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Assessment on Integrating Artificial Intelligence Technological and Pedagogical Competencies among Secondary School Chemistry Teachers in Kaduna State, Nigeria

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Abstract

The study assessed the Integration of Artificial Intelligence Technological and Pedagogical Competencies among Secondary School Chemistry Teachers in Kaduna State, Nigeria. Adopting a descriptive survey design, the research was guided by two research questions and two corresponding null hypotheses. A random sampling technique was employed to select a representative group of chemistry teachers from various secondary schools within the state. The sample comprised 150 chemistry teachers (72 males and 78 females), drawn from a population of 1,500 teachers across 80 secondary schools. To collect data, the researcher developed a structured questionnaire comprising two sections: Section 1, titled Artificial Intelligence Chemistry Teachers' Technological Competence for Curriculum Implementation Questionnaire (AICTTCCIQ), and Section 2, Artificial Intelligence Chemistry Teachers' Pedagogical Competence for Curriculum Implementation Questionnaire (AICTPCCIQ), each containing seven items. The instrument was face-validated by two data analysts and two senior chemistry educators from the Department of Science Education, Ahmadu Bello University, Zaria. Reliability testing using Cronbach's alpha yielded coefficients of 0.71 and 0.73 respectively, indicating a satisfactory level of internal consistency. Data analysis involved the use of means to address the research questions, while t-test statistics were used to test the hypotheses at the 0.05 significance level. Key findings from the study include: (i) Both male and female chemistry teachers exhibited low levels of competence, technologically and pedagogically, in the application of AI tools for teaching. (ii) There was no statistically significant difference between male and female teachers regarding their technological competence in AI. (iii) Similarly, no significant difference was found in pedagogical competence related to AI usage between genders. Based on these findings, the study recommended that the Kaduna State government, in collaboration with relevant educational agencies, should prioritize the provision of essential AI tools and infrastructure. Such support would enable chemistry teachers to effectively integrate AI into lesson planning, delivery, and assessment, thereby enhancing the quality of chemistry education in secondary schools.

Keywords: Artificial Intelligence, Competence, Chemistry teachers, Secondary school.

Introduction

The world is undergoing a significant transformation driven by the rise of Artificial Intelligence (AI), which is reshaping various aspects of human endeavor, including education. In the 21st century, AI has the potential to revolutionize chemistry education by offering personalized learning experiences, interactive simulations, and data-driven instructional strategies. According to Anaso (2024a), chemistry is a vital branch of science concerned with the composition, properties, and reactions of substances, and the ways these reactions can be harnessed to form new materials. Within the secondary school curriculum, chemistry holds a prominent position due to its foundational role in scientific understanding. Science itself, as Anaso (2021) emphasized, is a dynamic discipline rooted in the empirical study of natural phenomena, underpinning much of modern life. AI's integration into science—particularly chemistry—empowers students to explore abstract concepts through dynamic visualization and individualized learning pathways. Anaso (2024b) further highlighted that such technologies enable students to gain deeper understanding through immersive simulations and modeling environments tailored to their unique learning needs. In today's interconnected world, integrating AI into chemistry instruction is not merely advantageous—it is essential for enhancing educational quality and fostering learner autonomy. Students can now learn at their own pace, concentrating on areas where they need the most support, ultimately improving their academic outcomes. This sentiment is echoed by Opesemowo & Ndlovu (2024), who described AI as a transformative force across numerous sectors, including education. Dai



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& Ke (2022) further characterized AI as a revolutionary tool in education, marking a paradigm shift from passive reception of knowledge to active, student-centered learning. AI algorithms can analyze individual learning styles and performance patterns to generate personalized educational experiences. Marr (2024) noted that in the modern educational landscape, AI stands out as one of the most transformative technologies, enabling smarter decision-making, automation, and tailored learning solutions. Specifically in chemistry, AI enhances the understanding of complex chemical structures and reactions. Culican (2024) affirmed the potential of AI and machine learning to significantly improve educational accessibility and learning outcomes. Berber et al. (2025) observed that AI is most commonly applied in pharmacology and biochemistry, particularly in molecule design and predictive modeling. However, they also pointed out a critical gap: the discussion around using AI in secondary-level chemistry education remains limited despite the increasing relevance of such technologies. To effectively bridge this gap, Lamas and Amab (2022) stressed the need for educators to develop the AI-related skills necessary for integration into the science classroom. Jiang et al. (2024) supported this view, noting that knowledge of AI methodologies is not yet widespread among secondary chemistry teachers. Koehler et al. (2013) underscored the importance of developing teachers' Technological Knowledge (TK), Technological Pedagogical Knowledge (TPK), and Technological Content Knowledge (TCK) to successfully design and deliver AI-enhanced instruction. They argued that these competencies are essential if educators are to fully understand and convey the underlying concepts of their subject areas. Against this backdrop, the current study was initiated to investigate the areas of technological and pedagogical competence where AI usage is currently applied in chemistry teaching. It also aims to explore gender differences in AI competence among secondary school chemistry teachers in Kaduna State, Nigeria.

Artificial Intelligence Competence, in this context, refers to a teacher's ability to understand how AI technology functions, their societal implications, and the capacity to engage with them ethically, responsibly, and collaboratively. Technological competence encompasses the foundational knowledge, skills, and abilities required to use technology effectively, while pedagogical competence in AI involves the strategies and attitudes necessary to meaningfully integrate AI into classroom instruction. To date, there appears to be a lack of specific empirical studies exploring AI competence both technologically and pedagogically among chemistry teachers in Kaduna State secondary schools. This study, therefore, seeks to fill this important research gap. Its goal is to provide educational administrators, policymakers, and curriculum developers with insights necessary for designing targeted interventions to enhance chemistry teachers' competencies in the application of AI, thereby improving teaching quality and learning outcomes in science education.

Artificial Intelligence (AI) holds immense potential for transforming the teaching of chemistry through the integration of advanced technologies such as Machine Learning (ML), Deep Learning (DL), and Natural Language Processing (NLP). These tools can enrich the educational experience by enabling predictive modeling, interactive simulations, automated assessments, and personalized learning pathways. However, despite increasing advocacy for AI integration within Nigeria's educational landscape, many secondary school chemistry teachers still struggle to understand how to meaningfully apply AI tools within their classroom instruction. A critical limitation lies in the quality and availability of data, as such, AI models are only as effective as the datasets they are trained on, and in the context of chemistry education, relevant data may be scarce or fragmented. While previous research has largely concentrated on the adoption and general potential of AI in education, far less attention has been paid to evaluating the actual competence of chemistry teachers or the practical challenges they face in leveraging AI in real classroom settings. In Kaduna State, the level of AI adoption and the competence of secondary school chemistry teachers both technologically and pedagogically remains unclear. This knowledge gap serves as the impetus for the current study, which seeks to assess the proficiency of chemistry teachers in utilizing AI tools and to uncover the specific barriers hindering successful integration. By identifying these constraints and evaluating teachers' readiness, the study aims to provide actionable insights that can guide policy formulation, training programs, and support systems for effective AI integration in chemistry education.

Objective of the study

The study aims at:

- i. Assessing the integration of AI technological competence among male and female chemistry teachers in secondary schools in Kaduna State.
- ii. Examining the integration of AI pedagogical competence among male and female chemistry teachers in secondary schools in Kaduna State.

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Research Questions

The following research questions guided the study

1. What is the mean response on integration of AI technological competence among male and female chemistry teachers in secondary schools in Kaduna State?
2. What is the mean response on integration of AI pedagogical competence among male and female chemistry teachers in secondary schools in Kaduna State?

Null Hypotheses

The following null hypotheses were formulated and tested at 0.05 significant levels:

1. There is no significant difference in the mean response on integration of AI Technological competence among male and female chemistry teachers in secondary schools in Kaduna State.
2. There is no significant difference in the mean response on integration of AI pedagogical competence among male and female chemistry teachers in secondary schools in Kaduna State.

Significance of the study

The findings of this study would aid educational administrators, policy makers and curriculum implementers on how to design effective means of improving the competence of chemistry teachers in AI usage in chemistry classrooms. The findings would also enhance accessibility and inclusivity of AI to wider range of teachers and students.

Literature Review

Artificial Intelligence (AI) in chemistry represents a specialized intersection of computer science and chemical sciences, where complex chemical—often biochemical—reactions are simulated to gain deeper insights into processes such as molecular evolution, self-assembly, and other intricate biochemical phenomena. This fusion of AI and chemistry is revolutionizing educational practices by enabling personalized learning, adaptive instruction, real-time assessment, and individualized feedback for students. At its core, AI encompasses a suite of technologies that allow machines to perform advanced cognitive functions—ranging from visual recognition and natural language processing to data analysis and predictive modeling. In the context of modern chemistry education, AI serves as a powerful tool for enhancing efficiency and productivity in the learning process. Some of these tools include Wolfram Alpha, a computational knowledge engine that provides students with instant answers and explanations to chemistry questions; PhET Interactive Simulation is another AI tool that allows students to explore complex chemical concepts in a visual and engaging way.

AI therefore enables students to explore chemical principles more deeply, simulate reactions with greater accuracy, predict outcomes, and visualize molecular structures and processes in real time. Additionally, AI facilitates the design of new molecules and materials, analyzes large chemical datasets, detects trends in reactions, and provides instant feedback—thereby helping students pinpoint areas needing improvement and guiding their progression. According to Daves (2023), AI systems are capable of processing and analyzing vast volumes of data in real time, empowering users to make informed decisions more quickly and effectively. The increased speed and precision offered by AI translate into cost savings, improved educational outcomes, and streamlined instructional workflows. Zafrullah et al. (2023) observed that AI applications in education have gained widespread attention, becoming increasingly popular across educational institutions. Falebita (2024) further emphasized that AI is transforming classroom instruction by revolutionizing every aspect of the teaching and learning process—from lesson planning and content delivery to student evaluation. They described AI as embodying the capacity of machines to respond adaptively to new situations, solve complex problems, answer questions, strategize, and exhibit behaviors traditionally attributed to human intelligence. In mathematics education, Aliyu et al. (2024) noted that AI technologies bring a host of benefits, including personalized tutoring, adaptive assessments, real-time feedback, and collaborative learning environments. Across all disciplines, AI enhances educational experiences by customizing learning paths to suit individual needs, automating administrative tasks, and improving the functionality and effectiveness of online learning platforms.

Methodology

The study employed a descriptive survey design to collect data from chemistry teachers in secondary schools across Kaduna State, Nigeria. A random sampling technique was adopted to ensure the selection of a representative sample from the broader population of 1,500 chemistry teachers spread across 80 secondary schools in the state. From this population, a sample of 150 chemistry teachers was drawn, comprising 72 males and 78 females. To collect data, the researcher developed a structured questionnaire divided into two sections: Section 1 contained 7 items under the title Artificial Intelligence Chemistry Teachers' Technological Competence for Curriculum Implementation Questionnaire (AICTTCIQ), while Section 2 featured another 7 items titled Artificial Intelligence Chemistry Teachers' Pedagogical Competence for Curriculum Implementation

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Questionnaire (AICTPCCIQ). The instrument was rigorously face-validated by a panel of experts, including two experienced data analysts and two senior chemistry educators from the Department of Science Education, Ahmadu Bello University, Zaria. Responses were recorded using a four-point Likert scale: Strongly Agree (4 points), Agree (3 points), Disagree (2 points), and Strongly Disagree (1 point). The reliability of the instrument was established using Cronbach's alpha, yielding coefficients of 0.71 and 0.72 respectively for the two sections—indicating a high degree of internal consistency. To facilitate effective administration of the questionnaire, the researcher collaborated with six trained research assistants. The return rate for the administered questionnaires was 100%, ensuring full participation from all sampled respondents. A benchmark score of 2.50 was set as the decision point for determining competence levels. Accordingly, a mean score of 2.50 and above was interpreted as indicating moderate to high competence, while scores below 2.50 reflected low competence. Data analysis was conducted using means and standard deviations to address the research questions, while independent sample t-tests were employed to test the hypotheses at a 0.05 level of significance. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS), Version 20.

Presentation of Results

The results are presented according to the research questions and hypotheses

Research Question1: What is the mean response on integration of AI technological competence among male and female chemistry teachers in secondary schools in Kaduna State?

Table 1: Technological Competence of chemistry teachers on AI usage

| S/N | Competence Area/variables | Mean Male | Mean Female | Grand Mean | Competence Level | Decision |
|-----|---------------------------------------------------------------------------------------------|-------------|-------------|------------|------------------|-----------|
| 1 | Use AI soft and hard ware for chemistry teaching in the classroom | 2.30 | 2.20 | 2.25 | Low | Disagreed |
| 2 | Use AI powered tutoring systems to provide immediate feedback based on students' progress | 2.10 | 2.05 | 2.08 | Low | Disagreed |
| 3 | Use AI to create interactive simulations that allow students to explore chemical reactions. | 2.20 | 2.30 | 2.25 | Low | Disagreed |
| 4 | Use AI to generate visualizations of complex chemical processes. | 2.30 | 2.20 | 2.25 | Low | Disagreed |
| 5 | Use AI in designing new molecules and materials by predicting their properties | 2.05 | 2.10 | 2.08 | Low | Disagreed |
| 6 | Use AI to track students' progress and patterns and providing targeted support | 2.35 | 2.40 | 2.38 | Low | Disagreed |
| 7 | Use AI to explore and support deeper understanding of chemical principles. | 2.45 | 2.30 | 2.38 | Low | Disagreed |
| | Overall Mean | 2.25 | 2.22 | | | |

The results in Table 1 show the overall mean score for male and female chemistry teachers as 2.25 and 2.22; with corresponding standard deviations of 1.02 and 1.21 respectively. Both male and female teachers had low level of technological competence in using Artificial Intelligence tools. Teachers' competence in using AI powered tutoring systems to provide immediate feedback based on students' progress was the lowest among the variables, indicating significant challenge in integrating AI into immediate feedback purposes. Another challenge observed was in the use of AI to design new molecules and materials by predicting their properties. Overall, the technological competence of chemistry teachers in using AI is low, with the male performing statistically insignificantly higher than the female teachers.

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Research Question 2: What is the mean response on integration of AI pedagogical competence among male and female chemistry teachers in secondary schools in Kaduna State?

Table 2: Pedagogical Competence of male and female chemistry teachers on Artificial Intelligence usage

| S/N | Competence Area/variables | Mean | Mean | Grand Mean | Competence Level | Decision |
|---------------------|----------------------------------------------------------------------|-------------|-------------|------------|------------------|-----------|
| | | Male | Female | | | |
| 1 | Use subject-specific AI applications in teaching chemistry | 2.30 | 2.10 | 2.20 | Low | Disagreed |
| 2 | Use of open-ended AI tools to support collaboration | 2.25 | 2.30 | 2.28 | Low | Disagreed |
| 3 | Use of AI for project-based learning | 2.35 | 2.40 | 2.38 | Low | Disagreed |
| 4 | Use AI to design and implement collaborative projects | 2.10 | 2.35 | 2.23 | Low | Disagreed |
| 5 | Use of AI algorithms to create customized learning | 2.05 | 2.10 | 2.08 | Low | Disagreed |
| 6 | Use of AI in generating visualizations of complex chemical processes | 2.30 | 2.25 | 2.28 | Low | Disagreed |
| 7 | Use of AI to provide translation services and adaptive text formats | 2.35 | 2.30 | 2.33 | Low | Disagreed |
| Overall Mean | | 2.24 | 2.23 | | | |

The findings presented in Table 2 show that the overall mean scores for male and female chemistry teachers were 2.24 and 2.23, with corresponding standard deviations of 0.99 and 1.01, respectively. These results indicate that both male and female chemistry teachers demonstrated a low pedagogical competence in the use of Artificial Intelligence (AI) in classroom instruction. Notably, the lowest scoring area among the evaluated variables was the teachers' ability to utilize AI algorithms for developing personalized learning experiences, highlighting a considerable difficulty in applying AI tools to assess students' performance and learning patterns. Although male teachers recorded a marginally higher mean score than their female counterparts, the difference was statistically insignificant. Overall, the pedagogical competence of secondary school chemistry teachers in AI integration remains low across gender.

Null Hypotheses

Ho1: There is no significant difference in the mean response on integration of AI Technological competence among male and female chemistry teachers in secondary schools in Kaduna state.

Table 3: T-test analysis on AI Technological competence among male and female chemistry teachers

| S/N | Variables | N | Mean | Std. Dev | Df | t-cal | t-crit | P |
|-----|-----------|----|------|----------|-----|-------|--------|-------|
| | Male | 72 | 2.25 | 1.02 | | | | |
| | Female | 78 | 2.22 | 1.21 | 148 | .721 | 1.96 | 0.521 |

The statistical data in Table 3 indicates that the male teachers reported a mean score of 2.25 while the female teachers had a slightly lower mean score of 2.22. The mean difference between the two groups is 0.03. The calculated t-value of 0.721 is significantly less than the critical t-value of 1.96 at 0.05 significant levels. The p-value of 0.521 exceeds the standard threshold of 0.05. The null hypothesis which states that "there is no significant difference in the mean response on integration of AI Technological competence among male and female chemistry teachers in secondary schools in Kaduna state" is therefore retained/accepted.

Ho2: There is no significant difference in the mean response on integration of AI pedagogical competence among male and female chemistry teachers in secondary schools in Kaduna State.

Table 4: T- test analysis on AI Pedagogical Competence among male and female chemistry teachers

| S/N | Variables | N | Mean | Std. Dev | Df | t-cal | t-crit | P |
|-----|-----------|----|------|----------|-----|-------|--------|-------|
| | Male | 72 | 2.24 | 0.99 | | | | |
| | Female | 78 | 2.23 | 1.01 | 148 | 0.652 | 1.96 | 0.841 |

The data in Table 4 shows that the male teachers reported a mean score of 2.24 while the female teachers had a slightly lower mean score of 2.23. The mean difference between the two groups is 0.01 which is statistically insignificant. The calculated t-value of 0.652 is significantly less than the critical t-value of 1.96 at 0.05 significant levels. The p-value of 0.841 exceeds the

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standard threshold of 0.05. The null hypothesis which states that “There is no significant difference in the mean response on integration of AI pedagogical competence among male and female chemistry teachers in secondary schools in Kaduna State” is therefore retained/accepted.

Summary of Findings

1. Overall, the technological competence of chemistry teachers in using AI in the classroom is low, with the male performing slightly higher than the female teachers.
2. Overall, the pedagogical competence of chemistry teachers in using AI in the classroom is low, with the male performing slightly higher than the female teachers.
3. There is no significant difference in the AI Technological competence among male and female chemistry teachers in secondary schools in Kaduna state.
4. There is no significant difference in the AI Pedagogical Competence among male and female chemistry teachers in secondary schools in Kaduna State.

Discussion of Findings

This study investigated the competence of chemistry teachers in the application of Artificial Intelligence (AI) within secondary schools in Kaduna State, Nigeria. The descriptive analysis revealed a generally low level of AI competence among both male and female teachers, encompassing both technological and pedagogical dimensions. While there was moderate consensus among the respondents regarding their abilities, the data clearly indicate that teachers possess limited proficiency in leveraging AI tools for chemistry instruction. This deficiency may have far-reaching consequences, potentially impeding students’ capacity to compete effectively in an increasingly globalized, technology-driven educational landscape. The findings underscore a significant shortfall in both AI-related resources and the professional development opportunities necessary to train teachers in effectively integrating AI into their instructional practices. Consequently, there is an urgent need for targeted interventions, including comprehensive capacity-building programs and the provision of up-to-date AI tools.

Strengthening teacher competence in this area would not only empower educators to enhance their instructional delivery but also contribute meaningfully to improved academic performance among chemistry students. Furthermore, the results from the two research hypotheses demonstrated no statistically significant differences between male and female teachers in both technological and pedagogical AI competence. This suggests a leveling of gender disparities in access to and application of AI resources within the educational context. These findings are consistent with the works of Koehler et al. (2013); Lameris and Amab (2022), and Berber et al. (2025), who emphasized the necessity of promoting both technological and pedagogical knowledge among educators—regardless of gender—to ensure the successful integration of AI in science, particularly in chemistry classrooms.

Conclusion

The findings of this study reveal that the overall competence of chemistry teachers in Artificial Intelligence (AI)—both technological and pedagogical—is notably low. Specifically, teachers demonstrated limited proficiency in utilizing AI-powered tutoring systems capable of delivering real-time feedback on students’ learning progress, underscoring significant barriers to effective AI integration in the classroom. These challenges point to a critical need for well-structured, targeted professional development initiatives aimed at enhancing teachers’ skills and confidence in applying AI tools in instructional settings. Implementing such training programs would significantly advance the integration of AI into chemistry education, thereby improving teaching effectiveness and student outcomes—not only in secondary schools across Kaduna State, but throughout Nigeria as a whole.

Recommendation

The following recommendations are hereby put forward

1. Chemistry teachers (male and female) should be encouraged to attend AI comprehensive programs which would increase their technological and pedagogical competence on how to use AI in designing new molecules and materials and also predicting their properties
2. Chemistry teachers should be trained on how to use AI to design and implement collaborative projects.
3. The state government in collaboration with educational bodies should provide the needed AI resources that will enable teachers implement AI curriculum in lesson planning and assessments more effectively.
4. Workshops and awareness for secondary education teachers should be developed and conducted to give teachers insight into the topic ‘AI in science’ in chemistry classrooms.

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