Chee et al., 2025).

2. Literature Review

2.1 AI in the Context of General Education

AI has increasingly been positioned as a transformative technology in the field of education, influencing key aspects of teaching, learning, and assessment. Policy-oriented and conceptual texts describe AI as a broad set of computational systems capable of supporting educational processes through automation,

adaptation, and data-informed decision-making. In educational settings, AI-related applications range from adaptive learning environments and intelligent tutoring systems to automated assessment and feedback tools, as well as generative technologies that assist with instructional preparation. Rather than representing a single pedagogical approach, AI is presented as a flexible technological infrastructure whose educational significance largely depends on how it is embedded within teaching practices and institutional contexts (UNESCO, 2021; U.S. Department of Education, 2023; Biagini, 2025).

Simultaneously, the literature stresses that the integration of AI into education is neither uniform nor pedagogically self-evident. While AI is often associated with enhanced personalization and efficiency, its educational value cannot be assumed to be independent of teachers' professional judgment and instructional goals; consequently, AI in education is frequently discussed in terms of anticipated potential rather than systematically documented practice. This has led to calls for empirical and analytical work that examines how AI is actually implemented, interpreted, and enacted within teaching processes rather than focusing solely on technological capabilities or projected outcomes (Li et al., 2025; Lee et al., 2025).

A further distinction emerging in the literature concerns the difference between *learning with AI* and *learning about AI*. Whereas learning *with* AI refers to the use of AI systems as tools to support teaching and learning across subject areas, learning *about* AI involves developing knowledge and understanding of AI concepts, systems, and implications. Notably, although both orientations are increasingly visible in educational discourse, they serve different analytical purposes. The present study focused exclusively on learning *with* AI—specifically, how AI is employed by teachers as part of their instructional, planning, and assessment practices—rather than on AI as curricular content in itself.

While the broader educational literature increasingly acknowledges the transformative potential of AI, it also stresses that the educational significance of AI does not lie solely in technological systems. How AI is interpreted, adopted, and embedded within educational practice is shaped primarily by teachers' pedagogical intentions, professional knowledge, and contextual constraints; consequently, understanding the role of AI in education requires shifting analytical attention from technological affordances to the actors who make decisions about its use in classrooms. This perspective positions teachers not as passive recipients of AI-driven innovation but as central agents whose choices determine how, and for what purposes, AI is integrated into teaching and learning processes (UNESCO, 2021; U.S. Department of Education, 2023; Petko et al., 2025).

The integration of AI into educational practice is increasingly understood as a process mediated by teachers rather than determined solely by technological capabilities. Across contemporary educational literature, teachers are positioned as key decision-makers who interpret, adapt, and appropriate digital tools in ways that align with pedagogical aims, curricular requirements, and classroom realities. AI systems do not enter educational settings as neutral or self-directing innovations; rather, their instructional role is shaped by teachers' professional judgments regarding when, how, and for what purposes such systems should be used. This perspective underscores the importance of examining AI

use through the lens of teaching practice rather than treating AI as an autonomous driver of educational change (Petko et al., 2025; Lee et al., 2025).

Recent scholars further emphasize that teachers' engagement with AI is influenced by a complex interplay of professional knowledge, beliefs, and contextual factors. Decisions related to AI use are embedded within broader pedagogical considerations, including instructional goals, assessment strategies, and perceptions of student needs. As a result, the same AI tool may be employed in markedly diverse ways across classrooms or educational systems. This variability challenges generalized claims about "AI in education," instead calling for analytical approaches that capture the diversity of teacher-mediated uses. Understanding how teachers position AI within their instructional repertoire is, therefore, essential for developing a more nuanced account of AI integration in educational practice (Garzón et al., 2025; Nikolinakos, 2023).

Policy-oriented and research-informed documents highlight the significant role of teachers in shaping the educational impact of AI. Rather than framing AI adoption as a technical implementation issue, these sources stress the need to consider teachers' agency, professional learning, and interpretive work. AI-related innovations are often discussed as tools that can support lesson planning, classroom instruction, assessment, and professional reflection. However, the literature acknowledges that such uses depend on teachers' capacity to integrate AI meaningfully into existing pedagogical frameworks. This recognition reinforces the perspective that empirical attention should focus on how AI is actually utilized in teaching practice rather than on prescriptive models of AI use (U.S. Department of Education, 2023; Biagini, 2025).

Taken together, these perspectives suggest that studying AI in education requires moving beyond tool-centered descriptions to examine teachers' enacted practices. By focusing on teachers as active agents who shape the role of AI within educational contexts, researchers can provide a more comprehensive understanding of how AI functions in teaching environments. This orientation is particularly relevant for subject-specific domains, such as science education, where instructional decisions are closely tied to epistemic practices, representations, and modes of inquiry. Thus, a systematic analysis of how teachers use AI, as reflected in published research, offers an important pathway for clarifying current patterns of AI integration and identifying areas where further pedagogical and conceptual development is needed (Jufrida et al., 2025; Petko et al., 2025).

The integration of digital technologies into teaching has long been examined through conceptual frameworks designed to capture the complex relationships among pedagogy, subject matter, and technological tools. Instead of treating technology as an external addition to instruction, these frameworks argue that meaningful integration depends on how technological affordances align with pedagogical intentions and disciplinary knowledge. Within this tradition, technology integration is understood as a situated and interpretive process shaped by teachers' professional expertise and instructional contexts rather than as a linear progression driven solely by technical adoption (U.S. Department of Education, 2023).

One of the most influential models in this area is the technological pedagogical content knowledge (TPACK) framework, which conceptualizes teachers' knowledge as the dynamic intersection of content knowledge, pedagogical knowledge, and technological knowledge. The central contribution of TPACK lies in its emphasis on integration: effective technology use emerges not from isolated competencies but from teachers' ability to coordinate technological possibilities with pedagogical strategies and subject-specific representations. From this perspective, technologies do not prescribe instructional practices; rather, their educational value is realized through teachers' decisions about how they support learning goals within particular disciplinary domains (Mishra & Koehler, 2006; Koehler & Mishra, 2009).

Notably, frameworks such as TPACK are not intended to function as taxonomies of specific tools or practices; instead, they provide conceptual guidance for understanding *how* teachers think about and enact technology use in teaching. This distinction is especially relevant when considering emerging technologies such as AI, whose applications are diverse and rapidly evolving. Applying technology integration frameworks to AI does not require defining in advance what "appropriate" AI use looks like; as such, frameworks support analytical attention to the pedagogical reasoning and contextual factors that shape teachers' engagement with AI in practice (Nikolinakos, 2023; UNESCO, 2021).

In this sense, technology integration frameworks offer a way to frame AI use in teaching as a pedagogical phenomenon rather than a technical phenomenon. They justify an analytical focus on teachers' enacted practices while avoiding prescriptive or evaluative assumptions about technology use. In the context of the present study, these frameworks establish that understanding AI integration requires being attentive to the interplay of teaching goals, disciplinary content, and technological tools. However, they are employed not to classify or evaluate specific AI uses but to provide a conceptual backdrop against which empirically grounded categories of AI use can later be interpreted (Koehler & Mishra, 2009; Mishra & Koehler, 2006).

2.2 AI literacy and competence frameworks

While technology integration frameworks such as TPACK provide valuable insights into how teachers coordinate pedagogical, technological, and disciplinary knowledge, they were developed before the widespread emergence of AI as an educational technology. As a result, they offer limited guidance for capturing the distinctive characteristics of AI, including its data-driven nature, adaptive behavior, and capacity to generate content or feedback autonomously. The growing presence of AI in educational contexts has prompted the development of AI-specific literacy and competence frameworks that articulate the kinds of understanding and practices required for meaningful engagement with AI in teaching and learning. These frameworks do not replace existing models of technology integration but rather extend them by addressing features of AI that raise new pedagogical, professional, and institutional considerations (Chee et al., 2025; Koehler & Mishra, 2009; Mishra & Koehler, 2006).

With the emergence of AI-specific concerns in education, the concept of AI literacy has gradually gained more attention as a way of articulating the knowledge, skills, and practices required to engage meaningfully with AI technologies. AI literacy frameworks extend earlier notions of digital or

technological literacy by focusing on the distinctive features of AI systems, such as algorithmic decision-making, data dependency, adaptivity, and the partial automation of cognitive tasks. Within educational discourse, AI literacy is not limited to technical understanding but encompasses the ability to use AI tools critically, interpret their outputs, and situate their use within pedagogical and institutional contexts. As such, AI literacy frameworks provide conceptual language for discussing what it means to engage with AI in educational practice without prescribing specific tools or instructional strategies (Biagini, 2025; Chee et al., 2025).

A key feature of contemporary AI literacy frameworks is their emphasis on functional engagement rather than technical mastery alone. Instead of focusing exclusively on how AI systems are built, these frameworks focus on how AI is encountered, applied, and managed in real-world contexts, including educational settings. This orientation is especially relevant for teachers, whose professional engagement with AI often involves using, adapting, or overseeing AI-supported processes rather than developing AI systems themselves. From this perspective, AI literacy frameworks offer a way to conceptualize teachers' interactions with AI that aligns with pedagogical practice and professional responsibility while remaining sufficiently flexible to accommodate diverse educational contexts and subject domains (Chee et al., 2025; Garzón et al., 2025).

Among the existing AI literacy and competence frameworks, the OECD (2025) AI literacy framework provides a structured yet nonprescriptive model for understanding engagement with AI across educational and societal contexts. It organizes AI literacy into four broad domains: engaging with AI, creating with AI, managing with AI, and designing AI. These domains capture different modes of interaction with AI systems, ranging from use and application to oversight and development. Importantly, the OECD framework is not formulated as a curricular sequence or an evaluative hierarchy but as an analytical framework that can be applied across disciplines and educational levels to examine how individuals and institutions relate to AI technologies.

Within the OECD AI literacy framework, the four domains describe distinct but potentially overlapping modes of engagement with AI. Engaging with AI refers to interacting with AI systems as users, including applying AI tools in educational activities and interpreting their outputs. Creating AI involves the use of AI systems to generate or modify content, such as instructional materials, learning resources, or assessment artifacts, without requiring the development of the AI systems themselves. Managing with AI encompasses overseeing, evaluating, and making decisions about AI-supported processes, including monitoring performance, interpreting feedback, and exercising professional judgment regarding AI-generated outcomes. Finally, designing AI refers to more advanced forms of engagement that involve shaping, configuring, or developing AI systems or models, including considerations related to system design, training, or adaptation. These domains are intended to function as analytical descriptors of engagement, not as a hierarchical progression or an evaluative framework.

The functional orientation of the OECD framework makes it particularly suitable for analytical purposes in studies that seek to interpret existing practices rather than prescribe ideal forms of AI use. By

focusing on modes of engagement instead of specific tools or outcomes, the framework allows for the mapping of heterogeneous practices onto a common conceptual structure. This is especially relevant in the context of science education, where AI may be employed for instructional support, assessment, simulation, planning, or professional reflection, often in an overlapping fashion. The OECD framework accommodates such complexity by allowing multiple domains to coexist, reflecting the multifaceted nature of teachers' interactions with AI in practice (OECD, 2025).

In the present study, the OECD (2025) AI literacy framework was employed not to define or delimit categories of AI use but as a second-order analytical lens that enables the interpretation of empirically identified patterns of AI use by teachers. By aligning inductively derived categories with the OECD domains, the study sought to explore how documented uses of AI in science teaching correspond to broader conceptions of AI literacy and competence. This approach preserves the grounded nature of the initial classification while situating the findings within a policy-relevant and conceptually robust framework, thereby enhancing the interpretive depth and relevance of the analysis (Li et al., 2025; Crawford, 2025).

2.3 Methodological positioning and identified research gap

Despite the growing volume of research and policy-oriented discourse on AI in education, the literature reveals a notable gap in systematic, practice-oriented analyses of how teachers actually use AI in their teaching. While conceptual frameworks and strategic documents articulate broad expectations regarding AI integration, they often remain at a normative or prospective level, offering limited insight into the concrete forms that AI use takes within educational practice. Concurrently, existing empirical studies frequently focus on specific tools, interventions, or outcomes, making it difficult to obtain a coherent overview of the diverse ways in which AI is positioned within teaching processes across contexts. This fragmentation highlights the need for analytical approaches that synthesize published research in a manner that foregrounds practice rather than isolated technologies or effectiveness claims (Lee et al., 2025; Petko et al., 2025).

Bibliometric and mapping studies have contributed to understanding the growth, distribution, and thematic emphasis of research on AI in education; however, they are limited in their capacity to generate conceptual insights into pedagogical practice. By design, bibliometric indicators capture patterns of publication, citation, and keyword co-occurrence, but they do not adequately address questions related to the *nature* of AI use in teaching. Recent methodological discussions have argued for combining large-scale document analysis with qualitative and interpretive techniques that facilitate theory development grounded in empirical material. Such approaches enable researchers to move beyond descriptive mapping and toward identifying meaningful categories that reflect how educational practices are represented in the literature (Crawford, 2025; de Oliveira, 2024).

Simultaneously, the use of predefined classificatory frameworks to analyze AI use in education poses methodological risks. For example, applying external taxonomies or competence models too early in the analytical process may constrain interpretation and lead to circular reasoning, particularly when the

same bodies of literature are used both to define analytical categories and to populate them with empirical evidence. Therefore, to mitigate this risk, research designs must clearly separate the inductive identification of practice-based categories from subsequent interpretive alignment with conceptual or policy frameworks. Such sequencing allows empirical patterns to emerge from the data before being situated within broader theoretical or normative perspectives (Cohen et al., 2017; Crawford, 2025).

In response to these challenges, the present study adopted a two-stage analytical approach. First, it developed an inductive classification of how AI is used by teachers in science education, grounded in the analysis of a large corpus of Scopus-indexed publications. This classification addresses the need for a practice-oriented understanding of AI use derived from the literature itself rather than being imposed a priori. Second, the study employed the OECD AI literacy framework as a second-order analytical lens to interpret how these empirically identified uses align with broader domains of AI-related engagement and competence. By combining grounded category development with deductive framework alignment, this study sought to contribute both descriptive clarity and interpretive depth while maintaining a clear distinction between data-driven findings and conceptual interpretation (Cohen et al., 2017; OECD, 2025).

On this basis, the literature review highlights a clear research gap: the absence of a systematic, empirically grounded classification of teachers' uses of AI in science education, along with a corresponding lack of insight into how such uses relate to established frameworks of AI literacy. Addressing this gap is essential for advancing the understanding of current pedagogical practices, informing teacher education and professional development, and supporting policy-relevant discussions on AI integration in education (de Oliveira, 2024; Crawford, 2025).

3. Methodology

3.1 Research Design

The present study adopted a qualitative, document-based research design aimed at developing a systematic understanding of how AI is used by teachers in science education, as reflected in published research. Rather than examining classroom practice directly, the study treated peer-reviewed publications as empirical material that documents, interprets, and represents educational practice. This approach is grounded in the assumption that research publications constitute a meaningful source for analyzing how pedagogical uses of AI are conceptualized, framed, and reported within the academic literature, particularly in fields where large-scale empirical access to practice is limited or methodologically challenging (Cohen et al., 2017).

Methodologically, the study combined inductive and deductive analytical logics within a single coherent design. The first stage of the analysis followed an inductive approach, drawing on principles associated with grounded and qualitative content analysis to identify recurring patterns in how teachers' use of AI is described across the literature. This stage is deliberately data driven and avoids the application of predefined classificatory frameworks, allowing categories of AI use to emerge from the corpus itself.

Such an approach is appropriate for exploratory research contexts in which existing typologies are either absent or insufficiently sensitive to the diversity of practices represented in the data (Cohen et al., 2017; de Oliveira, 2024).

In the second analytical stage, the study adopted a deductive interpretive perspective by aligning the empirically derived categories with an established AI literacy framework. This sequential design ensured a clear separation between category development and conceptual interpretation, thereby reducing the risk of circular reasoning. The use of a framework at this stage was useful not for generating or constraining categories but for supporting the interpretation of findings in relation to broader conceptions of AI-related engagement and competence. The combination of inductive category construction and deductive framework alignment allowed the study to balance empirical openness with conceptual clarity while maintaining methodological transparency (Crawford, 2025; OECD, 2025).

Overall, this research design was deemed suitable for addressing the study's objectives of mapping and interpreting teachers' uses of AI in science education at scale. By analyzing a large corpus of publications through a structured yet flexible qualitative approach, this study aimed to contribute both an empirically grounded classification of AI use and an analytically meaningful connection between documented practices and policy-relevant frameworks. This design positioned the study at the intersection of qualitative document analysis, educational technology research, and AI-related educational policy discourse—without privileging any single perspective at the expense of empirical grounding (Cohen et al., 2017; Petko et al., 2025).

3.2 Data Source and Corpus Construction

For this study, the data were obtained from Scopus, which was selected as the sole bibliographic database owing to its broad coverage of peer-reviewed journals in education, science education, and educational technology, as well as its structured metadata and advanced search functionality. Scopus is widely used in large-scale reviews and document-based studies because it provides consistent indexing standards and facilitates the systematic retrieval of publications across disciplines. The use of a single database was a deliberate methodological choice aimed at ensuring transparency and coherence in corpus construction while maintaining a manageable and replicable search strategy (Crawford, 2025; de Oliveira, 2024).

A comprehensive search strategy was developed to identify publications relevant to the use of AI in science education. The search was conducted by executing a command containing combinations of keywords related to AI and science education, which were applied to titles, abstracts, and keywords. More specifically, the command was as follows:

(TITLE-ABS-KEY ("Science education" OR "Science teaching" OR "Science lesson" OR "Science class" OR "Science learning") AND TITLE-ABS-KEY ("Artificial intelligence" OR "AI"))

Only peer-reviewed journal articles were included, ensuring a baseline level of academic quality and methodological scrutiny. Publications were retained if they explicitly addressed the use of AI in

educational contexts related to science teaching or learning, regardless of educational level. Moreover, no restrictions have been imposed on geographical location or methodological approaches, allowing the corpus to capture a wide range of perspectives and research traditions (Li et al., 2025; Petko et al., 2025).

The search was rerun before the final analysis to ensure the currency and completeness of the dataset. This updated retrieval resulted in a final corpus of 795 publications, all of which included abstracts and were, therefore, retained for analysis. Abstracts were treated as the primary unit of analysis, as they provide concise representations of a study's focus, context, and reported practices. Additionally, they are commonly used in large-scale qualitative document analyses. The decision to analyze abstracts rather than full texts was guided by the scale of the dataset, and the study aimed to identify broad patterns of AI use across the literature instead of conducting fine-grained analyses of individual studies (Cohen et al., 2017; de Oliveira, 2024).

The resulting corpus constitutes a structured representation of contemporary research on AI in science education, as reflected in indexed academic publications. By analyzing abstracts from a large and diverse body of literature, the study sought to balance breadth and analytical depth, enabling the identification of recurring patterns of AI use while maintaining methodological feasibility. This corpus provides the empirical foundation for the subsequent inductive and deductive analytical procedures described in the next section (Cohen et al., 2017; Crawford, 2025).

3.3 Analytical Procedure

The analytical procedure followed a sequential qualitative approach designed to identify and interpret patterns of AI use by teachers in science education. The analysis was conducted on the abstracts of the 795 publications included in the final corpus, which served as concise representations of how AI-related practices were described and framed in the literature. Abstracts in peer-reviewed journals follow structured conventions that summarize a study's focus and reported practices, making them suitable for large-scale pattern identification. The procedure combines inductive category development with subsequent framework-based interpretation, ensuring a clear separation between data-driven analysis and conceptual alignment (Cohen et al., 2017; de Oliveira, 2024).

In the first phase of the analysis, an inductive coding process was employed to identify recurring ways in which teachers' AI use was described across the corpus. Abstracts were examined iteratively with a focus on the pedagogical functions attributed to AI in teaching practice, such as instructional support, assessment, planning, or professional activity. Coding was conducted via a bottom-up approach, allowing patterns to emerge from the data without the application of predefined categories or external frameworks. Through repeated comparison and refinement, conceptually distinct yet overlapping categories of AI use were identified. These categories were not treated as mutually exclusive, reflecting that individual publications often described multiple forms of AI use within teaching contexts. During the inductive phase, categories of AI use were developed independently of the OECD domains. The OECD framework was introduced only after category stabilization, at which point a matrix was constructed to

examine how the empirically derived categories aligned with broader AI literacy domains. This sequencing ensured that framework alignment did not determine initial category formation (Cohen et al., 2017; Crawford, 2025).

Following the stabilization of the inductively derived categories, a second interpretive phase was undertaken in which the identified categories were aligned with the OECD AI literacy framework. At this stage, the framework was introduced as an analytical lens to support interpretation rather than classification. Each category of AI use was examined in relation to the OECD domains of engaging with AI, creating with AI, managing with AI, and designing AI, enabling the construction of a two-dimensional analytical matrix. This alignment facilitated the exploration of how empirically identified teaching practices correspond to broader conceptions of AI-related engagement and competence while preserving the grounded nature of the initial classification (Crawford, 2025; OECD, 2025).

Throughout the analytical process, attention was given to consistency and transparency. Coding decisions were systematically applied across the corpus, and categories were revisited as the dataset expanded from earlier iterations to the final set of 795 publications. The stability of the identified patterns across this expansion was taken as an indicator of analytical robustness. By combining inductive identification of practice-oriented categories with deductive framework-based interpretation, the analytical procedure supports both descriptive clarity and conceptual insight while avoiding circular reasoning between data and theory (Cohen et al., 2017; de Oliveira, 2024).

3.4 Trustworthiness and analytical rigour

Several measures were implemented to support the trustworthiness and analytical rigor of the study. First, the analytical procedures were consistently applied across the entire corpus, using the same coding logic and interpretive criteria for all 795 abstracts. The inductive categories were refined iteratively and remained stable as the dataset expanded, suggesting that the identified patterns were not artifacts of a limited sample but reflected recurring ways in which AI use by teachers is described in the literature. Transparency was further enhanced by the explicit sequencing of inductive category development followed by deductive framework alignment, which reduced the risk of circular reasoning between data and conceptual interpretation (Cohen et al., 2017; de Oliveira, 2024).

Furthermore, the study relied exclusively on bibliographic data retrieved from Scopus, a curated database of peer-reviewed publications. Clarification was obtained from the Scopus support team, which confirmed that data extracted from indexed publications may be reused for analytical purposes, including the production of original tables and figures, provided that appropriate credit is given to the source. Accordingly, all the quantitative summaries and graphical representations presented in the study were generated by the author on the basis of the retrieved metadata and abstracts rather than reproduced from existing publications. This approach ensures both the ethical use of data and transparency in the presentation of findings (Crawford, 2025).

Additionally, coding was conducted by the author via an iterative comparative approach. As the corpus expanded, previously coded abstracts were revisited to ensure consistency in category application. Category definitions were refined through repeated comparisons across the dataset, and the stability of coding patterns across the full corpus was taken as an indicator of analytical robustness. This approach aligns with qualitative document analysis procedures in large-scale text corpora (Cohen et al., 2017).

4. Findings

4.1 Inductive Classification of AI Use in Science Teaching

The inductive analysis of the 795 abstracts included in the final corpus led to the identification of six categories that describe how AI is used by teachers in science education, as represented in the analyzed literature. These categories were derived from a data-driven coding process that, instead of focusing on specific tools or technical characteristics, focused on the pedagogical functions attributed to AI within teaching practice. This approach is consistent with qualitative document analysis traditions that emphasize identifying recurring patterns of meaning across large textual corpora (Cohen et al., 2017; de Oliveira, 2024).

The identified categories reflect broad areas of pedagogical activity in which AI is positioned within science teaching. Notably, the categories are not mutually exclusive. Individual publications frequently described multiple forms of AI use, indicating that AI is often embedded in teaching practice in complex and overlapping ways. This nonexclusive categorization allows for a more accurate representation of how AI use is described in the literature, avoiding artificial separation of practices that may cooccur within the same instructional context (Cohen et al., 2017; Crawford, 2025).

The six categories that emerged from the analysis are (1) instructional delivery and pedagogy, (2) assessment and feedback, (3) lesson planning and curriculum design, (4) interactive agents (chatbots and intelligent tutors), (5) simulations and virtual environments, and (6) teacher professional development and support.

Together, these categories provide a structured overview of the pedagogical roles attributed to AI in science education research while remaining sufficiently flexible to capture variation across educational levels, contexts, and research traditions (Petko et al., 2025).

Across the corpus, instructional delivery and pedagogy emerged as the dominant category, encompassing more than three-quarters of the analyzed publications. This finding indicates that AI is most frequently discussed in relation to classroom-facing teaching processes and instructional activities. Assessment and feedback also constitute a substantial proportion of the corpus, appearing in nearly half of the publications, suggesting sustained interest in AI-supported evaluative and monitoring functions. Lesson planning and curriculum design are present in approximately one quarter of the corpus, reflecting growing attention to AI-supported preparatory work. The remaining categories—interactive agents, simulations and virtual environments, and teacher professional development and

support—appear at lower but still meaningful frequencies, indicating that while these uses are less prominent, they form recurring strands within the broader research landscape. Approximately 11% of the publications did not explicitly describe teacher-related AI use within the predefined categories and were therefore classified as unclassified. These publications typically address conceptual, policy-oriented, or broader discussions of AI in science education without detailing specific pedagogical applications (de Oliveira, 2024; Crawford, 2025).

Table 1 presents the frequency and percentage distribution of publications across the six categories. As categories are nonexclusive, the total exceeds the number of analyzed publications.

Table 1. Frequency and percentage distributions of AI use categories in science education (N = 795).

AI Use Category	Number of Publications	Percentage (%)
Instructional delivery and pedagogy	619	77.9
Assessment and feedback	365	45.9
Lesson planning and curriculum design	189	23.8
Interactive agents (chatbots and intelligent tutors)	123	15.5
Simulations and virtual environments	94	11.8
Teacher professional development and support	78	9.8
Unclassified	90	11.3

4.1.1 Instructional Delivery and Pedagogy

This category encompasses publications in which AI is positioned as a tool that supports or enhances instructional processes during science teaching. In these studies, AI is described as contributing to classroom activities such as presenting content, guiding inquiry-based learning, scaffolding conceptual understanding, or facilitating interaction between teachers and students. Moreover, in these studies, AI is integrated directly into teaching practice, often shaping how scientific concepts are introduced, explored, or discussed rather than functioning solely as a background technology. The prominence of this category reflects the centrality of instructional concerns in discussions of AI use within science education research (Lee et al., 2025; Petko et al., 2025).

4.1.2 Assessment and feedback

Publications classified under this category describe the use of AI to support assessment-related processes in science education. In these studies, AI is presented as a means of automating or enhancing formative and summative assessment, offering feedback on student performance, or supporting teachers' evaluative decision-making. These studies frequently frame AI as assisting with the

analysis of student responses, monitoring learning progress, or generating feedback aligned with learning objectives. The recurrence of this category indicates sustained interest in AI's potential to support assessment practices and reduce the evaluation workload in science teaching contexts (Crawford, 2025; de Oliveira, 2024).

4.1.3 Lesson Planning and Curriculum Design

This category includes publications in which AI is associated with preparatory aspects of teaching, such as lesson planning, curriculum design, or the development of instructional materials for science education. In these studies, AI is described as supporting teachers in organizing content, aligning learning objectives with activities, or generating instructional resources before classroom implementation. Unlike instructional delivery, the focus here is on planning and design processes that occur before teaching takes place. The presence of this category reflects the growing recognition of AI as a support tool for teachers' preparatory and organizational work (Biagini, 2025; Garzón et al., 2025).

4.1.4 Interactive Agents (Chatbots and Intelligent Tutors)

Publications in this category focus on AI systems that interact directly with learners or teachers through conversational or tutoring interfaces. These include chatbots, intelligent tutoring systems, or other interactive agents designed to respond to queries, guide learning activities, or provide instructional support in science education contexts. In such studies, AI is characterized by its interactive and responsive nature, often functioning as a supplementary instructional presence alongside the teacher. Although less frequent than broader instructional uses, this category represents a distinct form of AI integration centered on dialog and interaction (Lee et al., 2025; Petko et al., 2025).

4.1.5 Simulation and Virtual Environments

This category comprises publications that describe the use of AI within simulations, virtual laboratories, or immersive environments for science teaching. In these studies, AI is presented as enabling dynamic modeling of scientific phenomena, adaptive simulation behavior, or interactive virtual experimentation. Furthermore, these studies emphasize experiential and exploratory learning opportunities, allowing students to engage with representations of scientific processes that may be difficult to access in physical classrooms. While comparatively less frequent, this category reflects a specific application of AI aligned with inquiry and experimentation in science education (Jufrida et al., 2025; Li et al., 2025).

4.1.6 Teachers' professional development and support

Publications in this category address the use of AI in relation to teachers' professional learning, reflective practice, or instructional support beyond direct classroom teaching. They describe AI as assisting with

professional development activities, providing feedback on teaching practices, or supporting teachers in developing competencies related to AI integration. In these studies, AI functions as a resource for teacher growth rather than as a classroom-facing tool. This category highlights the recognition of AI's role not only in teaching and learning processes but also in supporting teachers' ongoing professional work (Biagini, 2025; Petko et al., 2025).

4.2 Alignment of AI Use Categories with the OECD AI Literacy Framework

Table 2 presents the alignment between the six AI use categories and the OECD AI literacy domains for the final corpus (N = 795). The patterns below are interpreted as cooccurrences, meaning that a single publication may align with more than one category and domain.

Table 2: Alignment of AI use categories with OECD AI literacy domains (N = 795)

AI Category	Creating with AI	Designing AI	Engaging with AI	Managing with AI	Unclassified
Instructional delivery & pedagogy	325	350	540	217	16
Assessment & feedback	206	202	321	166	6
Lesson planning & curriculum design	100	125	168	64	4
Interactive agents	67	75	111	47	5
Simulations	49	47	80	26	3
Teacher professional development & support	50	51	73	35	0
Unclassified	31	33	46	17	28

Across the matrix, the most prominent pattern is the strong alignment with the OECD domain of engaging with AI, particularly within the category of instructional delivery and pedagogy, accompanied by substantial secondary alignment with designing AI. This suggests that a significant proportion of the literature frames AI use in science teaching in terms of not only interactions with existing systems but also design-oriented activities, such as developing or configuring AI-supported instructional solutions, adapting AI-enabled environments, or structuring AI-related processes within teaching practices. In this sense, "design" frequently appears as part of how AI integration is conceptualized in science education research, especially when authors describe the development, adaptation, or structured implementation of AI-supported tools and learning activities (OECD, 2025).

A closely related pattern is the strong presence of engaging with the AI domain, which is particularly high in the instructional delivery and pedagogy category (547) and remains substantial across other categories. This confirms that AI use in science education is widely represented as classroom-facing and interactional, involving teachers and students engaging with AI systems during instruction, inquiry activities, or learning tasks. Moreover, the co-occurrence of high design and engaging values within the same category indicates that the literature often combines descriptions of interactive use with descriptions of the instructional structures or AI-enabled environments that facilitate such interaction (OECD, 2025).

The category of assessment and feedback shows a similarly multidimensional alignment, with strong associations not only with engaging with the AI domain (265) but also with designing AI (297) and creating AI (204) domains. This finding indicates that assessment-related publications frequently describe AI use as more than managerial oversight; instead, they often involve the design or configuration of AI-supported assessment approaches and the generation of assessment-related resources, feedback, or evaluative outputs. While the managing with AI domain is still present (86), it is less dominant than the combination of engagement, creation, and design, suggesting that assessment-focused uses are frequently framed around how assessment is constructed, supported, or shaped through AI-enabled processes rather than solely monitored or administered (OECD, 2025).

The category of lesson planning and curriculum design also demonstrates substantial alignment with the design AI domain (156), alongside meaningful associations with creating AI (115) and engaging with AI (122) domains. This pattern suggests that planning-related uses frequently include design-oriented activities such as structuring AI-supported resources, aligning AI use with curricular goals, or configuring AI tools to support preparatory work. Simultaneously, the presence of creating with the AI domain indicates that planning is often linked with generative functions, such as producing instructional materials or adapting lesson resources, whereas engaging with the AI association suggests that the planning literature also frequently discusses the anticipated classroom interaction with AI systems as part of the planned instruction (OECD, 2025).

More specialized categories exhibit clear but differentiated alignment patterns. The interactive agent (chatbots and intelligent tutors) category aligns most strongly with the engaging with AI domain (107) while also showing strong associations with the designing AI domain (102), reflecting the combined emphasis on interaction and the construction, adaptation, or instructional integration of conversational systems. The simulations and virtual environments category shows a similar dual emphasis, with both the designing AI (132) and engaging with AI (125) domains being prominent, which is consistent with the literature that treats virtual environments as both interactive learning spaces and designed AI-enabled systems. Finally, the teacher professional development and support category also aligns most strongly with the design AI domain (94), indicating that professional-context publications frequently address the design or configuration of AI-supported professional learning resources, alongside engagement and creation-related uses (de Oliveira, 2024).

The matrix indicates that AI use in science education is most frequently represented through combined design-oriented and interaction-oriented modes of engagement. Across categories, designing AI and engaging with AI are consistently prominent, whereas managing with AI appears comparatively less common. The alignment with the OECD AI literacy framework thus highlights literature that commonly frames AI integration as involving the development, configuration, or structured implementation of AI-supported educational solutions alongside classroom interaction rather than focusing primarily on administrative oversight or managerial monitoring (OECD, 2025).

5. Discussion

5.1 Dominant Patterns of AI Use in Science Teaching

The findings of this study indicate that AI is most frequently represented in the literature as a tool supporting core pedagogical functions in science education, particularly instructional delivery and assessment. This pattern suggests that current representations of AI use prioritize immediate teaching needs—such as facilitating classroom interaction, supporting conceptual understanding, and evaluating student learning—over more technically complex or experimental applications. Rather than being framed as a transformative or disruptive technology, AI appears to be largely integrated into existing pedagogical practices, aligning with teachers' established instructional responsibilities (Garzón et al., 2025; Petko et al., 2025).

The prominence of assessment- and feedback-related uses further reflects the enduring challenges within science education, including the need to monitor learning processes, provide timely feedback, and manage increasing demands for data-informed decision-making. AI is frequently positioned as a means of supporting these evaluative tasks, often with an emphasis on efficiency, automation, or enhanced insight into student performance. This suggests that AI is not only perceived as a teaching aid but also as a response to structural pressures on teachers' time and workload, particularly in assessment-intensive educational contexts (Crawford, 2025; de Oliveira, 2024).

Simultaneously, the dominance of these categories highlights a relatively conservative pattern of AI integration. The literature largely frames AI as reinforcing or augmenting existing pedagogical practices rather than fundamentally reshaping them, a finding that aligns with broader observations in educational technology research, where modern technologies are often assimilated into established instructional routines before more transformative uses emerge. Thus, the findings point to a phase of AI adoption characterized by pedagogical continuity rather than radical change within science education (Lee et al., 2025; Petko et al., 2025).

5.2 Teachers' Roles: Pedagogical Agency over Technical Design

A central insight emerging from the findings is how teachers are positioned in the literature primarily as classroom-facing users of AI systems and as pedagogical decision-makers who shape how AI is

implemented in teaching rather than as designers or developers of AI systems. Across the analyzed publications, AI is most often described as a tool that teachers select, apply, oversee, or interpret within their existing instructional responsibilities, a positioning that reflects a conception of teacher agency that is rooted in pedagogical judgment and professional expertise rather than in technical authorship or system-level innovation (OECD, 2025; Petko et al., 2025).

The substantial alignment between the identified categories of AI use and the OECD domain of designing AI suggests that the literature frequently frames AI integration in design-oriented terms. In this study, this domain is interpreted primarily as involving the pedagogical and organizational shaping of AI-supported teaching, including configuration, adaptation, and structured implementation of AI-enabled tools and learning environments, rather than implying that teachers are developing AI technologies themselves. Thus, the prominence of designing AI reflects the extent to which the literature treats AI integration as requiring deliberate instructional and contextual design decisions alongside classroom use (OECD, 2025).

This emphasis on pedagogical agency over technical design may also reflect pragmatic considerations within educational contexts. Since teachers operate within institutional, curricular, and temporal constraints that shape the forms of technological engagement that are feasible in practice, AI is most often appropriated in ways that complement existing teaching roles and responsibilities rather than requiring teachers to adopt fundamentally new professional identities. In science education, especially where disciplinary content, inquiry practices, and assessment demands already place substantial cognitive and organizational demands on teachers, AI is positioned as a support for pedagogical work rather than as an object of technical production (Garzón et al., 2025; Lee et al., 2025).

Moreover, the findings do not suggest an absence of creative or innovative engagement with AI but indicate that such engagement is typically mediated through pedagogical aims rather than through system design. Teachers' interactions with AI are framed in terms of selecting appropriate tools, interpreting AI-generated outputs, and making informed decisions about their use in teaching and learning contexts. This finding reinforces the perspective that teacher agency in AI integration is expressed through pedagogical judgment and contextual adaptation, highlighting the importance of supporting teachers in developing competencies related to the critical use and management of AI rather than focusing narrowly on technical design skills (OECD, 2025; Chee et al., 2025).

5.3 AI Use Beyond the Classroom: Planning and Professional Support

The findings indicate that AI is being increasingly discussed in relation to teachers' work beyond direct classroom instruction, particularly in lesson planning, curriculum design, and professional support. Although these applications are less frequent than those focused on instructional delivery or assessment, their distinct presence suggests a growing recognition of AI as a resource that supports teachers' preparatory and reflective practices. This pattern reflects an emerging view of AI not only as a tool for facilitating learning activities but also as a means of assisting teachers in managing the complex

organizational and cognitive demands associated with science teaching (Biagini, 2025; Garzón et al., 2025).

In the context of lesson planning and curriculum design, AI is commonly framed as a support resource for organizing content, aligning learning objectives, and generating instructional materials. These representations position AI as a preparatory aid that operates upstream of classroom interaction, influencing teaching indirectly through planning decisions rather than through real-time instructional engagement. Such uses suggest a shift toward recognizing AI's potential to support the design phase of teaching while maintaining teacher control over pedagogical intent and curricular coherence (Biagini, 2025; Petko et al., 2025).

The category of teacher professional development and support further extends this perspective by highlighting AI's role in facilitating teachers' ongoing learning and reflective practice. In these publications, AI is described as assisting with activities such as professional feedback, instructional reflection, and developing competencies related to AI integration itself. While comparatively limited in frequency, these uses signal an awareness of AI as a tool for teacher growth rather than solely for student-facing instruction. This orientation aligns with broader discussions in the literature that stress the need to support teachers' professional capacity when navigating emerging technologies, particularly in subject-specific contexts such as science education (Chee et al., 2025; OECD, 2025).

Taken together, these findings suggest that AI use in science education extends beyond the classroom in ways that remain closely tied to teachers' professional responsibilities. Rather than displacing pedagogical expertise, AI is framed as augmenting planning, organization, and professional learning processes. However, the relatively lower frequency of such uses compared with classroom-focused applications indicates that these roles are still developing and may depend on institutional support, access to appropriate tools, and professional development opportunities. Thus, AI's role in supporting teachers beyond direct instruction represents an emerging but not yet dominant dimension of AI integration in science education (Garzón et al., 2025; Petko et al., 2025).

5.4 Interpreting the findings through the OECD AI literacy framework

Interpreting the inductively derived categories through the OECD AI literacy framework provides a structured perspective on how current representations of AI use in science education correspond to broader modes of AI-related engagement. The updated matrix indicates that AI use aligns most strongly with the domain of engaging with AI, followed by substantial but secondary alignment with designing AI, whereas managing with AI and creating with AI domains appear less prominent. This pattern suggests that AI literacy in science education is framed primarily in terms of active interaction with AI systems rather than administrative oversight or advanced technical development.

The dominance of engaging with the AI domain reflects the classroom-oriented nature of the literature, particularly within the instructional delivery and pedagogy and assessment and feedback categories. In

these contexts, AI is commonly presented as a tool that teachers and students apply, integrate, and interact with during instructional and evaluative processes. This engagement-oriented framing positions AI as embedded within pedagogical activity, reinforcing the view that AI integration is understood primarily through its practical use in teaching and learning contexts (OECD, 2025; Petko et al., 2025).

While the domain of designing AI also shows substantial alignment across categories, its prominence appears to be linked to the structuring, configuration, or instructional integration of AI-supported systems rather than to the technical development of AI models themselves. In several cases, “design” refers to adapting AI-enabled environments, structuring AI-supported activities, or configuring tools for pedagogical purposes, indicating that design-oriented discourse in science education research frequently concerns instructional design involving AI rather than system-level engineering of AI technologies.

The domain of managing with AI appears across categories, particularly in assessment and feedback, where monitoring and evaluative oversight are central. However, its comparatively lower frequency suggests that the literature does not frame AI integration primarily as an administrative or governance-oriented activity; instead, managerial aspects are typically embedded within broader pedagogical processes rather than functioning as the dominant mode of AI engagement (de Oliveira, 2024; OECD, 2025).

Similarly, creating with the AI domain appears in relation to generative uses, such as producing instructional materials or assessment outputs, but does not surpass engagement-oriented patterns, indicating that while generative functions are present, they are generally situated within instructional and design contexts rather than representing an independent or dominant mode of AI integration.

Overall, the alignment with the OECD (2025) AI literacy framework highlights a body of literature that conceptualizes AI integration in science education primarily through interactional and pedagogically structured engagement. Design-oriented elements are present but embedded within instructional contexts, and managerial dimensions remain secondary. This pattern reinforces the broader finding that AI use in science education is most frequently framed as an extension of teachers’ pedagogical practice rather than as a shift toward technical authorship or system-level AI development (Chee et al., 2025; OECD, 2025).

5.5 Synthesis of Key Findings and Implications

The findings show that AI is widely represented in the literature as a pedagogical support resource embedded in multiple aspects of science teaching practice. The inductive categorization suggests that AI is most frequently discussed in relation to instructional delivery and pedagogy, whereas assessment and feedback also constitute a substantial area of emphasis. Simultaneously, planning-related uses, simulation-oriented applications, interactive agents, and professional support functions are also present, indicating that the literature increasingly portrays AI integration as spanning both classroom-facing teaching and broader dimensions of teachers’ work. Because the categories are nonexclusive, these

patterns should be interpreted as overlapping portrayals of practice rather than as isolated or mutually exclusive roles for AI in science education (Garzón et al., 2025; Petko et al., 2025).

Across the analyzed publications, teachers are consistently positioned as active decision makers who shape AI use through pedagogical judgment and contextual adaptation. However, the updated OECD-based alignment suggests that this agency is expressed not only through interaction and oversight but also through design-oriented engagement. In particular, the prominence of designing AI alongside engaging with AI indicates that a substantial portion of the literature frames AI integration in terms of structuring, configuring, and pedagogically shaping AI-supported environments, tools, or instructional sequences rather than treating AI solely as a ready-made classroom technology. Thus, the findings suggest that teachers' roles are frequently represented as involving the deliberate design of AI-supported implementation, even when teachers are not positioned as developers of underlying AI technologies or model architectures (OECD, 2025; de Oliveira, 2024).

The synthesis further highlights that creating with AI remains meaningfully represented across multiple categories, particularly in areas such as lesson planning, curriculum-related work, and assessment-related tasks where generative functions can support preparation, resource adaptation, and feedback production. Meanwhile, managing with AI appears less prominent than in earlier interpretations, although it remains relevant where monitoring, evaluation, and responsible oversight are central. Taken together, these patterns support the view of AI integration in science education as multidimensional: the literature frequently combines interactive use with design-oriented representations and, in several cases, creation-oriented representations, reflecting the complexity of real teaching contexts and the tendency for AI tools to serve multiple functions within a single instructional setting (Chee et al., 2025; OECD, 2025).

In terms of implications, the findings support the value of conceptualizing AI integration through teachers' practices rather than through tool types alone. The six-category typology provides a practical lens for organizing a diverse research landscape, whereas the OECD alignment offers an additional interpretive structure for understanding how AI-related engagement is framed in the literature. For teacher education and professional development, the results suggest that support should focus not only on tool adoption and classroom interaction but also on the design-oriented competencies required to integrate AI meaningfully into science teaching, including configuring tools, structuring AI-supported learning environments, and aligning AI use with disciplinary goals such as inquiry, modeling, and evidence-based reasoning. Simultaneously, the continuing presence of assessment and planning applications indicates the need to address responsibility, transparency, and professional judgment in relation to AI outputs, particularly where AI influences evaluation or instructional decisions (Crawford, 2025; OECD, 2025).

6. Conclusions

This study aimed to provide a systematic and empirically grounded account of how AI is represented in science education, drawing on a corpus of 795 Scopus-indexed publications. The findings indicate that

AI is most frequently positioned within core pedagogical functions, particularly in instructional delivery and assessment-related practices. Across the literature, AI is described as supporting classroom interaction, guiding inquiry processes, scaffolding conceptual understanding, and facilitating both formative and summative evaluation. While additional uses, such as lesson planning, simulations, interactive agents, and professional development, are present, they are less prominent than classroom-facing instructional and assessment applications. Because the categories were developed inductively and applied nonexclusively, these patterns reflect overlapping representations of practice rather than mutually exclusive domains of AI integration.

When interpreted through the OECD (2025) AI literacy framework, the identified categories align most strongly with engaging with AI, followed by substantial but secondary alignment with designing AI. Creating with AI appears meaningful in planning and assessment contexts, whereas managing with AI, although present, is comparatively less dominant. This distribution suggests that AI integration in science education is framed primarily as interactional and pedagogically embedded rather than as a predominantly administrative or system-level design endeavor. Moreover, the strength of the design dimension indicates that AI use is often conceptualized in terms of structuring, configuring, and pedagogically shaping AI-supported tools and environments. Thus, the literature portrays teachers not only as passive users of ready-made technologies but also as professionals who actively interpret and adapt AI systems within instructional contexts (Chee et al., 2025; OECD, 2025).

In addition to descriptive mapping, the study contributes theoretically in three interrelated ways. First, it offers a large-scale, inductively derived typology of AI use in science teaching that is grounded in published research rather than imposed from predefined frameworks. By separating category development from subsequent framework alignment, the study addresses methodological concerns regarding circular reasoning in document-based research (Cohen et al., 2017; Crawford, 2025). Second, by aligning the emergent categories with the OECD AI literacy framework, the study bridges practice-oriented analysis with broader conceptual discussions of AI-related competence, extending the discourse on AI literacy into subject-specific educational research (Biagini, 2025; OECD, 2025). Third, the findings reinforce and refine the notion of teacher agency in AI integration. Consistent with technology integration frameworks such as TPACK, AI use is framed as emerging from the interplay between pedagogical aims, disciplinary knowledge, and technological affordances rather than from technical capability alone (Koehler & Mishra, 2009; Mishra & Koehler, 2006; Petko et al., 2025).

For scholars, the results suggest several directions for future research. Although instructional and assessment uses dominate the literature, areas such as AI-supported professional development and managerial oversight remain comparatively underexplored. Additionally, while the alignment with designing and engaging domains is strong, there is limited evidence of research that critically examines the epistemic implications of AI use for science-specific practices such as modeling, experimentation, and evidence evaluation. Hence, more fine-grained qualitative studies could deepen the understanding of how AI integration affects disciplinary reasoning and inquiry processes in science classrooms. Furthermore, future research may benefit from moving beyond descriptive representations and toward

comparative analyses across subject domains or educational systems (Jufrida et al., 2025; Li et al., 2025).

With respect to policy and teacher education, the findings indicate that effective AI integration cannot be reduced to tool adoption or technical training. Because AI use is predominantly framed as pedagogically mediated and design oriented, professional development initiatives should emphasize teachers' capacity to interpret, configure, and critically evaluate AI-supported systems within disciplinary contexts. AI literacy frameworks, including those of the OECD (2025), gain practical significance when connected to subject-specific teaching practices rather than being treated as abstract competence models. Supporting teachers in developing critical engagement, generative use awareness, and responsible oversight appears essential for aligning AI use with educational goals (UNESCO, 2021; U.S. Department of Education, 2023; Chee et al., 2025).

Several limitations of the study must be acknowledged. The corpus was constructed exclusively from Scopus-indexed publications, which may privilege English-language and internationally visible research while underrepresenting locally published or nonindexed studies. Moreover, the analysis was conducted at the level of abstracts rather than full texts, which may limit the depth with which complex pedagogical practices are captured. Additionally, the study analyzed representations of AI use in published research rather than directly observing classroom practices; consequently, the findings reflect how AI use is conceptualized and reported, not necessarily how it is enacted in situ. Finally, because categories were applied nonexclusively, frequency counts represent discursive prominence in the literature rather than the empirical prevalence of specific practices (Cohen et al., 2017; Crawford, 2025).

Despite these limitations, this study provides a structured and empirically grounded overview of how AI use by teachers in science education is currently represented in academic research. While the primary focus is on science education, the broader patterns identified, particularly the predominance of engagement-oriented and design-mediated AI use, may extend to other subject areas where teachers operate within similar pedagogical and institutional constraints. The findings suggest that AI in education is normalized within existing instructional structures, with teachers positioned as pedagogical integrators rather than technical developers. Thus, by clarifying how AI use is currently conceptualized, this study offers a foundation for more theoretically informed, practice-sensitive, and policy-relevant research on AI integration in education (Chee et al., 2025; OECD, 2025).

Declarations

Conflict of interest:

The author declares no conflict of interest.

Funding:

The author received no specific funding for this research. Access to the Scopus database was provided through institutional subscription.

Author Contribution

Konstantinos Karampelas conceived and designed the study, conducted the literature search and data collection, carried out the qualitative document analysis, interpreted the findings and drafted and revised the manuscript. The author read and approved the final version of the manuscript.

Acknowledgement

The author acknowledges the institutional support that enabled access to the Scopus database used for this study. The author also appreciates the language editing support provided during the preparation of the manuscript.

Data Availability

The dataset analyzed during the current study consists of bibliographic records retrieved from the Scopus database through institutional access. The use of metadata for academic and noncommercial research purposes complies with Scopus data usage policies. The dataset is available from the author upon reasonable request.

References

1. Biagini, G. (2025). Toward an AI-literate future: A systematic literature review exploring education, ethics, and applications. *International Journal of Artificial Intelligence in Education*, *35*(4), 2616–2666. https://doi.org/10.1007/s40593-025-00466-w
2. Chee, H., Ahn, S., & Lee, J. (2025). A competency framework for AI literacy: Variations by different learner groups and an implied learning pathway. *British Journal of Educational Technology: Journal of the Council for Educational Technology*, *56*(5), 2146–2182. https://doi.org/10.1111/bjet.13556
3. Cohen, L., Manion, L., & Morrison, K. (2017). *Research methods in education* (8th ed.). Routledge. https://doi.org/10.4324/9781315456539
4. de Oliveira, J. O. (Ed.). (2024). *Bibliometrics—an essential methodological tool for research projects*. IntechOpen. https://doi.org/10.5772/intechopen.1001662
5. Garzón, J., Patiño, E., & Marulanda, C. (2025). Systematic review of artificial intelligence in education: Trends, benefits, and challenges. *Multimodal Technologies and Interaction*, *9*(8), Article 84. https://doi.org/10.3390/mti9080084

6. Jufrida, J., Kurniawan, W., Furqon, M., Anwar, K., Shidow Falah, H., & Riantoni, C. (2025). AI-driven ethnoscience learning: Enhancing physics education through Malay cultural insights. *Journal of Information Technology Education Innovations in Practice*, *24*, Article 13. https://doi.org/10.28945/5520
7. Koehler, M., & Mishra, P. (2009). What is Technological Pedagogical Content Knowledge (TPACK)? *Contemporary Issues in Technology and Teacher Education*, *9*(1), 60–70. https://www.learntechlib.org/primary/p/29544/.
8. Lee, G., Yun, M., Zhai, X., & Crippen, K. (2025). Artificial intelligence in science education research: Current states and challenges. *Journal of Science Education and Technology*. https://doi.org/10.1007/s10956-025-10239-8
9. Li, Y., Tolosa, L., Rivas-Echeverria, F., & Marquez, R. (2025). Integrating AI in education: Navigating UNESCO global guidelines, emerging trends, and its intersection with sustainable development goals. ChemRxiv. https://doi.org/10.26434/chemrxiv-2025-wz4n9
10. Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content Knowledge: A framework for teacher knowledge. *Teachers College Record (1970)*, *108*(6), 1017–1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x
11. Nikolinakos, N. T. (2023). *EU policy and legal framework for artificial intelligence, robotics and related technologies—the AI act*. Springer International Publishing. https://doi.org/10.1007/978-3-031-27953-9
12. OECD. (2025). *Empowering learners for the age of AI: An AI literacy framework for primary and secondary education*. https://ailiteracyframework.org.
13. Petko, D., Mishra, P., & Koehler, M. J. (2025). TPACK in context: An updated model *Computers and Education Open*, *8*, Article 100244. https://doi.org/10.1016/j.caeo.2025.100244
14. UNESCO. (2021). *AI and education: guidance for policy-makers.* https://doi.org/10.54675/pcsp7350
15. U.S. Department of Education, Office of Educational Technology (2023). *Artificial intelligence and future of teaching and learning: insights and recommendations*. Available from https://www.ed.gov/sites/ed/files/documents/ai-report/ai-report.pdf