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LAVOISIER: CHEMISTRY EDUCATION JOURNAL
Vol. 5 (1), 2026

Implementation of Deep Learning for AI-Based Adaptive Chemistry Learning using Literature Review Method

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Article History

Received 10 12th 2025
Revised 04 17th 2026
Accepted 06 12th 2026
Available Online 06 30th 2026

Keywords:
Adaptive Learning
Artificial Intelligence (AI)
Chemistry Education
Literature Review

Abstrac

This literature review study aims to analyze and synthesize the implementation of Deep Learning in adaptive and inclusive chemistry learning based on Artificial Intelligence (AI). The background of this research is based on the demands of the digital era and Ki Hajar Dewantara's educational philosophy regarding guidance that humanizes humans, which requires pedagogical innovation to overcome the abstract nature of chemistry subjects. Chemistry, which involves microscopic concepts and high visual representation, is often a source of learning difficulties for students. Therefore, Deep Learning is presented as a solution to create a personalized and responsive learning system. The method used was a systematic literature study by analyzing ten relevant articles published between 2015 and 2025, with the main keywords "Deep Learning," "Artificial Intelligence/AI," and "Chemistry Learning." The synthesis of the ten articles shows that the implementation of AI and Deep Learning has three main impacts: (1) Improved Understanding of Chemical Concepts: AI/Deep Learning, through differentiated learning systems, virtual laboratories, and digital tutors, effectively addresses the abstract nature of chemical concepts (A2, A4). This technology facilitates the visualization of molecular structures and provides targeted automated feedback (A10), thereby improving student understanding, (2) Strengthening Teacher Competence: AI integration assists teachers in providing simulations, digital media (A6), and rapid feedback, which significantly improves teachers' pedagogical abilities in designing innovative learning (A1, A3), (3) Development of 21st Century Skills: The use of Deep Learning (A8) and Generative AI (A10) models has been proven to develop multiple creativity, critical thinking, and collaboration among students in the context of chemistry, in line with sustainability demands (SDGs). However, consistent implementation challenges include infrastructure limitations, low digital literacy, and the need for teacher training (A1, A7). Overall, this

DOI : https://doi.org/10.24952/lavoisier.v5i1.18182

study concludes that Deep Learning and AI are important and strategic components in shaping an adaptive, personalized, efficient, and inclusive chemistry learning environment that is capable of aligning the complexity of the material with the unique needs of each student in the digital age.

1. Introduction

Ki Hajar Dewantara, the Father of Indonesian National Education, explained that education is a process of guidance in the growth and development of children. Through education, all the potential and natural strengths possessed by children are guided so that they can develop fully as individuals and as members of society, enabling them to achieve the highest level of safety and happiness. Education can be interpreted as the process of "humanizing humans" as a whole. Therefore, education does not only aim to shape a person to be different from others in terms of daily habits such as eating, dressing, and having a place to live, but education is more than that. It strives to humanize humans in a more profound way. This process involves character development and the instilling of values that shape individuals to not only function in society but also contribute positively (Atun & Nabilah, 2025).

Education is one of the means to shape a future generation of high-quality leaders for the nation. The rapid development of science and technology today requires education to participate in the use of technology as a form of innovation in learning (Akhmad, 2015). Along with technological developments, the world of education faces new challenges to integrate digital innovation so that the learning process becomes more effective, relevant, and able to respond to the increasingly diverse needs of students. One area of technology that is developing very rapidly is artificial intelligence (AI), particularly the branch of deep learning, which enables machines to learn complex patterns from data and generate recommendations or decisions that resemble human thought processes. In the context of education, the use of AI is no longer limited to administration or data processing, but has expanded to the development of adaptive learning systems that are able to adjust material, strategies, and difficulty levels based on the individual abilities of students. This development becomes even more relevant when linked to fields of study that have complex and abstract characteristics, one of which is chemistry.

In chemistry learning, the existence of AI-based adaptive systems is very important considering that chemistry is a subject that has abstract characteristics, is full of microscopic representations, and involves high visualization abilities (Prastika et al., 2024). Many students have difficulty understanding concepts such as atomic structure, chemical bonds, or electron configuration, so a more personalized and responsive learning approach is needed. Through Deep Learning, various applications such as learning difficulty recognition, automatic 3D visualization, and smart tutors can be developed to help students understand chemistry concepts more deeply and interactively.

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In addition to improving learning effectiveness, AI and Deep Learning also have the potential to support inclusive education, which is education that ensures all students, including those with disabilities, have equal learning rights (Setyawati et al., 2025). Students with visual, hearing, or motor impairments often encounter difficulties in following chemistry lessons, mainly due to limited access to visualizations, chemical symbols, and laboratory activities. Deep Learning-based technology is capable of providing adaptive features such as text-to-speech, visual-to-audio description conversion, automatic subtitles, and personalized recommendation systems that can be tailored to the needs of each student (Hermanto et al., 2025). Thus, the implementation of Deep Learning in chemistry learning not only offers pedagogical innovation but also opens up opportunities for the creation of a more inclusive, humanistic learning environment that supports student diversity.

Based on this potential, this study uses a literature review method to analyze the implementation of Deep Learning in AI-based adaptive chemistry learning. This review aims to compile the latest empirical findings, identify research trends, and formulate challenges and opportunities for developing adaptive and inclusive chemistry learning in the digital age. The results of this study are expected to contribute theoretically and practically to the development of educational innovations in line with technological developments and the needs of today's students.

2. Materials and Methods

The research method used is a literature study, which involves the process of problem identification, literature search, selection of relevant literature, and systematic data analysis. Data collection was carried out by searching various national and international references in online databases published in the last 10 years (2015-2025). This literature study used 10 relevant articles. In addition, journals relevant to the topic were obtained through searches in databases using the keywords "*Deep Learning*," "*Artificial Intelligence/AI*," and "Chemistry Learning." From the search results, 10 articles were selected that were considered most relevant to the research topic. All articles were then analyzed in depth to identify research trends, key findings, and their implications for the application of artificial intelligence technology in chemistry learning.

3. Results and Discussions

The application of deep learning in AI-based adaptive chemistry learning has shown great potential in improving learning personalization, facilitating the identification of student learning difficulties, and providing material recommendations that are more suited to individual needs, thereby supporting in-depth conceptual understanding and increasing the effectiveness of the learning process, as shown in Table 1

Table 1. Results of the literature review analysis of several scientific articles.

Code	Article Title and Authors	Journal of Publication	Publication Results

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A1	High School Chemistry Teachers' Views on the Integration of Artificial Intelligence in Learning in the Digital Age (Susilo et al., 2025).	Naradidik: Journal of Education & Pedagogy	This study found that although high school chemistry teachers in Sleman showed interest in AI (especially ChatGPT and Gemini) and felt its benefits in providing quick feedback and increasing student motivation, their understanding and skills were still limited, school facilities were inadequate, and the majority had never participated in AI training. Therefore, there is a need to improve teacher training and infrastructure to optimize the use of AI in chemistry learning.
A2	Transforming Chemistry Education through the Use of Artificial Intelligence (AI) in the Society 5.0 Era (Akbar & Djakariah, 2024b).	Edudikara: Journal of Education and Learning	The use of AI in chemistry learning in the Society 5.0 era helps make the learning process more personalized and effective through tools such as virtual labs, adaptive learning systems, and automatic analysis of student difficulties. This technology facilitates the understanding of abstract concepts, increases interactivity, and supports teachers in designing more appropriate learning strategies, although it still requires adequate digital literacy and infrastructure.
A3	Implementation of Innovative Learning Technologies in MGMP for Improving the Quality of Chemistry Teachers in Aceh Tamiang (Nasir et al., 2025).	Aceh Service Journal	The implementation of innovative learning technology in the chemistry MGMP in Aceh Tamiang helps improve teacher competence through training in the use of digital media, interactive platforms, and modern learning strategies. This activity strengthens teachers' ability to design

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			more engaging and effective learning, enhances collaboration among teachers, and encourages the use of technology as part of improving the quality of the teaching process in schools.
A4	Study on the Role of Artificial Intelligence in Supporting Differentiated Learning Strategies in Chemistry Lessons at School (Ridwansyah et al., 2024).	Undiksha Chemistry Education Journal	AI plays a role in supporting differentiated learning in chemistry by providing analysis of students' learning needs, recommending materials appropriate to their ability levels, and providing tools such as simulations, virtual labs, and digital tutors that allow students to learn at their own pace. This technology supports teachers in designing more personalized and effective learning, although its implementation still requires adequate infrastructure and digital literacy.
A5	Integration of Artificial Intelligence (AI), Deep Learning, and Curriculum Based on Sustainable Development Goals for the Global Generation (Yuniar et al., 2023).	Al-Haytham: Journal of Islamic Education	The integration of AI, deep learning, and SDG-based curriculum aims to shape a generation that is technologically adaptive and sustainability-oriented. AI and deep learning are used to personalize learning, improve educational data analysis, and enrich the learning experience, while the SDG curriculum ensures that global values such as social responsibility and sustainability remain fundamental. This combination is expected to create learning that is relevant to the needs of the 21st century

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			and prepare students to face global challenges.
A6	Development of Artificial Intelligence-Based Learning Videos Assisted by Lumen5 on Hydrocarbon Material in Senior High Schools/MA (Ranni et al., 2025).	Journal of Community Service and Educational Research	The development of AI-based learning videos using Lumen5 helps teachers present hydrocarbon material in a more visual, concise, and interesting way, making it easier for students to understand abstract concepts. The use of AI speeds up the video creation process, improves media quality, and supports independent learning, while trials show that these videos are effective in increasing student interest and engagement in learning chemistry.
A7	Opportunities and Challenges in Using AI (Artificial Intelligence) in Chemistry Education (Taruklimbong & Sihotang, 2023).	Tambusai Education Journal	Research shows that the use of AI in chemistry learning can help students understand difficult concepts through simulations and automatic feedback. However, its implementation still faces challenges such as limited teacher competence, inadequate technological facilities, and ethical issues surrounding the use of AI. Overall, AI has great potential to improve the quality of chemistry learning if supported by adequate training and facilities.

DOI : https://doi.org/10.24952/lavoisier.v5i1.18182

A8	Integrating ESD into Green Chemistry Education Using the Deep Learning-Based C-R-E-A-T-E Model to Develop Multiple Creativity in High School Students (Wahyu et al., 2025).	Journal of Chemistry Education Research and Practice	This study shows that the integration of ESD in Green Chemistry learning with the deep learning-based C-R-E-A-T-E model can significantly improve the multiple creativity of high school students. Students become more active, creative, and understand the connection between chemistry and sustainability issues, while teachers see an increase in 21st-century skills such as problem-solving and digital literacy. Overall, this model is effective in developing students' creativity and sustainability awareness.
A9	The Application of Artificial Intelligence (AI) in Chemistry Learning (Akbar & Djakariah, 2024a).	Literacy: Journal of Education and Social Sciences	This study found that the application of AI in chemistry learning provides significant benefits such as the ability to predict molecular properties with high accuracy, accelerate molecular structure modeling, analyze large chemical data efficiently, and open up new breakthrough opportunities in chemical research. However, it faces challenges in the form of limited data quality, complexity of model interpretation, the need for strong computing infrastructure, and issues of ethics and data security.
A10	Integration of Generative AI and Digital Curation in Stoichiometry Learning to Improve Critical Thinking and Cooperation Among	As-Sabiqun: Journal of Early Childhood Islamic Education	The results of the study show that the integration of Generative AI and digital curation in stoichiometry learning can improve high school students' critical thinking and teamwork skills. The use of Generative AI helps students analyze

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	High School Students (Gani, 2025).	stoichiometry problems more deeply through examples, explanations, and automatic feedback, while digital curation encourages students to work together in collecting, selecting, and organizing chemistry learning resources collaboratively. Overall, the combination of these two technologies has been proven to improve students' understanding of stoichiometry concepts, evaluation and analysis skills, and strengthen group cooperation and interaction in the classroom.

Based on a review of ten analyzed articles, it appears that the application of Artificial Intelligence (AI) and Deep Learning in chemistry learning is increasingly showing a significant contribution to improving the quality of the teaching and learning process. Overall, all articles consistently describe that AI technology offers great opportunities to personalize learning, facilitate the understanding of abstract concepts, improve students' analytical skills, and help teachers design more effective learning strategies. However, each article also highlights challenges that still need to be overcome for AI implementation to run optimally.

Research A2 and A4 directly show that AI technology is capable of overcoming the abstract characteristics of chemistry learning through differentiated learning systems, virtual laboratories, and deep learning-based digital tutors. This technology allows students to visualize molecular structures, chemical reactions, or electron configurations in a more interactive way. The adaptive learning system developed is capable of analyzing students' difficulties—for example, when understanding stoichiometry, hydrocarbons, or microscopic concepts—and then providing material recommendations according to their abilities. This is in line with the findings of A10, where the use of Generative AI provides automatic feedback that helps students understand the steps to solve stoichiometry in a more coherent and focused manner.

Meanwhile, from the teachers' perspective, studies A1 and A3 explain that the integration of AI in chemistry learning not only affects students but also plays an important role in improving teachers' pedagogical competencies. Teachers feel assisted because AI can provide quick feedback, provide relevant chemistry simulations, and facilitate the delivery of abstract concepts through digital media. In addition, the technology-based MGMP activities studied in A3 improve teachers' ability to design more modern, interactive chemistry lessons that make maximum use of digital

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media. However, the results of the study also show that limited digital literacy and a lack of AI training for chemistry teachers remain major obstacles, as emphasized in A1 and A7.

Beyond pedagogical aspects, the integration of AI and deep learning also appears to influence the development of chemistry learning media. Research in A6 shows that the use of Lumen5 as an AI-based platform can produce concise, visual, and more student-friendly hydrocarbon learning videos. With AI's ability to automate content creation, teachers can produce quality chemistry media without spending a lot of time. These findings reinforce that AI not only functions as an analysis tool but also as an effective tool for producing chemistry teaching materials.

The development of 21st-century character and skills through chemistry learning is also an important issue in several articles. Research in A8 found that the integration of deep learning in the C-R-E-A-T-E model on the topic of Green Chemistry was able to increase students' multiple creativity. Deep learning-based learning allows students to process data, interpret experimental results, and solve chemistry problems with a more critical and creative approach. Meanwhile, A10 adds that the use of Generative AI and digital curation encourages collaboration and mutual assistance in understanding stoichiometry concepts. This shows that AI technology not only supports conceptual understanding but also builds higher-order thinking skills in the context of chemistry.

Meanwhile, studies A5 and A9 explain that AI and deep learning also have a strategic role in chemical analysis, integration with the curriculum, and molecular modeling. Research A9 emphasizes that AI can predict molecular properties, model structures, and analyze large chemical data, which is relevant for advanced chemistry research and learning. Meanwhile, research A5 emphasizes that the integration of AI and deep learning in SDG-based curricula allows chemistry learning to focus not only on content but also on sustainability, digital literacy, and student readiness to face global demands.

Overall, the synthesis of the ten articles shows that the application of AI and deep learning in chemistry learning has three main impacts: improved understanding of chemistry concepts through visualization, simulation, and personalization; strengthened teacher competence in designing innovative chemistry learning; and the development of 21st-century skills such as creativity, critical thinking, and collaboration. However, most studies also note challenges such as infrastructure limitations, the need for teacher training, low digital literacy, and issues of ethics and data security. Nevertheless, the findings in A1–A10 consistently reinforce that AI and deep learning are important components in shaping chemistry learning that is more adaptive, responsive, and relevant to current technological developments.

Thus, the integration of AI in chemistry learning not only addresses students' difficulties in understanding abstract concepts but also opens up great opportunities to create personalized, interactive, and inclusive learning. This technology is a pedagogical solution for the future that can align the needs of students with the complexity of chemistry material through an adaptive approach supported by artificial intelligence.

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5. Conclusions

Based on this literature, the implementation of *Deep Learning* and Artificial Intelligence (AI) plays a major role in making the chemistry teaching and learning process more adaptive and inclusive. This is because technology can support differentiated learning, improve the analysis of individual student needs, and provide interactive tools for understanding chemistry subjects. Although there are still many challenges to be faced, *Deep Learning* and Artificial Intelligence (AI) are key to creating a personalized, efficient, and modern education system. This is because these technologies enable research to advance further in harmonizing learning.

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