



Application of Artificial Intelligence Tools in Chemistry Education: Opportunities, Challenges and Possible Solutions

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Abstract

Education in the 21st Century can be quite challenging owing to transformation in teaching and learning paradigm. Additionally, qualitative Chemistry education is imperative as a vehicle through which chemical knowledge and skills are imparted on students as equipment for national advancement through science and technology. Application of artificial intelligence (AI) in Chemistry education in this era when both teachers and students are faced with demands of creativity, critical thinking and innovativeness has the potential to advance the frontiers of Chemistry teaching and learning at both secondary and tertiary levels of education. This paper discussed the opportunities available in the of application of artificial intelligence in Chemistry teaching and learning, with reference to areas such as personalized learning, students' engagement, conceptual understanding, accessibility and equity, and assistance to Chemistry educators in various aspects of teaching. The paper further discussed the challenges/concerns of integrating artificial intelligence into Chemistry teaching and learning such as ethical concerns about academic integrity, and apprehensions about inaccuracies and biases in AI-generated contents, and cyber security risks. Possible solutions to these concerns were also proffered, which included adherence to regulations, verification of AI-generated contents to ensure contextual relevance and absence of biases. Finally, recommendations were made.

Keywords: Artificial Intelligence, Chemistry education, GenAI tools, ChatGPT, personalized learning

Introduction

Qualitative Chemistry education is imperative as a vehicle through which chemical knowledge and skills are imparted on students in preparation for advancement in science and technology. However, many roadblocks confront the realization of this qualitative Chemistry education resulting in unsatisfactory achievements of students and hindering scientific and technological advancements. Some of these roadblocks include lack of adequate number of qualified and experienced Chemistry educators, inadequate facilities in terms of structures and materials, obsolete pedagogical approaches, overcrowded curriculum, abstract nature of many Chemistry concepts. Nevertheless, with the advent of artificial intelligence (AI) technology, it is hoped that many of these roadblocks can be surmounted.

Artificial intelligence is a system that operates with intelligence that can be likened to that of humans. According to Samoili et al. (2020), AI refers to systems that are capable of undertaking tasks that require the intelligence of humans. Such tasks include learning,

making decision, and adapting to new situations. Stryker and Kavlakoglu (2024) defined AI as technology that gives computers and machines ability to mimic human learning, comprehension, decision-making, problem-solving, creativity and autonomy. Key aspects of AI are machine learning (ML), and deep learning. ML involves creation of models by training an algorithm to make predictions based on data. It encompasses a wide range of techniques that enable computers to learn from and make inferences based on data without being particularly programmed for specific tasks. In essence, whereas AI is all about making machines act like humans, ML is focused on teaching machines how to do particular jobs well (Iyamuremye et al., 2024).

AI can be broadly classified into two-Generative AI and Traditional AI. Generative AI, often referred to as Gen AI refers to deep learning models which are capable of creating original content in response to a user's prompt or request. Such content may include texts, images, videos, and audio.



Generative models are a type of AI model that can learn patterns (through machine learning) and generate new data similar to the training data it was exposed to. The application of AI in Chemistry teaching and learning can potentially transform traditional teacher-centred teaching methods into more engaging, interactive, and accessible experiences and thus revolutionize the way Chemistry is taught and learned (Palanisami, 2024; Yuriev, Wink & Holme, 2024). Clark (2023) investigated the use of AI chatbot with general chemistry examination and found out that students demonstrated higher levels of retention of knowledge and problem-solving abilities when compared to traditional instructional methods. Furthermore, Iyamuremye and Ndiokubwayo (2024) in their study showed that the use of ChatGPT AI resulted in considerable increase in students' performance in chemical bonding and atomic structure. Walsh et al. (2002) showed that use of assessment tools based on AI resulted in enhanced students' achievement in balancing of chemical equations.

Opportunities Offered by Application of AI in Chemistry Education

Application of artificial intelligence in Chemistry education offers many opportunities that could revolutionize Chemistry teaching and learning resulting in enhanced learning outcomes in Chemistry. Here are some of these opportunities.

Personalized Learning

GenAI tools such as ChatGPT and intelligent tutoring systems (ITS) such as ALEKS can tailor explanations to individual learners' learning styles, learner's needs, abilities and paces and address misconceptions (Mahroof, 2020). By so doing, students still struggling with a particular Chemistry concept can receive simplified explanations on it while others can be guided to explore deeper applications or real-world situations. Mahroof (2020) saw GenAI models as intelligent tutoring systems and adaptive learning platforms that provide personalized learning experiences for students, allowing them to make progress at their own pace through a material. Ng et al. (2024) viewed GenAI tools as learning companions that aid learning motivation and self-regulated learning among science students as well as serving as a tutor providing personalized guidance and adapting to students' needs. AI tools also provide personalized feedback to students, which is important in improving their understanding and retention of Chemistry concepts (Walsh et al., 2002). The findings of Akbar

(2024) supported the ability of AI tools to tailor learning experiences to the special needs of students, resulting in enhanced learning outcomes in Chemistry teaching and learning.

Students' Engagement

Students' engagement is vital for depth of understanding and any considerable learning outcome in students. GenAI chatbots serve as "agents-to-think-with", engaging learners in dialogues that promote critical thinking and problem-solving (dos Santos, 2023). Ariely et al. (2024) applied ML algorithms to personalize Chemistry instruction based on the individual students' learning needs and preferences of and reported higher engagement and mastery of difficult concepts. The study by Emenike and Emenike (2023) revealed that the use of AI and ML in learning can enhance student engagement while fostering critical thinking and enhance problem-solving abilities. Further, GenAI tools can generate Chemistry-based games and quizzes, making learning more engaging and interactive. These interactive activities such as reaction puzzles and molecule assembly challenges reinforce concepts taught through play.

Creating interactive simulations

GenAI can produce realistic simulations of chemical reactions, allowing students to observe changes at the molecular level. Students can understand complex Chemistry concepts in greater depth through enhanced learning tools and interactive simulations. It has been shown that virtual laboratories and simulations powered by AI improve the understanding of chemical processes which are complex and which students usually find difficult to visualize (Pence, 2020). Furthermore, these virtual laboratories by allowing students to conduct experiments in simulated environments, provide hands-on learning experiences while eliminating the constraints associated with physical laboratory settings (Yuriev, Wink, & Holme, 2023).

Enhancing Accessibility and Equity

By providing explanations and support upon demand, GenAI tools can make Chemistry education more accessible, especially for students with limited access such as those living with disabilities and those in underrepresented groups. In addition, AI tools also help bridge cultural gaps and language barriers thus making education more universally accessible for students (Giam & Thanh, 2022).

Supporting Educators

AI tools are of immense benefits to educators in facilitating instruction. Surveys suggest that teachers

use GenAI tools more than students (Johnson, 2023). Use of AI tools can help teachers in many aspects of teaching. These include: lesson planning, preparation of instructional materials, student evaluation and grading. GenAI tools assist teachers in creating learning materials such as customized lesson plans, presentation slides, and worksheets (Cooper, 2023). Ng et al. (2025) explored how ChatGPT specifically help teachers develop learning rubrics and quizzes. Moundridou et al., (2024) examined the usefulness of GenAI in content creation in learning, students' assessment, and activity design within the frameworks of inquiry-based learning. The research of Hooda et al. (2022) showed that applying AI tools aids Chemistry educators in streamlining the process of assessment and grading. This is in support of the assertion of Volvoka (2020) that teachers' use of AI-powered assessment tools to grade student work enables them do so more efficiently by reducing grading time and improving consistency. By reducing the workload of teachers and the likelihood of grading bias, (Minn, 2022) opined that use of AI tools can lead to a more equitable learning environment. (Afzaal et al., 2021) asserted that the automation of the administrative duties of Chemistry educators by the use of AI tools will enable them pay more attention to improving on instructional strategies, students' mentoring and other students' needs. In all educators agree that the use of AI tools is of immense benefit, but caution that it must be used responsibly.

Collaborative Learning

The use of AI tools promotes students' interaction and collaboration. For example, AI-powered chatbots are used to facilitate online discussions among students, answer Chemistry questions, and encourage peer-to-peer learning (Atmosukarto et al., 2021). This encourages team work and sharing of knowledge among students, resulting in improved learning outcomes of Chemistry students (Lolinco & Holme, 2023). Teachers and educational institutions could adopt the use of AI and ML in Chemistry teaching and learning to make for more effective collaboration thus enhancing learning outcomes

Enhancing Conceptual Understanding and Addressing Misconception

AI tools serve as effective instruments for enhancing conceptual understanding and addressing misconceptions. Research findings of El Fathi, Saad, Larhzil, Lamri and Ibrahim (2025) showed the effectiveness of use of ChatGPT as a supplementary tool in improving understanding of concepts and thus reducing misconception in an introductory

thermodynamics course. A comparative case study by dos Santos (2023) found that tools such as ChatGPT and BingChat effectively enhanced deeper understanding and creativity in Chemistry learning

AI Tools for Chemistry Education

There are several AI tools that are utilised for teaching and learning of Chemistry. They include:

- Virtual labs and simulations e.g Labster and PhET interactive simulations offer simulated laboratory experiments with step by step instructions. They serve as safe alternatives to real labs when resources are limited.
 - ChatGPT/SmartGuide: Offer personalized tutoring and revision help. Provide explanations for difficult concepts
 - Chemix: Design and visualize laboratory setups. Helps students understand apparatus arrangement and usage.
 - Microsoft Math Solver/Socratic by Google: Step by step solutions to Chemistry related math such as mole concept calculations.
 - Quizlet with AI: Generate custom flashcards and quizzes from topics. AI suggests questions based on study habits.
 - Diffit and Curipod: provide content creation for teachers:
 - Cognii: Use AI to evaluate open-ended student responses and provide constructive feedback in line with learning objectives.
 - ALEKS(Assessment and Learning in Knowledge Space): An intelligent tutoring system: An AI tool that diagnoses student knowledge and delivers personalized learning modules.
 - WAEC past Question Apps with AI: Practice WAEC Chemistry past questions with feedback. Recommends focus areas based on weak areas.
- (Choudhary et al.; 2022; dos Santos, 2023; Daher et al., 2023, ChatGPT, personal communication, June 10, 2025)

Concerns/Challenges and Limitations of AI Integration in Chemistry Education and Possible Solutions

The numerous benefits of application of AI tools in Chemistry education notwithstanding, there are several concerns, challenges, and limitations that must be addressed for effective integration in Chemistry education. Alasadi and Baiz (2023) argued that to

integrate GenAI in Chemistry education effectively, a thoughtful, ethical, and inclusive approach must be adopted. Blonder and Feldman-Maggor (2024); Ng et al. (2025) also raised ethical concerns regarding academic integrity, in addition to worries about inaccuracies and bias in AI-generated content, and cyber security risks in the integration of AI tools in education.

The first ethical concern is the issue of academic integrity. Academic integrity bothers on using content with necessary permission from appropriate authorities. GenAI models often make use of large amounts of data in various forms obtained from the internet without due approval of the content owners. This raises concerns about possible violations of intellectual property rights (Lee & Perret, 2022), especially as these AI companies are not transparent about the sources of data they use in training their models. Academic integrity demands that companies should get consent from the data owners, collect only what is necessary and protect any personal information. Another concern along this line is the likelihood of increase in cheating and plagiarism with reliance on AI tools (Ng et al. 2025). Ethics also demands that both educators and learners maintain responsible use of AI tools. This entails being accountable in its use, by verifying the outputs from the prompts given to the tools to identify inaccuracies. If anything goes wrong, the user and not the AI tools should be responsible.

Another ethical concern is that of bias. AI-generated contents reflect popular views at the time of data collection and training of models. Such data may include notable biases such as gender roles stereotypes as well as racial and socio-economic biases. Such biases result in unfair representation of certain groups of learners (Blonder & Feldman-Maggor, 2024; Iyamuremye, 2024). To mitigate incidences of bias, it is crucial to use diverse representative data and regularly evaluate and refine AI tools to ensure fairness (Iyamuremye, 2024).

AI tools can automate tasks undertaken by humans, which can lead to loss of jobs. Ethics demands that mechanisms must be put in place to support Chemistry educators through transitions and focus on how AI tools can be used to assist and not replace them.

Again, excessive reliance on AI can lead to a reduction in human interaction and social skills among learners. In addition, students may not scrutinize the correctness of AI-generated content. Further, it could also hinder critical thinking, creativity and analytical skills (Ng et al., 2025). This calls for responsible use of

AI to ensure that these essential 21st Century skills are not sacrificed.

Unequal access to AI tools is also an area of concern as most learners rely on open versions of AI tools which at times may not provide adequate and accurate information. This results in undue inequalities between learners and institutions that can afford the more advanced tools and those who cannot thereby increasing digital poverty (Blonder & Feldman-Maggor, 2024). Also, not every student may have a device or internet access at home. Equity demands that stakeholders in education should ensure that AI tools benefits are available to all, not only to those who can afford advanced technologies.

Chatbots generally lack mechanistic reasoning, and are thus limited in the ability to understand real-world contexts. Further, they lack ability to meaningfully understand user inputs and their own outputs, operate based on patterns (hence can hallucinate), and do not possess consciousness and emotions (Deng et al., 2023). Thus, AI models may struggle with accurate interpretation of chemical structures and reactions which are complex, thereby requiring continuous improvement and validation by domain experts (Maestrales et al., 2021).

A very critical area of concern is the readiness and competence Chemistry educators. The integration of AI into Chemistry education is still in its developmental stage, and as such many Chemistry educators are still ignorant of their availability and use. Efforts should therefore be made towards training programmes to equip Chemistry teachers with necessary skills on how to effectively integrate AI tools in the classroom.

Another crucial area of concern is cyber security. Cyber security refers to the measures, practices, and technologies used to protect data, systems, and users from cyber threats (ChatGPT, personal communication, May 20, 2025). As AI becomes increasingly embedded in education, its role in enhancing the teaching and learning of Chemistry is rapidly expanding. AI powered tools such as virtual Chemistry labs, personalized tutoring systems, and intelligent assessment platforms are radically changing the teaching and learning of Chemistry. Without strong cyber security measures, the large amounts of sensitive data used in the AI systems can be exposed to threats such as: unauthorized access to students' records, manipulation of grading systems, breaches that compromise privacy, and unfair academic profiling. AI systems should be designed to prevent misuse, hacking

and unintended harmful outcomes through measures such as encryption of data and multi-factor authentication.

Finally, to ensure responsible use of AI tools in Chemistry education, there is need for establishment of practical regulations and best practices by all stakeholders. The UNESCO framework (2023) for use of AI tools can be of great help in this area.

Conclusion

The application of AI tools in Chemistry teaching and learning offers many opportunities for personalized learning, students' motivation, engagement, inclusivity, aiding of Chemistry educators among others. These opportunities are however not without concerns, challenges or limitations such as ethical concerns, equity and access, as well as cyber security risks. Adherence to strict and practical rules and regulations by appropriate authorities is key to mitigating these challenges for effective integration.

Recommendations

1. Educational institutions should integrate AI tools into Chemistry curricula to enhance experiential learning, conceptual understanding and learning outcomes.
2. Programmes on professional development should be mounted to train teachers on effective utilization of AI tools.
3. More empirical studies should be conducted to evaluate the impact of AI tools on student learning outcomes and long-term retention of Chemistry concepts. This will give evidence-based information that will guide better integration and policy decisions.
4. Equity with regards to access to AI tools and ethical use of these tools must be prioritized by educational authorities and policy makers.
5. Developers and educational policy makers should invest in the creation of AI tools tailored to local contents, languages and curricula (e.g., WAEC and NECO).

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