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Systematic Literature Review: Urgency of AI Integrated Chemistry Learning Models to Improve Student's Self-Regulated Learning

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Abstract: Systematic Literature Review: Urgency of AI Integrated Chemistry Learning Models to Improve Students's Self Regulated Learning. Objectives: This study aims to analyze the urgency of developing an AI-integrated chemistry learning model as a learning assistant to enhance students' self-regulated learning. Method: The study employed a Systematic Literature Review (SLR) method based on the PRISMA framework. The search was conducted via Google Scholar for the years 2019–2026, yielding 50 articles, with 12 meeting the inclusion criteria for analysis. Findings: The results indicate that integrating AI into chemistry learning can boost motivation, engagement, and critical thinking, as well as help students grasp abstract chemical concepts. AI also supports more personalized, adaptive, and self-directed learning, thereby contributing to the enhancement of self-regulated learning. However, its implementation still faces challenges related to AI literacy, teacher readiness, and technological infrastructure. Conclusion: Therefore, the development of AI-integrated chemistry learning models is a critical need to support more effective, interactive, and self-directed learning.

Keywords: Artificial Intelligence, Self Regulated Learning, and Chemistry Education.

Abstrak: Tinjauan Literatur Sistematis: Urgensi Model Pembelajaran Kimia Terintegrasi AI untuk Meningkatkan Regulasi Diri Pembelajaran Peserta Didik. *Tujuan: Penelitian ini bertujuan menganalisis urgensi pengembangan model pembelajaran kimia terintegrasi AI sebagai asisten belajar untuk meningkatkan self-regulated learning peserta didik. Metode: Penelitian menggunakan metode Systematic Literature Review (SLR) berdasarkan kerangka PRISMA. Penelusuran dilakukan melalui Google Scholar pada rentang tahun 2019–2026 dan diperoleh 50 artikel, dengan 12 artikel memenuhi kriteria inklusi untuk dianalisis. Temuan: Hasil penelitian menunjukkan bahwa integrasi AI dalam pembelajaran kimia mampu meningkatkan motivasi, keterlibatan belajar, berpikir kritis, serta membantu peserta didik memahami konsep kimia abstrak. AI juga mendukung pembelajaran yang lebih personal, adaptif, dan mandiri sehingga berkontribusi terhadap peningkatan self-regulated learning. Namun, implementasinya masih menghadapi tantangan berupa literasi AI, kesiapan guru, dan infrastruktur teknologi. Kesimpulan: Oleh karena itu, pengembangan model pembelajaran kimia terintegrasi AI menjadi kebutuhan penting untuk mendukung pembelajaran yang lebih efektif, interaktif, dan mandiri.*

Kata kunci: *Kecerdasan Buatan, Regulasi Diri dalam Belajar, dan Pembelajaran Kimia.*

▪ INTRODUCTION

The development of Artificial Intelligence (AI) in education has opened up opportunities to create learning experiences that are more adaptive, personalized, and learner-centered. AI has the potential to serve as a learning assistant capable of providing instant feedback and supporting learning that is more responsive to the individual needs of learners (Zawacki-Richter et al., 2019). Additionally, AI enables personalized learning, allowing students to learn at their own pace and in their preferred learning style, thereby facilitating a deeper understanding of concepts (Holmes et al., 2019). Recent research indicates that the use of AI in education has seen a significant increase during the 2021–2024 period through various applications such as chatbots and ChatGPT, which can enhance student engagement in learning (Erümit & Sarıalioğlu, 2025). With these characteristics, AI functions not only as a technological tool but also as a learning facilitator with the potential to support the development of students' self-regulated learning (SRL).

Self-Regulated Learning (SRL) is a student's ability to independently manage, monitor, and evaluate their learning process. This ability is viewed as a critical competency in 21st-century learning, as students are expected to independently manage their learning strategies, motivation, and academic responsibilities (Panadero, 2017). Students with strong SRL tend to be better able to determine learning strategies, manage their time, and complete tasks without relying on others. However, empirical evidence indicates that students' self-regulation skills remain suboptimal. Research shows that students' level of learning autonomy is still in the moderate category, at around 65% (Winda Permata et al., 2022). Low learning initiative and high dependence on others indicate the need for learning innovations that can support students' learning processes to become more independent, active, and focused.

Independent learning in science education, particularly in chemistry, is no longer merely a supplementary component but has become a key factor in helping students understand abstract chemical concepts. Previous studies have developed Android-based learning media to help students practice self-regulated learning skills and adapt their learning strategies (Kurniawan & Hidayah, 2020). However, the chemistry learning models widely used in schools still tend to rely on static digital media, such as inflexible electronic modules that cannot yet adapt to the learning needs of each student (Simbolon et al., 2024). This situation highlights the need to integrate Artificial Intelligence (AI) into chemistry learning design so that the learning system can provide personalized recommendations for materials, learning assistance, and feedback tailored to each student's abilities and self-regulated learning pace.

Instructional models play a crucial role in determining the effectiveness of chemistry instruction. Conventional, teacher-centered instruction is considered ineffective in enhancing student engagement and independent learning. Therefore, it is important to implement innovative instructional models that are oriented toward student-centered learning. Various studies indicate that active and collaborative learning models can stimulate metacognitive awareness, facilitate time management, and develop students' self-assessment skills (Moral & de Benito, 2021). The integration of active learning models with digital technology support, including the use of AI as a personal learning assistant, provides students with the opportunity to explore information, solve problems, and reflect on their thinking processes independently (Faza & Lestari, 2025).

Nevertheless, the current implementation of AI in learning remains largely piecemeal and has not been systematically integrated into the pedagogical syntax or design of learning models (Bond et al., 2024).

Although various studies have discussed self-regulation strategies and the use of educational technology, most research remains limited to conventional digital platforms that are passive in nature and not yet adaptive to students' learning needs (Panadero, 2017). Previous research has also not extensively explored how AI can be systematically integrated into learning models to provide personalized, adaptive, and continuous learning support at every stage of the learning process (Moral & de Benito, 2021). Consequently, there remains a theoretical and practical gap regarding the design of learning models that explicitly utilize AI as a learning assistant to stimulate students' metacognitive processes and self-regulation. These limitations highlight the urgency of developing an AI-integrated chemistry learning model that not only focuses on technology use but also systematically supports the enhancement of students' self-regulated learning.

Given these conditions, there is a need to develop a chemistry learning model capable of integrating the collaborative strengths of active learning with the adaptive advantages of AI as a learning assistant to enhance students' self-regulated learning. To date, studies on the integration of AI into chemistry learning models remain limited and have not systematically addressed its development to support students' self-regulated learning. Therefore, this study aims to analyze the urgency of developing an AI-integrated chemistry learning model through a Systematic Literature Review (SLR) approach to identify the potential, challenges, and opportunities for developing a learning model that supports the improvement of students' self-regulated learning.

▪ METHOD

This study employs the Systematic Literature Review (SLR) method to identify, evaluate, and synthesize various studies related to the urgency of developing an Artificial Intelligence (AI)-integrated chemistry learning model to enhance students' self-regulated learning. The SLR method was chosen because it provides a systematic, comprehensive, and structured overview of the research, thereby helping researchers identify trends and research gaps on a specific topic (Ramayanti et al., 2023).

The research was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, which consist of the identification, screening, eligibility, and article inclusion stages (Page et al., 2021). The use of the PRISMA guidelines aims to ensure that the article selection process is transparent and easily replicable by other researchers.

The literature search was conducted using the Google Scholar database with a combination of keywords related to artificial intelligence, chemistry education, and self-regulated learning. The search strategy employed Boolean operators such as AND and OR to both broaden and refine the search results. The keywords used include: *"Artificial Intelligence"* OR *"AI"* AND *"Chemistry Education"* OR *"Chemistry Learning"* AND *"Self-Regulated Learning"* OR *"Self-Directed Learning."*

The publication year range used was 2019–2026. This range was selected based on the development of Artificial Intelligence research in the field of education, which began to increase significantly after 2019, particularly with the emergence of generative AI technology, educational chatbots, and adaptive learning platforms during the era of digital

transformation in education. The retrieved articles were then screened based on the following inclusion and exclusion criteria.

Table 1. Inclusion and Exclusion Criteria

No	Inclusion Criteria	Exclusion Criteria
1	The article discusses chemistry education integrated with Artificial Intelligence	The article does not discuss the integration of AI into education
2	The article was published between 2019 - 2026	The article was published outside the 2019–2026 timeframe
3	The article is from an indexed national or international journal	Proceedings or non-journal articles that are not indexed
4	The article is available in full text	Articles that are not fully accessible

During the identification phase, 50 articles were retrieved from the Google Scholar database. A duplication check was then conducted, identifying 8 duplicate articles, leaving 42 articles for the screening phase. During the screening phase, based on titles and abstracts, 20 articles were eliminated because they were irrelevant to the research focus, did not discuss the integration of AI in chemistry education, or were unrelated to self-regulated learning. The next stage, eligibility, was conducted by examining the content of the articles in greater depth. At this stage, 10 articles were eliminated because the full text was unavailable or they did not meet the study's inclusion criteria. Consequently, 12 articles were determined to meet all criteria and were used in the final analysis of the study.

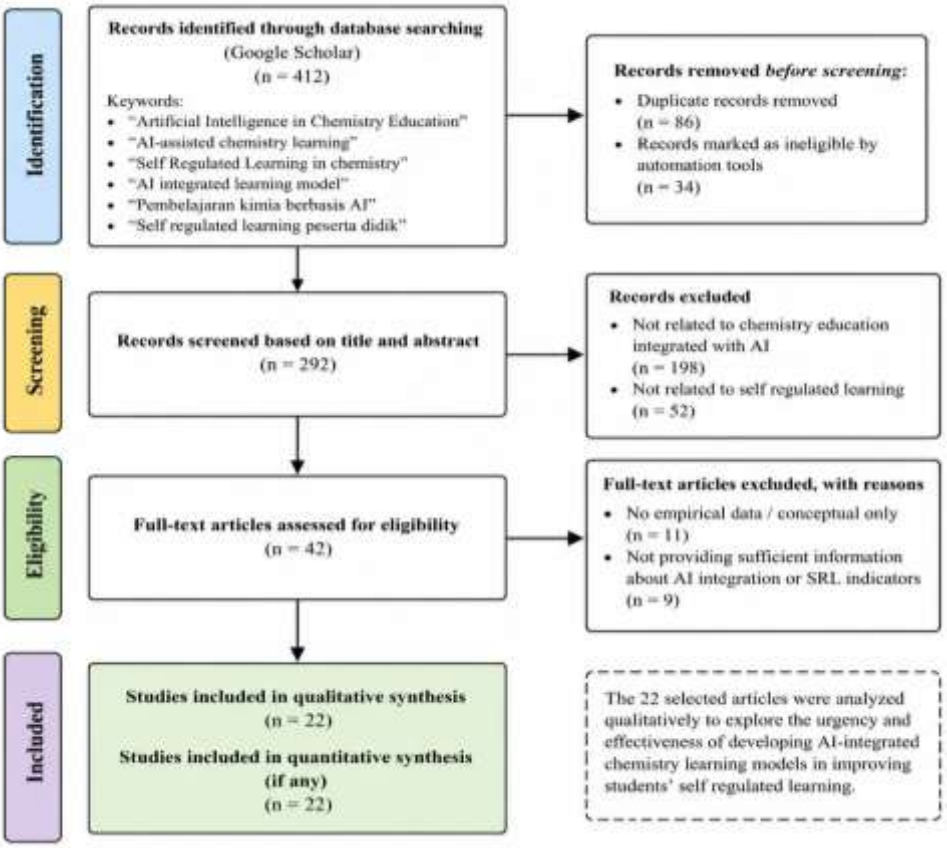

Figure 1. Article Screening PRISMA Diagram
Source: adapted from (Ramayanti et al., 2023)

The selected articles were then analyzed to obtain information regarding AI-based learning models, forms of AI implementation in chemistry education, the benefits and challenges of AI application, and the potential of AI as a learning assistant in supporting students' self-regulated learning. The data obtained were analyzed using qualitative descriptive analysis techniques by grouping the research results based on the focus of discussion and the urgency of AI integration in chemistry education. This approach was used so that the research results could provide a clearer picture of the opportunities and challenges in developing AI-integrated chemistry learning models.

Table 2. Research Questions

No	Research Question	Objective
1	What research methods are most commonly used in studies on AI-integrated chemistry education?	Identify the dominant research methods used in the reviewed articles, such as quasi-experimental, Research and Development (R&D), qualitative descriptive, and literature reviews.
2	What are the advantages and challenges of implementing Artificial Intelligence (AI) in chemistry education?	Identify the benefits and challenges of using AI in chemistry education, such as more personalized learning, increased creativity and motivation, as well as challenges related to infrastructure, AI literacy, ethics, and technological dependency.
3	How does the integration of Artificial Intelligence (AI) support chemistry education?	Examining the role of AI in supporting chemistry learning through interactive, adaptive, contextual, and technology-based learning experiences.
4	What are the prospects for using AI as a learning assistant in chemistry education in the future?	Identifying the potential of AI as a learning assistant in supporting self-directed learning, adaptive learning, and the development of 21st-century skills in chemistry education

▪ RESULT AND DISCUSSION

Based on the results of a literature review, 50 articles were identified in the Google Scholar database that discuss the integration of Artificial Intelligence (AI) in chemistry and science education. These articles were then selected based on predetermined inclusion criteria, namely that they were published between 2019 - 2026, were relevant to chemistry education, and discussed the urgency of applying AI in education today to enhance students' self-regulated learning.

During the screening phase, several articles were excluded due to duplication, unavailability of full-text versions, and irrelevance to the research focus. Additionally, some articles only discussed the general use of AI in education without linking it to science learning. After the eligibility phase, 12 articles that met all criteria were selected and used in the analysis process.

The synthesis of findings in this study was conducted using a qualitative descriptive approach. The selected articles were then grouped based on the form of AI integration in

chemistry and science learning, the learning models used, and indicators of students' self-regulated learning. The results of the study indicate that the integration of AI in chemistry learning is essential because it supports independent learning, enhances motivation, improves critical thinking skills, aids in managing the learning process, and encourages students' active engagement in understanding abstract chemical concepts.

Table 3. Article Analysis Results

No	Authors	Key Findings	Index
1	Lin & Chang (2025)	The AI-based DT-STEAM learning model has been proven to significantly improve students' understanding of AI concepts, their attitudes toward AI, and their design creativity, thereby supporting more active, innovative, and collaborative learning.	Quartile 1
2	Głushkova & Malinova (2024)	The use of AI and chatbots in STEAM education enhances student motivation, creativity, and learning outcomes, particularly in collaborative programming and robotics projects.	Quartile 4
3	Kasman et al. (2025)	An AI-integrated STEM-based chemistry module effectively enhances students' critical thinking skills regarding chemical bonding through AI-assisted interactive and adaptive learning.	Sinta 2
4	Salsabila et al. (2026)	STEAM-ESD-based AI chatbots can significantly improve students' science literacy through personalized, contextual, and problem-solving-based learning.	Sinta 3
5	Yildirim & Akcan (2024)	Chemistry teachers require AI competency development to effectively integrate AI into chemistry instruction, particularly in lesson planning and chemistry experiments.	Quartile 4
6	Hafiz Aldwinarta í et al. (2024)	AI chatbot-based learning media for thermochemistry content are deemed necessary as they can enhance student motivation, interactivity, and engagement in understanding challenging chemical concepts.	Sinta 3
7	Nugraha & Harsono (2024)	The use of AI in chemistry storytelling through e-books enhances students' creativity, engagement, and understanding of chemical concepts through more engaging and communicative learning.	Sinta 3
8	Hsu et al. (2021)	AI-STEAM learning based on experiential learning improves learning outcomes, self-efficacy, and students' active engagement in understanding science and technology concepts.	Quartile 1
9	How & Hung (2019)	Integrating AI into STEAM education can enhance students' critical thinking, creativity, analytical skills, and problem-solving abilities more effectively and dynamically.	Quartile 2

No	Authors	Key Findings	Index
10	Munawwarah et al. (2025)	Students view AI as helpful in understanding chemistry concepts, improving learning efficiency, and strengthening learning interactions, although there are concerns regarding AI dependency and a decline in critical thinking.	Sinta 3
11	Akbar & Djakariah (2024)	AI transforms chemistry learning through personalized learning, complex data analysis, and interactive learning, although it still faces technical and ethical challenges in its implementation.	Sinta 4
12	Ruth & Danladi (2025)	The integration of AI in STEAM education supports the development of critical thinking, creativity, problem-solving, and personalized learning relevant to 21st-century skills.	Quartile 4

Based on a synthesis of the 12 articles analyzed, it was found that the integration of Artificial Intelligence (AI) in chemistry education contributes positively to improving the quality of learning, particularly in supporting the development of students' self-regulated learning. Various AI technologies such as chatbots, adaptive learning, virtual assistants, and AI-based learning media help students obtain information quickly, understand abstract chemical concepts, and provide a more personalized and flexible learning experience. The use of AI also encourages students to be more independent in managing their learning process through information search, material organization, learning planning, and self-monitoring of understanding via instant feedback and automated assessment.

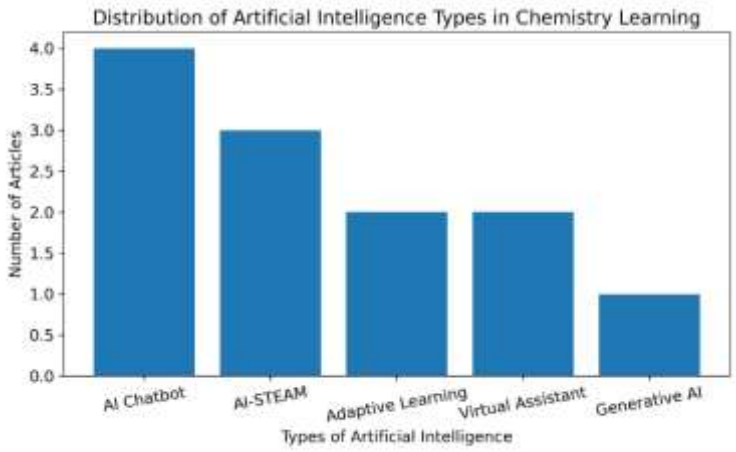

Figure 2. Distribution of Artificial Intelligence Types Used in Chemistry Learning Based on the Reviewed Articles

Based on Figure 2, AI Chatbots are the most widely used type of AI, appearing in 4 articles. Next, AI-STEAM ranks second with 3 articles, indicating that the integration of AI with the STEAM approach is also becoming increasingly common in chemistry education. Meanwhile, Adaptive Learning and Virtual Assistants each appear in 2 articles, demonstrating the use of AI to support more personalized and interactive learning. Generative AI, on the other hand, is the least-used type of AI, appearing in only 1 article. These findings suggest that the use of AI in chemistry education is still

dominated by chatbot-based AI and interactive systems that support communication and student learning support.

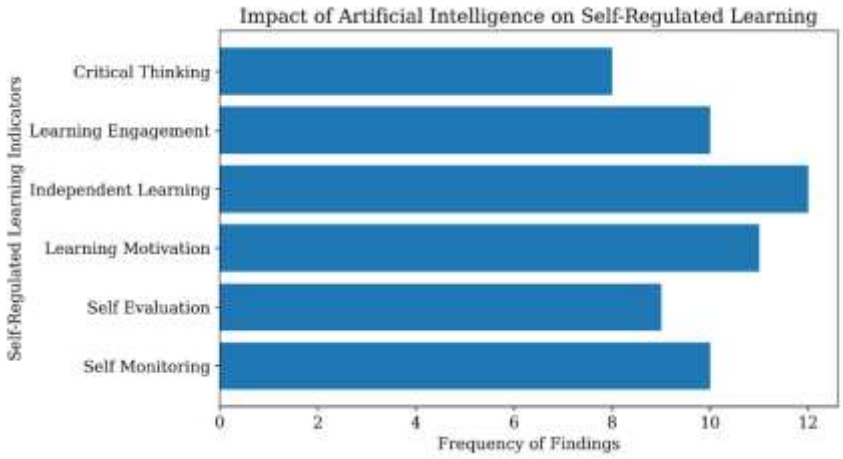

Figure 3. Impact of Artificial Intelligence on Students' Self-Regulated Learning in Chemistry Education

Based on Figure 3, the indicator that showed the greatest increase was independent learning, with a frequency of 12 findings. This indicates that the use of AI in learning is able to encourage students to learn more independently. Additionally, learning motivation had a frequency of 11, while learning engagement and self-monitoring each had a frequency of 10, indicating that AI also contributes to enhancing students' motivation, engagement, and ability to monitor their learning process. Meanwhile, self-evaluation had a frequency of 9 and critical thinking 8, although both still showed a positive influence from the use of AI in learning. These findings indicate that the integration of AI in chemistry learning is more dominant in supporting aspects of independent learning and student engagement in the learning process.

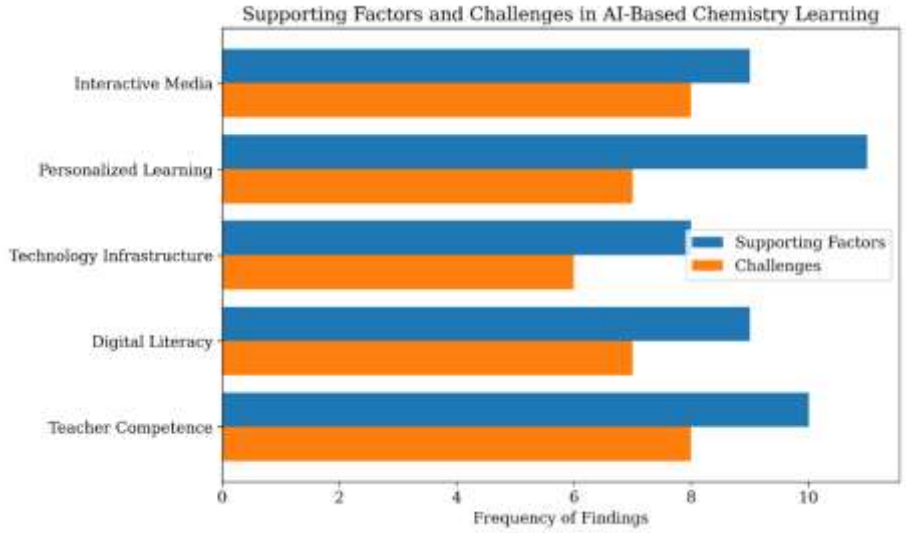

Figure 4. Supporting Factors and Challenges in the Implementation of Artificial Intelligence-Based Chemistry Learning

Based on Figure 4, personalized learning emerged as the most dominant supporting factor, with a frequency of 11. This indicates that AI's ability to provide learning tailored to the individual needs and abilities of students is a key strength in chemistry education.

Additionally, teacher competence had a frequency of 10, while interactive media and digital literacy each had a frequency of 9, indicating that teacher competence, interactive learning media, and digital literacy skills also play a significant role in supporting AI implementation. Meanwhile, technology infrastructure was cited 8 times as a supporting factor but also remained a challenge, cited 6 times. Regarding challenges, interactive media and teacher competence were each cited 8 times, while personalized learning and digital literacy were cited 7 times. These findings indicate that the success of AI implementation in chemistry education is influenced not only by technological sophistication but also by teacher readiness, digital literacy, and adequate infrastructure support.

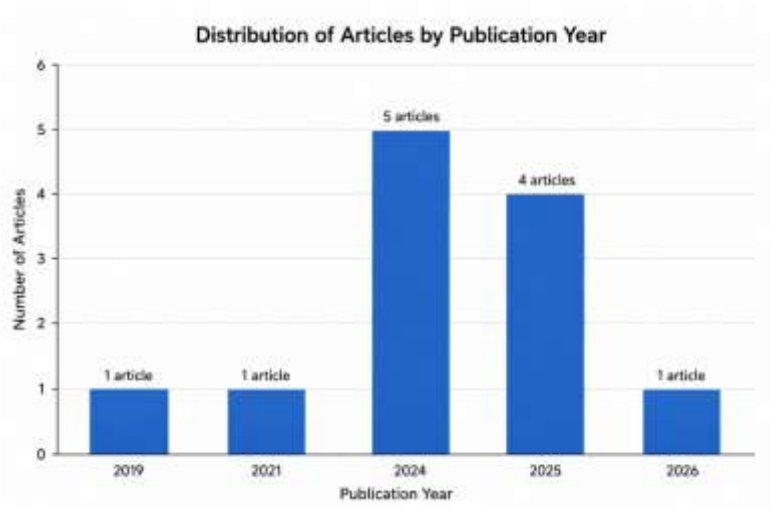

Figure 5. Distribution of Research Publications on Artificial Intelligence in Chemistry Education by Year

Based on Figure 5, the distribution of articles by year of publication shows that research on the use of Artificial Intelligence (AI) in education has seen a significant increase in recent years. Of the total 12 articles reviewed, the highest number of publications was found in 2024, with 5 articles, followed by 2025 with 4 articles. Meanwhile, only 1 article was found in each of the years 2019, 2021, and 2026. These data indicate that studies on the integration of AI in learning, particularly those related to the development of Self-Regulated Learning (SRL), have become a topic receiving increasing attention in recent years. The rise in the number of publications in 2024 and 2025 suggests that the use of AI in education is growing rapidly alongside the increasing adoption of digital technology and the need for more adaptive and personalized learning.

According to Zimmerman & Martinez-Pons (1990), indicators of Self-Regulated Learning (SRL) include self-evaluation, organizing and transforming information, setting goals and planning learning, seeking information, recording and monitoring the learning process, managing the learning environment, seeking social support, and reviewing learning outcomes. Based on a literature review of 12 articles, it was found that the use of Artificial Intelligence (AI) in learning is most closely associated with the indicators of information seeking, organizing and transforming information, setting goals and planning learning, recording and monitoring the learning process, managing the learning environment, and reviewing learning outcomes. This is evident in the use of AI chatbots, adaptive learning platforms, interactive simulations, and AI-based learning media that help students quickly access information, understand abstract concepts, and support more personalized and flexible learning.

The "seeking information" indicator is evident in the use of AI chatbots that help students access scientific references, answer questions, and provide additional explanations when students encounter learning difficulties. Furthermore, the "organizing and transforming information" indicator is evident when AI helps simplify abstract chemistry concepts through visualizations, simulations, concept maps, or summaries of material, making the information easier to understand. Indicators of setting goals and planning learning are also evident when AI helps students outline steps to complete tasks and provides systematic learning guidance. Additionally, indicators of recording and monitoring the learning process and reviewing learning outcomes emerge through instant feedback and automatic evaluation features, which allow students to independently track their progress in understanding. As for the indicator of managing the learning environment, this is evident in the flexibility of AI use, which is accessible at any time, allowing students to learn independently outside of formal class hours. Thus, the results of the literature review indicate that AI plays a role in supporting the development of several indicators of students' Self-Regulated Learning in the learning process.

▪ CONCLUSION

The results of this systematic literature review indicate that the integration of Artificial Intelligence (AI) into chemistry education has significant potential to enhance students' self-regulated learning. The use of AI through chatbots, adaptive learning systems, and AI-integrated learning creates a more personalized, interactive, and flexible learning environment, thereby encouraging students to become more independent, motivated, and active in managing their own learning process. Furthermore, AI integration also supports the development of critical thinking skills, creativity, and 21st-century skills required in modern education. These findings suggest that AI serves not only as a learning support technology but also as a means to transform chemistry education into a more student-centered approach.

Practically, the results of this study can serve as a reference for chemistry teachers in designing more adaptive learning by utilizing AI as a learning assistant to provide quick feedback, offer more personalized learning resources, and support students' independent learning. Furthermore, these findings can also serve as a foundation for curriculum developers to integrate AI more systematically into chemistry education to support the development of self-regulated learning and 21st-century skills. Therefore, further research is needed to develop a more comprehensive AI-integrated chemistry learning model while maintaining the teacher's role as a facilitator in the learning process.

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