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Exploring the Implementation and Implications of AI-Based Media in Chemistry Learning at Secondary Level: A Systematic Literature Review

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Abstract: This study aims to systematically examine the implementation and implications of Artificial Intelligence (AI)-based media in chemistry learning at the secondary education level. Using the Systematic Literature Review (SLR) approach which refers to the PRISMA guidelines, as many as 19 scientific articles from the Science Direct database were analyzed qualitatively. The research focus includes the identification of the types of AI media used, the chemical materials supported by AI, the forms of implementation in the classroom, as well as the pedagogical implications of the integration of AI in chemistry learning. The results show that the most widely used AI media is generative chatbots such as ChatGPT, Gemini, and Claude, followed by immersive technologies such as Virtual Reality (VR) and Augmented Reality (AR). This media is used to improve students' understanding of concepts, especially in abstract materials such as atomic structure, molecular visualization, and organic reactions. However, a number of challenges were found, including inaccurate content, low digital literacy, ethical and academic integrity issues, and limited technological infrastructure. On the other hand, AI media also opens up opportunities for adaptive and personalized learning, increased student learning engagement, and teacher efficiency in learning planning. This study recommends strengthening teacher training, ethical policies, and adaptive curriculum design to support the optimal application of AI in chemistry learning in the digital era.

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INTRODUCTION

Chemistry learning has a strategic role in the development of science and technology, especially in shaping a conceptual understanding of matter and the changes that occur in nature. However, learning chemistry is often considered one of the difficult science subjects by students because of its abstract, complex, and requires representational skills from the macroscopic, microscopic, and symbolic levels (Lederman *et al*., 2013). Understanding chemical concepts cannot be achieved only through verbal or textual delivery, but requires learning media that can bridge the limitations of students' perception of phenomena that cannot be observed directly.

Along with the development of digital technology, especially artificial intelligence, new opportunities have emerged in designing more innovative and adaptive chemistry learning. In the context of chemistry education, artificial intelligence technologies offer various capabilities such as prediction of molecular properties, drug discovery, application in nanotechnology, wastewater treatment, retrosynthesis planning, and prediction of reaction outcomes, all of which are relevant in the context of chemistry education (Clark, 2023; Yildirim *et al*., 2024). AI can provide a more personalized and interactive learning experience, as well as provide real-time feedback that helps students understand the material more deeply (Luckin & Holmes, 2016; Zawacki-Richter *et al*., 2019).

Several literature reviews have addressed the application of AI in education, including in the context of STEM in general. For example, a study by Xu & Ouyang (2022) reviewed the use of AI in STEM education, but did not provide an in-depth focus on chemistry learning specifically. Similarly, a study by Chiu (2021) discusses the use of digital technology in chemistry education, but the scope is still broad and does not delve into the function of AI as a learning medium. Even in SLR by Iyamuremye *et al*., (2024) although AI and machine learning in chemistry education are highlighted, the focus is still limited to the potential of AI in assessment and not in the context of learning media. In addition, most of the existing studies review the application of AI in general in chemistry education without specializing in its function as a learning medium, and have not specifically highlighted its application at the secondary education level.

The absence of a systematic study that explicitly analyzes the function of AI as a medium of learning chemistry at the secondary education level shows that there are research gaps that need to be filled. Systematic assessment of the use of artificial intelligence (AI)-based media in chemistry learning at the secondary education level is becoming increasingly important as the complexity of materials increases and the need for adaptive learning innovations. Chemical concepts such as molecular structure, reaction mechanisms, and energy changes are abstract and difficult to visualize without the support of technology. In this context, AI media such as Virtual Reality (VR), Augmented Reality (AR), and generative chatbots have been proven to be able to improve students' conceptual understanding as well as strengthen interactive learning experiences (Amirbekova et al., 2023; Raucci et al., 2023). In addition, AI also plays a role in facilitating personalized, independent, and adaptive learning, which is especially relevant post-pandemic when the gap in literacy and student learning motivation increases (Yuriev et al., 2024).

Therefore, this study aims to conduct a systematic literature review to answer key questions related to the form of Artificial Intelligence (AI)-based media, chemical topics that adopt the media, the application of AI as a learning medium in the context of chemistry education and its implications. While AI implementation has great potential to address various challenges in chemical learning, it also faces a number of limitations. Some of the main obstacles include the need for large amounts of data for AI model training, infrastructure and cost limitations, lack of educators' skills in using AI-based technologies, as well as ethical issues related to student data privacy and bias (Ardyansyah & Rahayu, 2024; Martin & Graulich, 2023). Therefore, mapping the current state of AI application in chemistry learning media is very important to design a more effective and adaptive implementation strategy.

Research question:
RQ1: What are the types of AI-based chemistry learning media that have been implemented at the secondary education level?
RQ2 : What are some chemistry topics that use AI-based media to improve students' understanding of concepts?
RQ3: How is the implementation of Artificial Intelligence as a chemistry learning medium applied at the secondary education level?

METHOD

This study uses the Systematic Literature Review (SLR) approach to identify scientific articles that discuss the application of Artificial Intelligence (AI) as a learning medium in chemistry education, especially at the secondary education level. This approach was chosen because it allows researchers to compile findings in a systematic, transparent and replicative manner based on the existing literature (Snyder, 2019). The systematic review procedure is carried out based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure the validity and traceability of the literature selection process (Page et al., 2021). The database used in this study is Science Direct because it provides access to reputable international journals that have gone through a peer-review process and have strong coverage in the fields of science, chemistry, and learning technology education. Articles that were successfully identified through the search process were then selected based on the inclusion criteria that had been set. These criteria include the suitability of the topic with the application of Artificial Intelligence (AI) as a medium of learning chemistry in secondary education level. No publication year limit has been set in this study to obtain a comprehensive picture of the development of the application of AI in chemistry learning, considering that studies that specifically discuss AI as a medium of learning chemistry at the secondary education level are relatively limited.

Articles that do not meet inclusion criteria such as not focusing on chemistry or chemistry education, and do not discuss the implementation of AI technology as a medium of learning chemistry, are excluded from the further analysis process. The screening process is carried out systematically through the stages of identification, screening of titles and abstracts, and the process of reviewing articles available in full text to ensure that the analyzed literature has substantive relevance, methodological validity and adequate contribution to the research objectives. Articles that met the inclusion criteria were then analyzed using a qualitative descriptive approach.

The following is a guideline for inclusion and exclusion criteria used in the selection of articles for analysis.

Table 1. List of inclusion and exclusion criteria guidelines for article selection

Inclusions	Exclusion
Topical articles (application of AI as a medium for learning chemistry in secondary education level)	Off-topic articles
Accessible articles	Articles are not accessible
The article is complete	Incomplete article

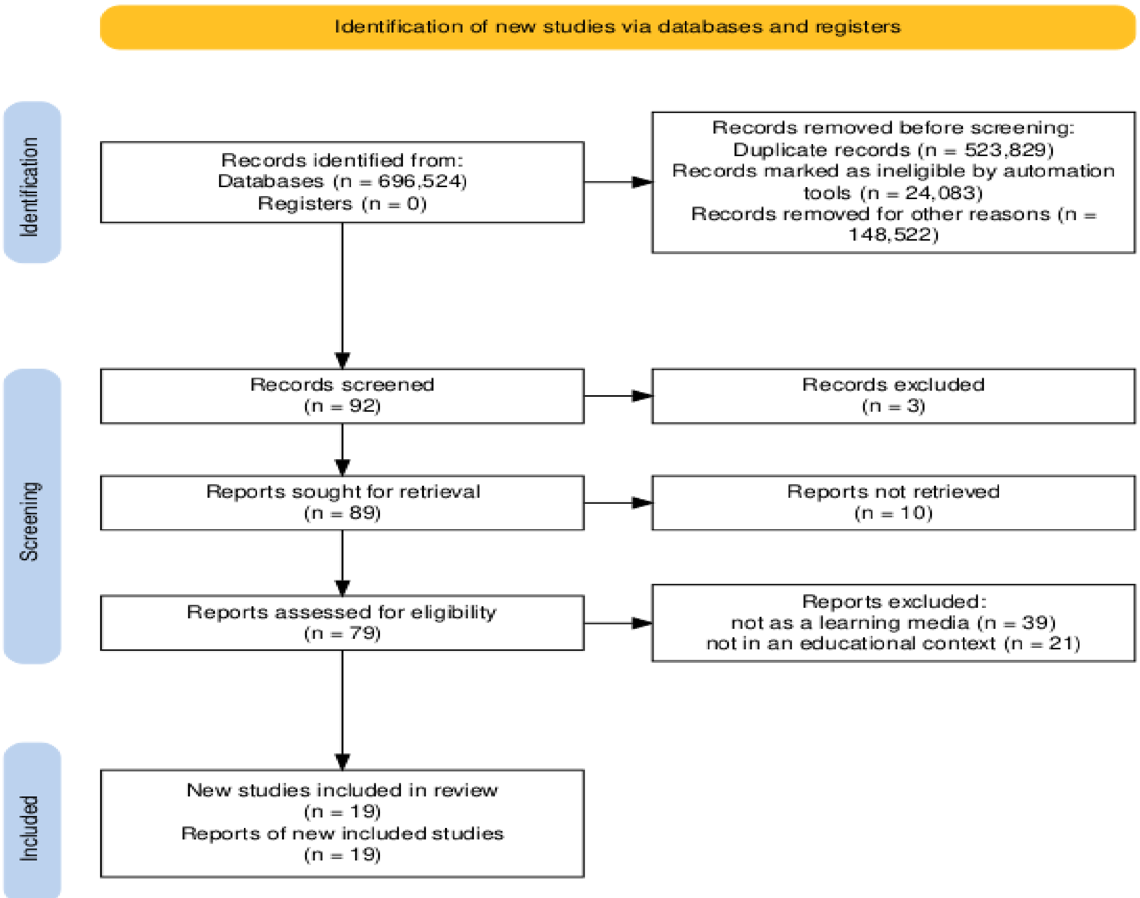

Figure 1. Article selection mechanism in the SLR method.

After the literature identification and selection process is completed, articles that meet the inclusion criteria are analyzed using a thematic coding approach combined with narrative synthesis (Yanto et al., 2024). This process is carried out by grouping articles based on the type of AI media used, the chemistry topics supported, the form of implementation in learning as well as the pedagogical implications reported. Furthermore, each study was systematically sampled to ensure relevance to the focus of the study. The analysis is also directed to identify patterns of findings, methodological tendencies, and the potential and challenges of using AI in the context of chemical learning. Article quality assessment is carried out qualitatively based on relevance, methodological clarity, and pedagogical contribution.

The article selection process in this systematic review follows the stages of identification, screening, feasibility assessment, and inclusion as shown in Figure 1. Based on the entire selection and evaluation process, 19 articles were obtained that were declared to meet the criteria and analyzed in depth in this study.

RESULT AND DISCUSSION

The results of the study presented answers to the formulation of the problem through a systematic analysis of nineteen selected scientific articles coded A1 to A19. The focus of the study includes the identification of the types and forms of Artificial Intelligence (AI)-based learning media used in the context of chemical learning, chemical topics involving the use of AI-based media, analysis of its application as a means of learning, and the implications of findings obtained through a careful and structured literature review.

Variations of the Types of AI Media Used

Table 2. Frequently Used AI Forms and Types Themes

Forms and Types of AI Used	Journal Code	Frequency	% Overall
ChatGPT	A1, A2, A3, A8, A9, A10, A11, A15, A19	9	27.27%
Virtual Reality (VR)	A4, A6, A12, A18	4	12.12%
Gemini	A3, A10, A19	3	9.09%
Augmented Reality (AR)	A4, A6, A12	3	9.09%
Copilot	A2, A19	2	6.06%
LLMs GPT-3.5/4	A6, A10	2	6.06%
DALL-E	A2	1	3.03%
Claude	A3	1	3.03%
Bard	A15	1	3.03%
ChemVox (Voice Assistant)	A4	1	3.03%
moleculARweb	A12	1	3.03%
AI Speaker (TTS + NLP)	A13	1	3.03%
AI/ML - image/speech recognition	A4	1	3.03%
NLP - keyword extraction	A5	1	3.03%
Web-based analytics platform	A16	1	3.03%

The distribution of variations in the form of AI used as a medium for learning chemistry is presented in Table 3. Based on the themes that emerge, ChatGPT is the most dominant form of AI used as a medium for learning chemistry at the high school level. This can be seen from the frequency of its occurrence which reached 9 times (27.27%) among the total journal entries analyzed, namely in journals with codes A1, A2, A3, A8, A9, A10, A11, A15, and A19. ChatGPT is used for various learning purposes, such as answering chemistry problems, explaining concepts, giving feedback, and helping teachers compile materials. Yuriev et al. (2024) state that AI like ChatGPT can be used to provide a gradual and easy-to-understand explanation of basic concepts

In addition to ChatGPT, Virtual Reality (VR) also shows a significant utilization rate, used in 4 journals (12.12%), such as A4, A6, A12, and A18. VR allows students to interact with chemical simulations in an immersive manner, such as molecular visualization, virtual lab experiments, or reaction observations. Followed by Gemini and Augmented Reality (AR) with 3 appearances each (9.09%), which are also used in visualization and explanation of abstract chemistry concepts. Other types of AI such as

Copilot, GPT-3.5/4 LLMs, and voice-based assistants such as ChemVox and AI Speaker (TTS + NLP), although less used, show potential for integration into practice-based learning and interactive narratives.

From these findings, it can be concluded that the types of AI media most commonly used in chemical learning are those that are generative and interactive, particularly those that support text-based learning (such as ChatGPT), as well as visual and experiential media (such as VR and AR). This suggests that the use of AI is geared towards addressing the abstraction of chemical materials and improving student engagement and personalization of learning at the secondary education level. Comparatively, these findings show that research on AI as a medium of learning chemistry at the intermediate level still tends to focus on exploring the potential of text-based generative AI compared to the development of AI systems that are integrated in learning design. The dominance of ChatGPT indicates the tendency to utilize AI as an instant response tool, while the development of more systematic AI-based pedagogical models is relatively limited. This opens up further research opportunities that emphasize AI-based structured learning design, not just its functional utilization.

Research conducted by Nguyen et al., (2023) also states that ChatGPT can tailor responses to the needs of individual students, providing explanations and resources that are in tune with their pace and learning style. Leite, (2023) also mentioned that ChatGPT helps in clarifying complex chemical concepts, making it more accessible to students.

Chemistry Topics Using AI-Based Media

Table 3. Chemistry Topics Using AI-Based Media

Chemical Topics Using AI	Journal Code	Frequency	% Overall
Atomic structure	A1, A2, A6, A14, A19	5	16.13%
Molecular structure and 3D visualization	A2, A4, A12	3	9.68%
Chemical and molecular substances	A10, A19	2	6.45%
Organic chemistry: reactions and mechanisms	A1, A3, A8	3	9.68%
Organic chemistry: IUPAC, functional groups, isomers	A15	1	3.23%
Basic chemical reactions	A3, A7, A18	3	9.68%
Basic concepts of chemistry and misconceptions	A11, A13, A17	3	9.68%
Practicum: titration, $KMnO_4$ solution, waste, safety	A13, A17	2	6.45%
Element classification and property prediction	A10, A14	2	6.45%
Thermodynamics	A12	1	3.23%
Kinetics	A12	1	3.23%
Basic laws of chemistry	A12	1	3.23%
Electrolysis	A19	1	3.23%
Ionic bonds	A16	1	3.23%
Crystal structure	A16	1	3.23%

Chemistry topics using AI-Based Media are presented in Table 3. Based on the coding results of 19 journals analyzed, it was found that the use of Artificial Intelligence (AI)-based media has been applied to various chemical materials at the secondary education level. The material that uses the most AI media is atomic structure, which appeared in five journals (16.13%). AI media is used in this topic to visualize the arrangement of subatomic particles, electron configuration, as well as help students understand the periodic properties of elements. The use of AI such as chatbots or adaptive systems helps simplify abstract concepts with a dialogical or visualization approach.

Furthermore, molecular structure and 3D visualization are also one of the materials that are greatly helped by AI media (9.68%). AI is used to visualize the shape of molecules in three dimensions through AR/VR technologies such as MolAR or ChemVox. This helps students understand the concepts of molecular geometry, bonds, and polarity in a more concrete and spatial way. Chemical and molecular substances, as basic concepts, also appear quite dominant because they are the basis in AI's introduction to chemical terms, used in chatbots and AI-based classification systems.

In the field of organic chemistry, two major categories were found, namely: (1) reactions and mechanisms (9.68%), and (2) IUPAC, functional groups, and isomers (3.23%). AI like ChatGPT is used to help students understand the mechanisms of organic reactions, and evaluate answers through interactive Q&A. On the topic of IUPAC and compound structure, AI plays a role in generating notation or compound names from visual representations given by students, although challenges are also found in the accuracy and consistency of outputs.

Basic chemical reactions were another topic that came up frequently (9.68%), where AI played a role in simulating reactions through chatbots, adaptive tutor systems, or VR applications to visualize chemical changes. Basic concept and misconception material was also touched by many teachers with the help of AI (9.68%) to clarify the concept and overcome students' misconceptions such as about OH^- or compound structure.

AI is also used in practicum materials such as titration, $KMnO_4$ solutions, waste management, and laboratory safety (6.45%). AI speakers or hands-free systems are used to guide students during experiments. In the material on element classification and trait prediction (6.45%), AI is used in the context of data-driven exploration, helping students recognize patterns and trends in the periodic table.

Some of the materials that appear less but remain relevant are thermodynamics (3.23%), kinetics (3.23%), and the basic laws of chemistry (3.23%), which are part of the topic of physical chemistry. AI is used in the form of simulations or adaptive platforms that provide practice questions, automated feedback, and personalization of learning. Other materials include electrolysis (3.23%), which arises in the context of self-training using chatbots, as well as ionic bonds and crystal structures, which are discussed through grid simulations and solid matter structure models.

Overall, these findings suggest that AI-based media has been used to aid students' understanding of chemical materials that are abstract, complex, and visual. AI is a tool in explaining concepts, simulating processes, and providing learning feedback, especially on topics that require visual, procedural, and conceptual representations, The integration of AI in advanced quantitative-based topics such as thermodynamics and kinetics is still relatively limited. This shows that there is a tendency to use AI to support basic conceptual understanding, while the exploration of AI in supporting mathematical reasoning and quantitative problem solving is still relatively minimal.

Implementation of Artificial Intelligence (AI) as a Chemistry Learning Media

The implementation of Artificial Intelligence (AI) in chemistry learning at the secondary education level is carried out through various approaches that utilize AI technology in the teaching and learning process. One of the most prominent forms of implementation is the use of generative chatbots such as ChatGPT, Claude, and Gemini as student learning companions in answering concept questions, practice questions, and national exam simulations (Jere, 2025; Leite, 2024). In addition, AI is also used by teachers in designing learning activities, drafting exam questions, and overcoming student misconceptions through interactive dialogue with AI, which helps the learning planning process become more reflective and contextual (Feldman-Maggor et al., 2024; Pernaa et al., 2024). In addition to text-based functions, AI implementations are also seen in interactive visual media. Nascimento Júnior et al. (2024) report on the use of DALL-E and Firefly to generate automatic visualization of chemical structures, making it easier for students to understand materials such as chemical bonds, IUPAC, and molecular structure. This visualization is further enhanced by the utilization of augmented reality (AR) and virtual reality (VR) technologies through applications such as MolAR, ChemVox, and InteraChem, which allow students to explore molecular structures and chemical reactions in three-dimensional form (Raucci et al., 2023; Amirbekova et al., 2023; Iqbal & Campbell, 2023). The technology is also used to create AI-based virtual labs with hand movement tracking, which provides an immersive kinesthetic learning experience (Iqbal & Campbell, 2023).

AI is also implemented in the form of adaptive and diagnostic learning systems through devices such as smart pens and tablets that record student error logs, allowing personalized learning according to individual abilities (Hao et al., 2024). This system is combined with web-based data learning analytics that allows predictions of student performance through data-driven interactive analysis (Roski et al., 2024). On the other hand, natural language processing (NLP) technology is also used to support chemical video learning through automated keyword extraction and additional relevant content recommendations (Schulten et al., 2020). In the context of practicum, the implementation of AI is carried out through TTS and NLP-based speaker AI that provides voice instructions during chemical experiments, such as titration and laboratory waste management, to support student focus and safety in the laboratory (Lee, G. G. et al., 2023).

Methodologically, most studies are still at the exploratory and descriptive stage of the use of AI, with the evaluation of long-term impacts on learning outcomes not being widely studied, These findings point to the need for experimental research that tests the effectiveness of AI more systematically on the improvement of students' conceptual and higher-level thinking skills.

Implications of Using AI as a Chemistry Learning Media in High School

The results of the analysis of the challenges and opportunities for the use of Artificial Intelligence (AI) as a medium of learning chemistry in secondary education level indicate that the integration of this technology has complex and multidimensional implications, both in terms of pedagogy, technological, and ethical. On the one hand, AI has transformative potential in supporting more personalized, adaptive, and independent learning. AI systems are able to provide automated feedback, adapt materials according to students' needs, and present three-dimensional chemical visualizations through AR/VR technology, opening up a much more flexible and contextual learning space compared to conventional media (Yuriev et al., 2024; Amirbekova et al., 2023). This supports differentiation-based learning and a deep understanding of abstract concepts of chemistry, which are often a challenge in traditional teaching.

In addition, AI also has positive implications in driving student learning engagement as well as the development of 21st-century skills, such as critical thinking and digital literacy. Interaction with AI encourages students to evaluate answers, formulate appropriate questions, and conduct independent exploration of chemical materials, thereby strengthening their role as active learners (Feldman-Maggor et al., 2024). For teachers, AI provides efficiency opportunities in compiling data-based materials, questions, and lesson plans, as well as supporting the process of reflection on student understanding. This shows that AI plays a role not only as a teaching tool, but also as a partner in designing and evaluating the learning process in an ongoing manner.

However, the various challenges that arise also need to be seriously considered because they can hinder or even mislead the learning process. Information inaccuracy, content bias, and hallucination phenomena in AI output are the most frequently encountered major challenges, with great potential to cause misconceptions in students if not properly criticized (Kollar & Alshibli, 2024; Yuriev et al., 2024). The implication of this is the importance of instilling evaluative and AI literacy skills in students so that they do not passively receive answers, but are able to verify the correctness of information. In addition, students' reliance on AI risks lowering learning independence, while teachers' low digital literacy and limited technological infrastructure can hinder optimal AI integration in the classroom (Duarte et al., 2023; Berber et al., 2025).

At the institutional and policy levels, these findings highlight the need for systemic support, including ongoing teacher training, curriculum updates that are responsive to technological developments, and ethical regulations related to data privacy and fair access to AI technologies. Without this support, the use of AI risks adding to the digital and pedagogical divide in the educational environment. Therefore, the implementation of AI as a medium of learning chemistry cannot be seen only as the adoption of new tools, but as a process of comprehensive transformation in learning design that requires pedagogical, technological, and institutional readiness.

Thus, a key implication of the use of AI in chemistry learning is the need for a critical, reflective, and adaptive approach to this technology. AI has the potential to enrich and revolutionize students' learning experiences, but only if it is supported by adequate technological literacy, flexible curriculum, and policies that favor teacher capacity building and the protection of students' learning rights.

Conceptual Synthesis of the Utilization of AI in Chemistry Learning

Based on the synthesis of 19 selected articles, the use of Artificial Intelligence (AI) in chemistry learning can be applied in the framework of constructivism where AI acts as an agent-to-think-with that supports concept exploration, reflective dialogue, and learning personalization (Dos Santos, 2023). In this perspective, AI is not positioned as a substitute for teachers, but rather as an agent that facilitates the construction of knowledge through socratic question and answer, adaptive feedback, and prompt-based scaffolding. In addition to text-based, AI also functions as a visual and simulative medium through the use of AR/VR and interactive visualizations that help students understand abstract chemical concepts, such as molecular structure and chemical reactions (Amirbekova et al., 2023; Raucci et al., 2023)

Conceptually, AI in chemistry learning can be understood as a facilitator of dialogue, adaptive tutors, interactive simulation media, and a supporter of teacher instructional planning. In order to be in line with the principles of constructivism, the implementation of AI requires an open-task design, the use of structured scaffolding, and the improvement of pedagogical literacy and teacher technology in integrating AI meaningfully (Lada, 2025; Kumar, 2025).

CONCLUSION

The use of Artificial Intelligence (AI) in chemistry learning makes a significant theoretical contribution to the transformation of pedagogical approaches, especially in bridging the understanding of abstract concepts and increasing the active participation of students. The findings show that platforms such as ChatGPT as well as Virtual Reality (VR) and Augmented Reality (AR)-based technologies are the most widely used types of media in chemistry learning, especially on general topics of chemistry, molecular structure, and organic reactions. This study expands the literature by emphasizing that AI is not just a medium, but part of a learning ecosystem that is more adaptive, personalized, and contextual to the needs of the 21st century. On the other hand, there are still a number of challenges that need to be critically considered, such as the inaccuracy of AI content, low digital literacy, and the limited technology infrastructure in secondary education level. The methodological limitation of this study lies in the limited scope of the literature on selected publications, so generalization of results requires caution. The practical implications of these findings emphasize the importance of strengthening education policies, teacher training focused on digital competencies, and a curriculum that is responsive to technological developments. Follow-up research is recommended to be carried out empirically at the education unit level to explore the direct perceptions of teachers and students, as well as develop interdisciplinary studies to evaluate the pedagogical, ethical, and social impacts of the use of AI in chemistry education.

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