



# Unlocking The Power of Generative and Multimodal Artificial Intelligence in Chemistry Education: Redefining Learning in the Digital Age

**Onoyima, Everestus Onyeka<sup>1</sup>, Orji, Chinasa Margrate<sup>1</sup> & GodBless, Ejike Emmanuel<sup>2</sup>**

<sup>1</sup> Department of Science Education University of Nigeria, Nsukka, Enugu State Nigeria

<sup>2</sup> Department of Science Education Federal University of Agriculture Makurdi Benue State, Nigeria

**Corresponding author:** everestus.onoyima.pg95584@unn.edu.ng

## Abstract

Artificial intelligence (AI) has emerged as a transformative technology with the potential to revolutionize various fields, including education. In the context of chemistry education, the integration of generative and multimodal AI techniques holds significant promise for enhancing learning experiences and redefining pedagogical approaches in the digital age. This paper explores the applications of generative AI and multimodal AI in chemistry education, highlighting their potential to facilitate concept comprehension, foster creativity, innovative teaching and improve students' engagement. Furthermore, it discusses the challenges and ethical considerations associated with the implementation of AI in education. By leveraging the power of AI, chemistry education can be transformed into a more interactive, personalized, and immersive experience, preparing students for the demands of a rapidly evolving scientific landscape.

**Keywords:** AI, Generative AI, Multimodal AI, Ethical Consideration, Personalized learning

## Introduction

Chemistry as one of the core science subjects has been evolving and challenging not withstanding its pedagogy. The associated challenges and difficulties in teaching and learning of chemistry could be attributed to its' nature of existence or multiple mode of representations. Also, the induction philosophical approach (that is the exposure to repeated associations between elements is guide to the general rule) that is generally applied in teaching and learning of chemistry could as well as present more challenge and difficulty with the learning of chemistry (Onoyima & Eya, 2019).

This philosophical approach of teaching chemistry always starts with the concept of atom and its' properties. With the building of the hypothetical atomic structures as postulated by John Dalton's, J. J. Thomson, Neil Bohr, Rutherford and Cloud atomic theories. This approach is like building castles in the air and creating critical uncertainty which has no resemblance with the daily realities of the learner. The intended learners struggle, in his/her preconceptions in trying to understand these concepts. By consulting

his/her mental repository in order to find a similarity or a schema that looks like what has been taught or presented. If there are no schema or resemblance of a such an alien imagery, he/she will start building or forming a schema of such an alien imagery. It is with this schema of an alien imagery that the learner shuttles in and out in trying to make a meaning out of the concept. If the concept has a resemblance or a tangent with the cognitive repository, the learner can start from there in constructing what forms his or her understanding or construct.

Account abounds that chemistry learning is so abstract and has many things to consider before arriving at a giving answer. Students assert that the use of common sense is always being defeated when it has to do with the learning of chemistry (Rudibyani, 2020). For example, a species with a negative charge is said to have been reduced and at the same time has gained electron(s). The other with a positive charge is said to have been oxidized and has lost electron (s).

Electron(s) is/are negatively charged and its' mass count to nothing to the mass of an atom, whereas

it charges count and proton is positively charged and its' mass and the mass of the neutron constitute the mass of an atom. Electron(s) can both be seen as particles and as waves and has energy of  $mv^2$  and is responsible for the bond formation in a molecule (Atkins et al., 2010).

Terms such as spectroscopy, quantum numbers, mesmeric effect, electronic effect, isoelectronic, pi electrons, sigma electron, electronegativity, resonance, degeneracy, catenation, hybridization, oxidant,  $SN_1$ ,  $SN_2$ , leaving group, incoming group, dissociation, association, chiral, achiral, racemic mixture, base peak, eigen value, reductant etc., are very difficult to comprehend. Take for an instance, drawing a line/stroke and saying that it represents a pair of electrons, and that the ends of the stroke/line represent carbon atoms. That the electrons in such a stroke/line are staying in a place called orbitals, and that these orbitals are categorized into s p d f g...with their characteristic shapes of varying energy. That the electrons migrate from s to p, and to d but not from s to s or p to p or d to d(forbidden transition), and that within the electronic transition the electronic state changes to S P D F G..., which are the spectroscopic total angular momentum. Trying to resolve all these, considering all the vectors and calculations that are required can be challenging.

Considering, the neurodivergence of a typical Nigeria classroom, and with the fact that most of these terms in chemistry has no L1 equivalence, in addition, to the use of unnegotiated language of instruction exacerbate the abstractness of chemistry concepts thereby, constitute a barrier in assimilating the chemical concepts(Pagliaro, 2019).

All these hypothetical assumptions which are often represented with symbols, and equations present a latent cognitive actuality which are capable of generate dissonance with the cognitive repository of the students. Thereby, forcing the learner to a mere memorization and thereby mare the ability to conceptualize learning (Onoyima, 2021). The inability of the learner to conceptualize chemistry learning coupled with a defeat in falsification of the hypothetical assumptions in chemistry by both the teacher and the learner, renders the students' cognitive ability weak in struggling on how to make this critical uncertainty a priority. The effect of these anomalies' manifests in chemistry students' reactions and anyone who has ever taken a course in chemistry saying chemistry is very difficult to learn. And the difficulty shows in students' performance in chemistry courses both in tertiary institutions and in high schools(Pagliaro, 2019).

The theory of meaningful learning as espoused by Craik (1943) asserts the following: (1)

the stimulus must be translated into an internal representation, (2) cognitive processes need to change the representation in order to generate new internal, and (3) these internal representation need to be retranslated back into action. In other words, for learning to be meaningful, the learner should be able to apply what he/she has learnt in a concept to other ideas; the ideas should be so real, and can be applied in a real-life situation. It is long-lasting, which means that students may apply the knowledge they have learnt to other topics, issues, or abilities and can readily retain the material since it is relevant (Rudibyani, 2020).

Researchers' efforts have been on finding a better way of communicating and presenting chemical concepts with less abstractness. PhET.com, physicsclassroom.com, myphysicslab.com, falstad.com, LabsLand.com, Amanogawa.com, and Similasites.com are online nonlinear chemistry-based simulations and virtual classroom that were created in trying to make students conceptualize chemistry concepts with reduced challenges inherent with the chemistry pedagogy. But the complexity nature of many chemical concepts have not been resolved with these tools thereby, pose a greater challenge and hinder progress in this direction.

### State of the Art

The recent advent of Artificial Intelligence Agency (AI), Generative Artificial Intelligence (GenAI), Multimodal Artificial Intelligence (MMAI) and Internet of Things (IoTs) is revolutionizing a lot of things including pedagogy notwithstanding chemistry. This machine has proven to be intelligent just like humans and is being used to carryout human supposed activities including teaching.

Lesson learnt from COVID-19 pandemic which interrupted in-person schooling close to 18 months subscribed to the old assertion that necessity is the mother of invention. In addition to the problem of equity in education which include disproportionate distribution of educational resources and the inability of the stakeholders to articulate properly the concept of freedom, and fairness in education prompted the need for technological solution.

The mass campaign for e-learning in order to continue the educational process of the child and the increased parental participation in education within the epidemic was encouraging. AI technology facilitated the process with ease and the human teacher's role was less felt.

Whether this technology will eventually become a lethal autonomous weapon is one concern, as well as whether it will take the role of a teacher or become a para educator is another concern. Whether

its interaction with the learner may affect the learner's affective domain ability at a long run and makes the learner less human is also a possibility. Its' ability to create a standardized personalized learning and encourage pace learning with all kinds of skills is amazing.

However, to establish value alignment problem objectives, that is making sure that what are objectively obtained are actually want are objectively humanly wanted is a necessity. Therefore, requires a thorough study and ponder reflection on what this tech is all about and the best way to use it in teaching and learning of chemistry to avoid the machine pursuing its' own objectives.

### Concept of Artificial Intelligence (CAI)

Artificial intelligence agency (AI) in this context refers to generative artificial intelligence (GenAI), is a large language model chatbot and the theory and development of digital algorithms capable of performing tasks that ordinarily required human intelligence, such as recognizing speech, making decisions, and identifying patterns. It is also defined as a digital system that has the capacity to interact with the world through capabilities that are comparable with that of the human beings(Kohnke et al., 2023a).

Machines that function in likeness of humans by imitating certain features and functionalities such as, perception, learning, reasoning, problem-solving, language interaction, producing creative works and blurring human intelligence. UNESCO, (2021) asserts that this is an era of experiencing AI revolution, and 5.0 industrial revolution, that has resulted in many sectors employing AI to accomplish many tasks in a short of period of time. This was made possible by the machine learning that can analyse huge amount of data which is integrated to AI.

Within, the past decades, AI developed and evolved in fits and starts, and the rapid progress is tremendous (Russell & Norvig, 2016). AI is a household name that encompasses the stream of digital tools, that architecturally houses machine learning (ML), deep learning (DL), and natural language processing (NLP)(Goh et al., 2017). AI can be structured along three evolutionary stages;(i) Artificial Narrow Intelligence (ANI), (ii) Artificial General Intelligence (AGI), and (iii) Artificial Super Intelligence (ASI).

ANI is a poor AI; it involves performing a simple specific task. Many existing systems that portray to use artificial intelligence are operating as a poor/weak AI. They have a single library trained to focus on a narrowly defined specific problems. Alexa is a good example of ANI. It operates within a

predefined perimeter of functions. It has no genuine intelligence or self-awareness despite being sophisticated. Other examples of these poor ANI include face verification app that is frequently used for security of phones, the autopilot feature at Tesla, the social human sophia, and google maps(Miao et al., 2023.).

Artificial General Intelligence (AGI) is also known as strong AI. It involves machines that possess the ability to perform many intelligent tasks that a human being does. It has libraries trained on different data and combined as a foundation model. It has a strong processing unit that can perform high-level computations, but they are not capable of thinking and reasoning like humans. It was suggested that AGI may take off on its own and redesign itself at ever-increasing rate(Vanhaelen et al., 2020).

Artificial Super Intelligence (ASI); this is a term that refers to the time when the capabilities of computers will surpass human beings. The ASI is presently a hypothetical situation as depicted in movies and science fiction books where machines will take over the world. Elon Musk believes that ASI will take over the world by the year 2040(Shchetinin & Sevastianov, 2021).

Although, the term artificial intelligence (AI) is frequently used to refer to a variety of current technologies, experts differ as to whether these truly qualify as artificial intelligence; rather, some contend that a large portion of today's technology is essentially very sophisticated machine learning, which is merely a precursor to true artificial intelligence, or "general artificial intelligence."(GAI)(Kohnke et al., 2023b). So, majority of persons today use the term artificial intelligence (AI) it refers to a suite of large language model(LLM), of machine learning based, in category of generative artificial intelligence (ChatGPT and DALL-E), despite the numerous philosophical debates over whether "true" AI actually exists (Shchetinin & Sevastianov, 2021).

The thingness of generative artificial intelligence (GenAI) includes, addressing educational injustice, improving teaching and learning methodologies, and hastening the realization of the sustainable development goal number 4, that centres on universal access to high-quality education by 2030. But as technology advances quickly, there will inevitably be a number of associated risks and challenges that have so far outpaced discussion of the legislator and legal frameworks (Rayhan et al., 2022). Nevertheless, UNESCO adds that it is committed to assisting member states utilise this intelligent agency (GenAI technology) to realise the goals of the Education 2030 Agenda. Hence, making sure that the



fundamental values of equality and inclusivity inform its implementation in educational settings. UNESCO's therein, advocates for a human-integral approach to AI. In addition, to ensuring that AI does not deepen digital divisions inside and across nations, it seeks to change the debate to address current inequities around access to knowledge, research, and the diversity of cultural expressions. "AI for all" must guarantee that everyone may benefit from the ongoing 5.0 digital revolution and reap its rewards, most notably in terms of creativity and knowledge. and not to soakaway the humanistic component of education.

### Multimodal Artificial Intelligence

Multimodal Artificial Intelligence (MMAI) is a subfield of generative artificial intelligence (GenAI) that combines multiple modes of communication, such as text, audio, and images, to create more effective and engaging interactions between humans and machines. A typical example of this is DALL-E2 and 3 model, products of OpenAI that was launched in 2021. DALL-E is a deep learning model that uses natural language processing (NLP) and computer vision techniques to generate multiple realistic images and videos from text prompts. It has the ability to change the approach and strategy of teaching and learning today by providing more personalized and interactive learning encounter that takes care of the individual needs and preferences (Kohnke et al., 2023b; Shchetinin & Sevastianov, 2021).

MMAI can be used in a variety of educational settings, such as online courses, virtual classrooms, and intelligent tutoring systems. For instance, a MMAI -based teaching and learning system can access the natural language processing to understand a student's learning difficulties and thereby provide personalized feedback in real-time (UNESCO, 2023). The use of MMAI in education however, raises important ethical and social issues that need to be addressed. The use of MMAI-based teaching and learning system may raise the bar of the existing biases or perpetuate discrimination if the concept of inclusivity is not enshrined with it (Zhai & Wibowo, 2023).

### Chat Generative Pre-Trained Transformer (ChatGPT)

An artificial intelligence twin of DALL-E and a language model-based chatbot that was developed by OpenAI and launched on November 30, 2022. The machine algorithm was designed to interact in a conversational style, mimicking human response pattern, takes in question, generates

responses, learns, admits it flaws, challenge incorrect premises, and reject inappropriate requests. It is trained using Reinforcement Learning from Human Feedback (RLHF) and is fine-tuned from a model in GPT- 3.5, 4.0 and now 4o1 (Ali et al., 2021a; Chen et al., 2020; Laupichler et al., 2022; Ng et al., 2021). ChatGPT is the chatbots of Artificial intelligence (AI), and a stochastic-predictive language model that focuses on textual communication.

This tech has been viewed as a threat to majorly four pillars of education system; (a) the commercial value of what the educators teach; (b) the accuracy and reliability of the information students are learning and (c) the true evaluation of students' knowledge and skills;(d) the position of the human educator in the business of teaching and learning spectrum (Kohnke et al., 2023c; Steele, 2023). Recently, GPteach has been introduced to help train teachers on simulated classroom and students powered by GPT(Bahroun et al., 2023). These technologies are the new now and the challenge being faced at the moment could be captured with the following questions: (i) How will instructors incorporate this new tool in teaching and learning of chemistry to increase the students critical thinking? (ii); What are the conceptual levels of GenAI in chemistry? (iii); What expert method does GenAI adopt in solving chemical problem? (iv); How will GenAI communicate chemical concepts to a bilingual learner?(v) What are the social cultural factors that will influence the adoption of GenAI in teaching and learning of chemistry? and (vi)To what extent will GenAI solve a particular chemical problem.

### Transforming Chemistry Education with GenAI

At the core of the artificial intelligence are the Machine Learning (ML) and Deep Learning (DL). A subset of representation learning known as deep learning (DL) combines several layers of internal representations, at first of basic structures like edges, to create progressively complex objects, like faces. Chemistry is a perfect example of this phenomena, where properties or behaviour of atoms, molecules and compounds change by interactions between functional groups at increasing ranges as well as their immediate grouping into atoms and at nanoscale. This attributes supposedly makes chemistry a good choice for using GenAI in instructional design. Regretfully, molecules also provide a number of difficult challenges, such as selecting sufficiently varied molecules and the conformational space that accompanies them in the chemical space, accurately describing molecules, and acquiring appropriately big data sets.



However, there are many exciting ways in which GenAI could be integrated into chemistry education and research. Presently, GenAI is extensively used in computational chemistry research and with a great success. Bench chemists have opined that automation of computational chemistry with AI will reduce the need for synthetic hands in the lab, this is because at present AI is used in drug discovery and reaction pattern prediction with ease (Hocky & White, 2022).

A robust agents-to-think with in chemistry education is GenAI, it benefits include interactivity, customization, multidisciplinary knowledge, critical thinking, problem-solving, creativity, and collaboration. GenAI foster dynamic conversations and personalized content and offer a wealth of knowledge across subjects. It facilitates discussions, debates and collaboration project in group settings, thereby deepening topic understand.

ChatGPT is not always correct and most often lack the ability to correct itself rather, repeat the same mistake over and over. Though substantially it facilitates students learning but in an event of a breakthrough or novelty of findings in scientific research the problem of who takes the credit arises Emenike and Emenike, (2023). Moreover, how instructors will incorporate this new tool in teaching and learning to increase the students critical thinking is also a challenge. Because it is difficulty to differentiate the ChapGPT generated text from the human generated text. Proper understanding on the principle and working underlying architecture behind ChapGPT is also required by both the instructor and the learner.

ChatGPT and DALL-E are unsupervised systems of learning and are sentient. In that case their thinking capability is predefined and within a box of algorithm unlike humans that can think outside the box. It lacks the learners'-awareness and cannot participate or share in the learning difficulty and challenge of the learners. Emphasis on representations and depth of understanding, Daher et al., (2023) posits that ChatGPT experienced tremendous conceptual conflicts across various categories hence, hindering the effective knowledge transfer. Inaccurate or partial answers suggested that ChatGPT had trouble deciphering complex chemical structures, representations, or formulas. This restriction was especially apparent when issues called for in-depth analysis and critical thought, indicating the need for more advancements in ChatGPT's analytical powers. et al., Daher (2023).

Furthermore, ChatGPT faced challenges in providing an explanation to the answers it generates.

Its' frequently sourced solutions require further precise justification or reasoning, which makes it more challenging for the users to comprehend the fundamental ideas guiding the principles behind the its' operations. This restriction may make it more difficult for the students to learn well and limit its use as a paraeducator or educational resource.

Reviewing what has been done in other areas of studies in application of Generative Artificial Intelligence (GenAI); Jonsson and Tholander(2022); Jinnie-Ansley et al (2022); MacNeil et al (2022) and (Khosravi et al., 2023) in computer studies, revealed that GenAI significantly impacted the pedagogy computer programming instruction. However, doubt and pertinent observations are entertained regarding the GenAI-generated code, suggesting the need for critical scrutiny of the credibility and reliability of code produced.

Large language models' (LLMs) capacity to explain programming ideas was also demonstrated, indicating that GenAI can improve students' comprehension of intricate programming ideas. Furthermore, useful perspectives on the consequences of GenAI-driven code generation tools are provided, illuminating the advantages and difficulties of implementing such technologies in educational contexts. Thus, these studies shed important light on the use of GenAI in computer science education while also drawing attention to the need of a thorough examination of its limitations and ethical issues. Even though the benefits of GenAI-generated code are frequently highlighted, it's important to be aware of any potential negative impact as well as, over reliance on automated coding and the potential for it to impair students' understanding of algorithms.

Moreover, the researches concentrate on immediate benefit in motivation and performance, leaving out the long-term consequences on holistic learning and problem-solving abilities. Therefore, future studies should weigh the benefits and drawbacks of integrating GenAI, addressing issues with academic integrity, assessment, and creative ways to integrate GenAI-generated code into programming curriculum.

Applications of GenAI in engineering education: Multiple studies demonstrated the transformative effects of GenAI in engineering education. Marquez et al. (2023), Humphrey and Fuller (2023), Sanchez-Ruiz et al., (2023), and Galdon et al. (2021), posit that utilising sophisticated chatbots and text generating models, and its integration into teaching and learning, expedites instructional procedures and enhanced active learning and problem-solving abilities. Engendering students'



ability to collaborate and engage creatively, constructively, and further enable them to come up with original ideas. The intelligence and accessibility of social robots in engineering education are enhanced by cloud-based frameworks, opening up new possibilities for interactive learning. Examining these researches critically reveals important concerns that require careful consideration in addition to the obvious benefits of GenAI for promoting active learning, improving problem-solving abilities, and expediting design processes. These worries include the possibility of lateral competency erosion as a result of an over-reliance on GenAI, difficulties in collaborating with GenAI, and the need for an instructional framework that integrates GenAI tools effortlessly without sacrificing the core components of value, quality education.

Although these studies highlighted how GenAI will significantly influence educational landscape, they equally hinted how urgent it is to apply it wisely, especially in fields that are always changing, like chemistry (Sanchez-Ruiz et al., 2023). Future research ought to improve GenAI integration and evaluate long-term effects to guarantee that its advantages are maximised while minimising possible drawbacks.

Research on the application of GenAI in higher education by Konecki et al. (2023), Eager and Brunton (2023), Chaudhry et al. (2023), and Iskender (2023) provides insights into a number of different elements of GenAI integration in higher education, such as how students accept and use GenAI. And equally, explored the possible effects of integrating GenAI tools on teaching and learning methods.

Concerns related to originality of work, critical thinking, predicting academic performance and employment at work were highlighted as part of a potential ethical and pedagogical discourse of ChatGPT. Additionally, the implication of ChatGPT on learning outcomes and academic integrity was assessed, leading to discussions on assessment methodologies that were yet to be resolved. These researches demonstrated inferential insights into the potential of GenAI tools in effecting higher education. However, there is a need to x-ray more the potent of GenAI, by having a balanced exploration of positive aspect, potential challenges, and unintended consequences in order to engender value, and quality of education.

While the effects of ChatGPT and similar technologies on student learning are studied, further research into the potential effects of these tools on academic work originality and critical thinking abilities could yield a more comprehensive knowledge. Furthermore, even if the studies mention

how well students adopt GenAI technology, a more thorough examination of the sociocultural elements affecting students' attitudes and views is necessary. Future studies in this field can offer a more thorough and nuanced understanding of the function and effects of GenAI in higher education by tackling these important viewpoints.

### **The Way Forward**

The rapid advancement of generative artificial intelligence and digital technologies is transforming things including learning in the 21st century. The ability of GenAI to analyze students' behaviors, responses, and reasoning to gain insights into their understanding of concepts and identify misconceptions ((Ali et al., 2021b; Su et al., 2023b; Chiu, 2021 & Hocky, 2021) is intriguing. These technologies are poised to fundamentally change how students learn and how instructors teach.

There is a growing movement to incorporate these emerging technologies into the art of teaching and learning curriculum to better prepare students for the digital age (Pagliaro, 2018). However, more research is still needed to fully understand how these technologies can be leveraged upon and to maximize learning outcomes (Chiu, 2021; Bellou, 2018). The preliminary studies done on this regard suggest that these technologies have significant potential to enhance chemistry education if thoughtfully implemented.

Therefore, researchers and practitioners' effort should be on understanding the full capabilities and modalities of the machine for a proper integration in teaching and learning of chemistry. Guard and caution should be made place in such a way that the use of this technology should not end up producing educated idiots that lack the capacity to care for her citizens and environment. It is imperative that the education of the west has produced loneliness and inability to take care of the old and aged members of her citizens rather, euthanasia which shouldn't be so in African context.

### **Conclusion**

Considering the ever-complex evolving nature of chemistry and the rapid growth in technological development. It has become imperative that any little lag in the follow up with the technological knowledge and application puts one behind the time. Chemistry plays a critical role in science and technological development and its teaching and learning cannot be atoned to the plight of the digital age without integration of GenAI. GenAI is a new fast-growing technology of the moment and the future is yet unclear on the level it

could go in transforming the learning landscape. Therefore, more research is called in this direction for proper understanding and implementation of GenAI in teaching and learning chemistry.

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