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Exploring Secondary School Students' Interest and Mastery of Atomic Structure and Chemical Bonding through ChatGPT

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Abstract

This research explored the impact of using ChatGPT, a chatbot-assisted artificial intelligence (AI), on students' interest and conceptual understanding of atomic structure and chemical bonding. A total of 92 senior and two secondary students, including 61 male and 31 female students from Rwanda, were randomly selected to participate in the study. The study used a sequential explanatory research design to collect and analyze data. A pre and post-achievement test was used to collect quantitative before and after using ChatGPT. On the other hand, focus group discussion was used to collect qualitative data to explore students' interest in using chatbots. Repeated measure ANOVA was used to analyze quantitative data from achievement tests, while thematic analysis was used to analyze qualitative data from focus group discussions. The results revealed that the generated response from the use of chatbot-AI is an effective method to supplement other active methods of teaching and learning atomic structure and chemical bonding. In this regard, the students' performance increased by 16.6% after the use of chatbot-AI. However, the study did not find a statistically significant difference between male and female students after using ChatGPT. Thematic analysis revealed three overarching themes. In this line, the use of ChatGPT stimulates students' engagement and interactivity, curiosity and motivation, and enhanced learning experience. Educators and policymakers were recommended to integrate this technology into the curriculum to supplement other active teaching and learning pedagogies.

Keywords: Chatbot, artificial intelligence, ChatGPT, atomic structure, chemical bonding, conceptual understanding, student interest

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Introduction

In the ever-evolving landscape of education, integrating innovative technologies has become pivotal in shaping engaging and effective learning experiences. Chemistry education at the secondary level plays a pivotal role in shaping students' foundational understanding of scientific principles (Mahaffy, 2004). Teachers of Chemistry and other STEM subjects use Artificial Intelligence (AI) to facilitate students' deep underrating of scientific concepts (Al Darayseh, 2023). The implication of artificial intelligence in education brought significant improvement to traditional models of teaching and learning processes.

Rwanda, like other developing countries, has adopted the use of technology at all levels of education. The use of AI requires a long-term investment in human capital and must start at a lower level of education (Darayseh, 2023). Most developing countries have adopted the use of AI and developed a National AI Strategy that will enable educationalists to support the adoption of AI (Bareis en Katzenbach, 2022). According to Clark (2023), the use of chatbot-AI in teaching covalent bonds creates assignments in which students can analyze and improve their responses. The use of AI chatbots in chemistry education helped grade 8^{th} to understand how to structure and construct the scenario (Giam en Thanh, 2022).

However, the use of AI chatbots is useful for both learners and in chemistry education, even though it is stated that ChatGPT has current limitations (Jasin *et al.*, 2023). In this context, some research has shown that chatbot is currently unsuitable for answering many typical test questions for students. A lot of discussion is currently going on around the possible use and abuse of these systems in education (Darayseh, 2023). These discussions can be more productive if they are informed by a better understanding of the scope and limitations of chatbot AI (Talanquer, 2023). Therefore, replies produced by AI chatbots and chemistry students participating in an explanatory exercise have intriguing similarities, according to one investigation.

As fundamental to this discipline, atomic structure and chemical bonding often present challenges due to their abstract nature. Traditional teaching methods may fail to capture students' attention and facilitate a deep understanding of these concepts. Similarly, high school senior students are more likely

to use artificial intelligence to study atomic structure and chemical bonding in school, have high expectations for atomic structure and chemical bonding performance, and do not encounter difficulties (Nguyen en Sirichokcharoenkun, 2023).

Throughout the history of the atom, various scientists have created concepts of atomic structure. John Dalton's 19th-century atomic theory assumed that matter was made up of indivisible atoms. J.J. Thomson's experiments with cathode rays, conducted in the late 19th century and his early 20th century, led to the "plum pudding" model, suggesting that electrons are embedded within a positively charged sphere. At the same time, Ernest Rutherford's gold foil experiments supported the nuclear model, suggesting a small, dense nucleus. In 1913, Niels Bohr introduced the Bohr model, which includes quantized electron energy levels. The modern understanding of atomic structure, with its roots in quantum mechanics, emerged in the early 20th century with the contributions of scientists such as Erwin Schrödinger and Werner Heisenberg.

Understanding atomic structure and chemical bonding is difficult due to its abstract nature, and visualizing subatomic particles, their behavior, and interactions requires conceptual leaps and often contradicts everyday experience (Park *et al.*, 2009). The microscopic scale of electrons orbiting around the nucleus is not directly observed. Additionally, quantum mechanics introduces complex mathematical principles. Chemical bonds involve the sharing or transferring electrons based on abstract models (Suryelita, Guspatni en Defriati, 2019). The dynamic nature of electrons in molecular orbitals requires mental abstraction (Tsaparlis, 1997). These difficulties make it difficult for senior learners to bridge the macroscopic and microscopic worlds. Teachers require secondary school students to understand and enable theoretical concepts and abstract thinking skills and use chatbot-assisted artificial intelligence to gain knowledge in atomic structure and chemical bonding. This research project explores using chatbot-assisted artificial intelligence (AI), specifically ChatGPT, to empower two senior Rwandan secondary school students to understand atomic structure and chemical bonding, crucial concepts in chemistry. The study proposes an interactive learning environment, addressing challenges students often face in understanding these abstract principles, contributing to the broader discourse on technology integration in science education.

Research objectives

1. To Assess the Impact of ChatGPT on Students' Interest in Atomic Structure and Chemical Bonding.

2. To Analyze the effectiveness of ChatGPT in addressing conceptual challenges and improving students' mastery of atomic structure and chemical bonding.

Methodology

Research design

The study employed a sequential explanatory research design. Sequential explanatory research design is particularly useful when the research question is complex and requires multiple perspectives for a comprehensive understanding (Creswell, 2014). It allows researchers to triangulate findings from different sources and methods, enhancing the credibility and validity of the research outcomes. Initially, a quantitative phase was conducted where pre- and post-intervention assessments were administered to two senior students to quantitatively measure changes in academic interest and mastery resulting from the incorporation of chatbot-aided artificial intelligence in the learning process. Subsequently, a qualitative phase followed focus group discussions to delve deeper into students' interests. The sequential explanatory design allowed for a comprehensive exploration of the intervention's effects by combining quantitative statistical findings with qualitative insights for enhancing the overall understanding of how ChatGPT AI impacts senior two students' interest and mastery in atomic structure and chemical bonding.

Research method

The study adopted a mixed research method to understand the impact of the intervention thoroughly. In this sense, we combined both quantitative and qualitative data to evaluate how students' interest and understanding of atomic structure and chemical bonding are affected by chatbot-assisted artificial intelligence. Pre-post achievement tests with statistical analyses were used in the quantitative phase to gauge the success of the intervention, while focus group discussion was used in the qualitative phase to learn more about students' interests. This mixed-methods approach combines qualitative insights with numerical data to provide a comprehensive understanding of the impact of the intervention.

Population and method of sampling

The study was done in one school in the Kayonza district. There were three classes of senior two. A total of 92 senior-two secondary students from 139 were randomly selected to participate in the study. Thus, we formed two classes. The selected students were 61 male and 31 female students. The

randomized selection of participants was used to ensure a representative sample from the larger population and enhance the findings' external validity.

Description of the intervention

The intervention involved integrating advanced educational technology in the form of a chatbot to augment the learning experience in the subject matter. This intervention includes the use of ChatGPT in the classroom setting. Students got regular access to the use of ChatGPT as a supplementary tool during the teaching and learning process. This was done in the first term academic year of 2023-2024 in the period of three weeks from 6th to 27th November 2023. In the context of the Rwandan competence-based curriculum (CBC), chemistry is taught four periods per week (40 minutes each); in this regard, the intervention took 12 periods, which is equivalent to 480 min (8 hours). Teachers served as a guider (after being trained by researchers) by showing how to use the chatbot effectively, incorporating it into lesson plans, and encouraging students to seek assistance and engage in interactive learning experiences. The topics that were discussed included atomic theories, composition of atoms, electronic configuration, formation of ions, ionic bonds, covalent bonds, and metallic bonds. Concurrently, data were collected throughout the intervention period through pre and post-assessments. Analyzing this data will provide valuable insights into the chatbot-aided artificial intelligence's effectiveness in empowering two senior students in their chemistry education.

Method of data collection

The collection of data involves blending quantitative measurements with qualitative perspectives to offer a nuanced portrayal of the impact of chatbot-aided artificial intelligence on students' interest and conceptual understanding of atomic structure and chemical bonding. The quantitative data were collected through pre and post-assessments. The achievement was composed of 30 questions, including 11 questions related to the atomic structure and 19 questions related to chemical bonding. The pre-test was designed to gauge students' baseline understanding and subsequent mastery of atomic structure and chemical bonding, while the post-test was used to evaluate the impact of chatbot-assisted AI on students' conceptual understanding of atomic structure and chemical bonding. The qualitative data were collected through focus group discussions to capture students' insight into experiences, challenges, and benefits encountered during the intervention.

Method of data analysis

Quantitative data obtained from pre and post-assessments were analyzed descriptively to examine changes in students' conceptual understanding of the atomic structure and chemical bonding over time. Additionally, inferential statistics, specifically a repeated measures ANOVA, was employed to assess the significance of any observed differences between pre and post-test, across gender. This statistical analysis was employed to provide insights into the overall effectiveness of the chatbot intervention in enhancing students' mastery of atomic structure and chemical bonding. Concurrently, qualitative data from focus group discussions were analyzed thematically, allowing for the identification of recurring patterns, themes, and nuanced insights into students' interests and experiences with the chatGPT. Integrating both types of analyses provided a comprehensive understanding of the intervention's impact, combining statistical evidence with rich qualitative perspectives to offer a well-rounded assessment.

Results

The influence of using ChatGPT on students' conceptual understanding of atomic structure and chemical bonding

The analysis of students' performance in the pre and post-test after integrating chatbot-assisted AI showed that students performed better after intervention (post-test) compared to the pre-test. Out of 11 questions related to the atomic structure, 10 scored above 50% in the post-test, while in the pre-test only seven scored above 50%. In this line, only one question (Q5) scored below 50% on both the pre-and post-tests. In the section on chemical bonding, out of 19 questions asked in this section, only 12 scored above 50% in the pre-test, while in the post-test, this number was increased to 16. Therefore, the number of questions scored above 50% were increased in the post-test by 3 and 4 in the section on atomic structure and chemical bonding, respectively. However, in this section, two questions (Q18 and Q25) scored below 50% in both pre-and post-test.

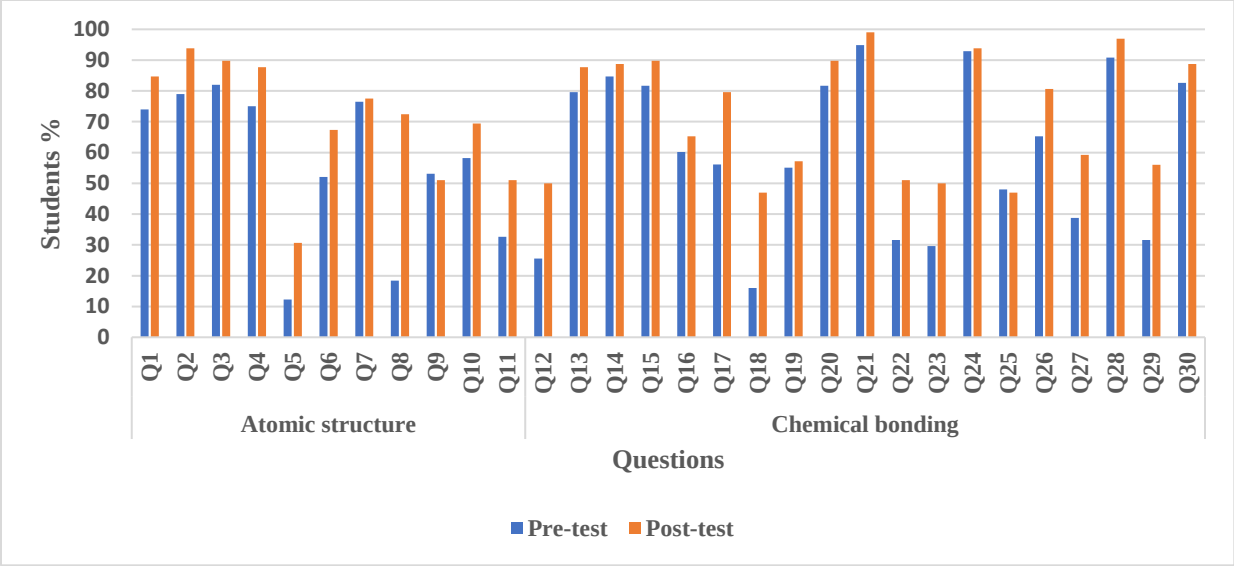

Figure 1. Students' performance in both pre and post-test

The research findings indicate a substantial positive impact on students' academic performance in the areas of atomic structure and chemical bonding following the intervention of chatbot-assisted AI. The increase in the average score by 16.2% signifies a significant improvement in students' comprehension and mastery of the subject matter. The shift from an average score of 53.8% in the pre-test to 70% in the post-test suggests that the chatbot-assisted AI intervention contributed positively to enhancing students' understanding. The finding underscores the potential of chatbot-assisted AI as an innovative and impactful educational tool for teaching complex scientific concepts, fostering an students' understanding of atomic structure and chemical bonding.

Table 1. Descriptive analysis of pre and post-test

Test	Gender	Mean	Std. Deviation	N
Pre-test	Male	53.86	9.25	61
	Female	53.80	10.08	31
	Total	53.84	9.48	92
Post-test	Male	69.21	9.92	61
	Female	71.54	11.03	31
	Total	70	10.31	92

The research findings suggest that the intervention of chatbot-assisted AI in teaching atomic structure and chemical bonding led to significant improvements in academic performance and the impact was observed across both male and female students. For male students, the average score increased by 15.35%, rising from 53.86% in the pre-test to 69.21% in the post-test. Similarly, female students

experienced a substantial improvement, with the average score increasing by 17.74% from 53.80% in the pre-test to 71.54% in the post-test. Figure 2 shows the visualization of male and female students in both pre and post-test.

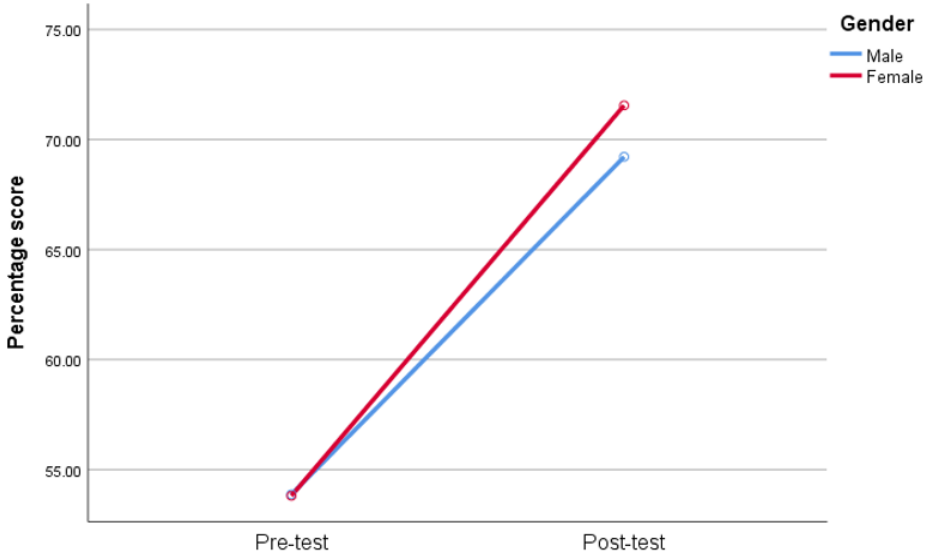

Figure 2. Students performance in both pre and post-test per gender

The results of the repeated measures ANOVA indicated a highly significant difference in the mean scores of students between the pre and post-test phases after the intervention of chatbot-assisted AI in teaching atomic structure and chemical bonding (*p*-value < 0.001) with a medium effect size of 0.618. However, the study did not find a significant difference in the mean score between male and female students, with p>0.05 and a small effect size of 0.008. However, female students showed much improvement than their male counterparts.

Table 2. Inferential statistics of pre, posttest and gender

Multivariate Tests[a]							
Effect		**Value**	**F**	**Hypothesis df**	**Error df**	**Sig.**	**Partial Eta Squared**
Tests	Pillai's Trace	0.618	145.440[b]	1	90	0.000	0.618
	Wilks' Lambda	0.382	145.440[b]	1	90	0.000	0.618
Gender	Pillai's Trace	0.008	.764[b]	1	90	0.384	0.008
	Wilks' Lambda	0.992	.764[b]	1	90	0.384	0.008

Influence of chatbot-assisted artificial intelligence on student' interest in learning atomic structure and chemical bonding

The focus group discussion's thematic analysis of student responses revealed three overarching themes: engagement and interactivity, curiosity and motivation, and enhanced learning experience.

Theme one: enhance engagement and interactivity

During focus group discussions, many students expressed a heightened interest in learning atomic structure and chemical bonding with the introduction of chatbot-assisted artificial intelligence. In this context, they appreciated the interactive nature of the technology, describing how it made the learning process more engaging and dynamic. In addition, students consistently highlighted the chatbot's role in making learning more engaging. The interactive features of the technology, such as real-time responses and dynamic simulations, captured students' attention and contributed to a more immersive learning experience. One student said: *"for me, integrating ChatGPT technology into my learning process for atomic structure and chemical bonding was relatively easy. The intuitive interface and user-friendly design made interacting with the chatbot and accessing relevant information straightforward."*

Theme two: stimulate students' curiosity and motivation

A notable number of students reported feeling more curious and motivated to explore the topics further. The chatbot's ability to provide instant clarifications and additional resources encouraged students to delve deeper into the subject matter, fostering a sense of curiosity and exploration. The introduction of chatbot-assisted AI sparked a sense of curiosity among students, motivating them to explore the subject matter more deeply. The instant access to additional resources and explanations fueled their desire to learn and discover, positively impacting their interest in atomic structure and chemical bonding. One student said: *"One aspect of chatbot-assisted AI that positively impacted my learning of atomic structure and chemical bonding is its ability to provide personalized explanations and feedback."*

Theme three: enhance the learning experience.

During the discussion, many students mentioned that the chatbot-assisted AI helped them understand complex concepts more easily. Students appreciated the chatbot's flexibility, allowing them to learn at their own pace. The adaptive nature of the technology catered to individual learning styles, making the process more personalized and accommodating. The chatbot's contribution to a clearer

understanding of atomic structure and chemical bonding. Students felt that the technology facilitated a more efficient and effective learning process, contributing to their overall mastery and interest in the subject. The technology captures students' attention and motivates them to explore and understand the subject matter more deeply, ultimately contributing to a more positive and dynamic learning environment. One student said: *"ChatGPT provides personalized assistance and explanations tailored to my specific queries, which has deepened my understanding of complex concepts."*

Discussion

Analyzing students' performance in the pre and post-tests following the integration of chatbot-assisted AI reveals a notable improvement in academic outcomes. The results demonstrate a statistically significant enhancement in students' mastery of atomic structure and chemical bonding, as evidenced by the overall higher post-test scores than the pre-test. Particularly in the atomic structure section, a substantial increase in the number of questions scored above 50% is observed, reflecting improved understanding and proficiency among students. Furthermore, the consistency of low performance in one question (Q5) in both pre and post-tests warrants further investigation to identify potential challenges in comprehension or teaching methods related to that specific topic. Similarly, in the chemical bonding section, the significant increase in the number of questions scoring above 50% in the post-test underscores the positive impact of chatbot-assisted AI on students' learning outcomes. The study found that chatbot-assisted AI improved students' academic performance in atomic structure and chemical bonding, demonstrating its effectiveness across gender lines. Both male and female students showed significant improvements, with male students seeing a 15.35% increase and female students seeing a 17.74 increase. Overall, these results suggest that the intervention effectively enhances senior four students' interest and mastery in atomic structure and chemical bonding, validating the efficacy of integrating chatbot technology into the educational process.

ChatGPT appears to significantly boost understanding of atomic structure and chemical bonding. Based on gender, female students experienced a slightly higher average score increase. While the cause of this difference warrants further investigation, the near-identical pre-test scores suggest that AI effectively benefited all regardless of initial understanding. This promising finding highlights the potential of AI to democratize science education across genders. This suggests that chatbot-assisted AI can enhance learning experiences and academic outcomes, regardless of gender. This indicates that

the intervention was consistent across genders. This highlights the inclusivity of the technology-driven approach in enhancing academic performance for all students, regardless of gender, despite the observed improvements. Further research could help refine educational strategies and address gender-specific learning needs. The obtained results are consistent with Clark (2023), who found that ChatGPT response creates tasks where students can analyze and evaluate the provided responses. Additionally, Watts et al. (2023) illustrated that using artificial intelligence chatbots raises questions in terms of open-ended writing on the movement of electrons. Using chatbot's artificial intelligence chemistry scenario fosters students' conceptual understanding of the atomic structure and chemical bonding (Giam en Thanh, 2022). The use of AI stimulates students' conceptual understanding of chemical bonding by predicting the molecular structure of substances (Choudhary, Bharti en Sharma, 2022).

The outcomes of the focus group discussion yielded compelling insights through thematic analysis of student responses, delineating three overarching themes that illuminate crucial aspects of the educational experience. Firstly, engagement and interactivity emerged prominently, emphasizing the significance of active involvement in the learning process. Students desired interactive elements that foster collaboration and participation, underscoring the pivotal role of engagement in effective learning environments. Secondly, the theme of curiosity and motivation surfaced, shedding light on the students' intrinsic drive to explore and understand the subject matter. This underscores the importance of cultivating a learning atmosphere that sparks curiosity and sustains motivation, fostering a deeper connection to the educational content. Lastly, the theme of an enhanced learning experience encapsulates the students' collective aspiration for a comprehensive and enriching educational journey. These identified themes collectively underscore the multifaceted nature of students' educational needs and aspirations, providing valuable insights for refining and optimizing educational practices. The results obtained agree with those of Giam et al. (2023), who showed that students are interested in using AI chatbots as they help them in their self-study and autonomous learning. The self-learning AI component provides the students with a classroom environment by providing interactive tutorials (Mahroof *et al.*, 2020). In addition, Lolinco and Holme (2023) illustrated that the interaction of AI chatbot supports students in developing and refining ideas in general chemistry assignments. The use of ChatGPT has a positive correlation with students' motivation in chemistry learning (Nja, 2023). Thus, the use of an AI chatbot provides valuable insights for refining teaching strategies and enhancing overall learning outcomes.

Conclusion and implication

The findings reveal significant improvements in academic performance, increased students interest, and a more personalized learning experience. Both male and female students benefited from the intervention, showcasing the technology's inclusivity. The implications of this research suggest that incorporating chatbot-assisted AI in chemistry education can be an effective strategy to enhance students' understanding, stimulate interest, and provide a dynamic, adaptive learning environment. Educators and policymakers should consider integrating such technologies into the curriculum, acknowledging their potential to address individual learning needs, promote curiosity, and contribute to a more enriched educational experience for senior-two secondary students.

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Conflict of interest

The authors declare no potential conflict regarding the publication of this paper.

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