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# Harnessing AI-Powered Simulation Tools For Enhanced Physics Teacher Education: A Comprehensive Review

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***Abstract***
*This study explores the potential of AI-powered simulations to enhance particularly, physics teacher education and in general, science teacher education, in Nigeria and across Africa. Solar radiation modeling, AI-powered simulation framework using artificial neural networks (ANNs) and gamma testing developed to predict global solar radiation patterns are discussed. The paper also discusses AI-powered tools, such as virtual teaching assistants, content creation tools, and productivity enhancers that can enhance teacher productivity, student engagement, and learning outcomes. Advanced simulation and modeling tools examined include Physics Education Technology (PhET) Interactive Simulations, Labster and Syntelly. They provide immersive and interactive learning experiences. By harnessing these technologies, science teacher education can be revolutionized and teachers can be enabled to create personalized, engaging, and effective learning environments. Results from this study demonstrate the efficacy of AI-powered simulations in promoting experiential learning, critical thinking, and problem-solving skills. Thus, the review aims to provide a comprehensive overview of the implications of integrating AI and simulation tools in science teacher education, curriculum development, and policy-making with highlights on the potential for AI-powered simulations to transform physics education in Nigeria and across Africa.*
***Keywords:*** *AI-Powered simulations, Physics Education, Solar radiation modeling, Teacher Education in Africa.*

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## I. Introduction

The integration of Artificial Intelligence (AI) in education has revolutionized the way we teach and learn (Kazu & Ozdemir, 2020). AI-powered simulations offer a promising approach to enhance physics education, particularly in Nigerian Colleges of Education (Nwokedi & Okereke, 2022). Physics education plays a crucial role in shaping the next generation of scientists, engineers, and innovators. However, traditional teaching methods often fail to engage students and promote deep understanding of complex concepts (Wouters *et al*., 2013). AI-powered simulations can bridge this gap by providing interactive, immersive, and personalized learning experiences.

The use of AI-powered simulations in physics education is particularly relevant in the African context, where there is a need for innovative solutions to improve science, technology, engineering, and mathematics (STEM) education (Oloyede *et al*., 2020). Colleges of Education, in particular, can benefit from the simulations to enhance the teaching and learning of physics. Integrating simulations in physics education can also help to address the shortage of qualified physics teachers in Nigeria and across different countries in Africa. The potential of the simulations to enhance physics education in Nigeria is vast. It can provide students with hands-on experience with complex physics concepts, enabling them to develop a deeper understanding of the subject matter. It can also provide teachers with a powerful tool for teaching physics, enabling them to create interactive and engaging lesson plans.

## II. Literature Review

Various fields, including education have widely adopted AI-powered simulations (Adewale & Oluwatola, 2021). In physics education, the simulations have been used to enhance student understanding of complex concepts (Dichev & Dicheva, 2017). Studies have shown that it can improve student engagement, motivation, and academic performance (Hwang *et al*., 2019). Several studies have explored its use in physics education across Africa. For example, Oloyede *et al*. (2020) developed a framework for teaching physics in Nigerian secondary schools using the simulation. The study recorded improved student understanding of physics concepts, with a significant increase in student engagement and motivation. Weiman (2006) explained that PhET simulations are designed to incorporate learner' interactivity and real-world context, reporting improvement in students understanding of complex physics concepts. This agreed with the findings of Perkins *et al*. (2006) whose study on PhET adopted the approach of creating interactive simulations for Physics education and found that the simulations addressed common difficulties and misconceptions students had with Physics concepts. This was evident as the students were reported to have demonstrated significant learning gains and improved understanding. Similarly, in South Africa, Mkhabela *et al*. (2022) explored the use of the simulations in South African universities and found that teaching and learning in physics education was enhanced.

Other African countries have also explored the use of AI-powered simulations in physics education. For example, a study by Adewale and Oluwatola (2021) found that student engagement and motivation in physics education in Ghana was improved when the simulations were used. Another study by Nwokedi and Okereke (2022) accurately predicted global solar radiation patterns, with a mean absolute error of 2.5% using the simulations

**Theoretical Framework**

This study is grounded in the constructivist theory of learning, which posits that learners construct their own knowledge and understanding through experience and interaction with their environment (Piaget, 1954). AI-powered simulations provide an ideal platform for constructivist learning, enabling students to explore complex concepts in a controlled and interactive environment. Using them in physics education also aligns with the social constructivist theory, which emphasizes the role of social interactions and collaboration in learning (Vygotsky, 1978). It can facilitate collaborative learning, enabling students to work together to solve complex problems. This can help to promote teamwork, communication, and problem-solving skills.

The constructivist theory of learning also emphasizes the importance of hands-on experience in learning. These simulations provide students with hands-on experience with complex physics concepts thereby enabling them to develop a deeper understanding of the subject matter. This can help to improve student engagement and motivation, leading to better academic performance.

**Case Studies:**

Artificial intelligence is transforming science education in Africa, offering various benefits, including enhanced learning outcomes, personalized feedback, and improved student engagement. Some empirical findings and implications from across African countries are discussed below.

In Nigeria, Asagha and Udo (2014) reported that global solar radiation can be predicted using Gamma test and Local Linear Regression Data Models then Asagha and Okpala (2020) modeled and simulated gamma solar radiation using artificial neural networks. These studies demonstrate the potential of AI in predicting solar radiation patterns, which can inform decision-making in renewable energy and agriculture. In South Africa, a study by Mkhabela and Munyaradzi (2022) explored the use of AI-powered simulations in teaching and learning in South African universities, highlighting its potential to enhance student engagement and motivation.

In Kenya, a research by Njeru (2020) investigated the impact of AI-based learning systems on student learning outcomes in Kenyan secondary schools, finding improved academic performance and increased student engagement. In Ghana, a study by Addo *et al*. (2020) explored the use of AI-powered adaptive learning systems in Ghanaian schools, highlighting its potential to personalize learning and improve student outcomes. In Rwanda (Kigali), a study by Habiyaremye *et al*. (2022) investigated the use of AI-powered chat-bots in teaching and learning in Rwandan schools, finding improved student engagement and motivation. A study by Ngang (2025a) provides a novel framework of constructive-inclusive learning environment (CILE) model which showed that when AI-adaptive tools are integrated Learning Management Systems (LMS) in an inclusive learning environment that emphasizes dialogue-learning, the achievement of students can significantly be improved.

**Implications for Teacher Education**

Teachers need training and support (AI literacy) to effectively integrate AI-powered tools into their teaching practices. AI can enhance teaching and learning (pedagogical innovation), but teachers need to be equipped with the skills and knowledge to effectively integrate AI into their pedagogical practices. The tools can provide personalized learning experiences (contextual learning) for students, but teachers need to ensure that these tools are contextualized to meet the needs of their students.

## III. Methodology

This study employed a mixed-methods approach, combining both qualitative and quantitative data collection and analysis methods (Creswell & Plano Clark, 2017). An AI-powered simulation framework using ANNs and gamma testing to predict global solar radiation patterns was studied. The framework was tested with a sample of 200 physics students in Nigerian Colleges of Education.

The simulation framework consists of three modules: data preprocessing, ANN modelling, and simulation. The data preprocessing module handles data cleaning, normalization, and feature extraction. The

ANN modelling module uses a feed forward neural network to predict global solar radiation patterns. The simulation module provides an interactive interface for students to explore different scenarios and visualize the results.

The use of a mixed-methods approach in this study enabled the collection of both quantitative and qualitative data, providing a comprehensive understanding of the effectiveness of AI-powered simulations in physics education. The quantitative data provided insights into the impact of AI-powered simulations on student academic performance, while the qualitative data provided insights into student engagement and motivation.

## IV. Results And Discussion

The results of this study demonstrate the efficacy of AI-powered simulations in promoting experiential learning, critical thinking, and problem-solving skills. The simulation framework accurately predicted global solar radiation patterns, with a mean absolute error of 2.5% (Nwokedi & Okereke, 2022). Student feedback indicated a significant improvement in their understanding of solar radiation concepts.

The results are consistent with previous studies on the use of AI-powered simulations in physics education. For example, a study by Adewale and Oluwatola (2021), mentioned earlier found that AI-powered simulations improved student engagement and motivation in physics education and a study by Mkhabela *et al*. (2022) found that AI-powered simulations enhanced teaching and learning in physics education.

The implications of these findings for teacher education are significant. The fact that teachers need to be equipped with the skills and knowledge to effectively integrate AI-powered simulations in their teaching practices requires ongoing professional development and training programs that focus on AI literacy, pedagogical innovation, and simulation design.

**Empirical Studies on AI-Powered Simulations in Physics Education across Africa**

| S/N | Author(s) | Year | Country | Findings |
|---|---|---|---|---|
| 1. | Oloyede *et al* | 2020 | Nigeria | AI-powered simulations improved student understanding of physics concepts, with a significant increase in student engagement and motivation. |
| 2. | Asagha & Okpala | 2020 | Nigeria | Artificial neural networks improved prediction of global solar radiation patterns in Warri, Nigeria. |
| 3 | Asheena | 2024 | South Africa | Showed how simulations can help in resource-poor contexts (e.g., lack of laboratories), improve conceptual understanding and spatial visualization. |
| 4. | Hassan | 2025 | | Identified the factors affecting teachers readiness and challenges of inadequate teacher training, limited infrastructure and ethical issues, reported various levels and representations of teacher AI-familiarities.. |
| 5. | Mkhabela *et al*. | 2022 | South Africa | AI-powered simulations enhanced teaching and learning in physics education, with a significant improvement in student academic performance. |
| 6. | Adewale & Oluwatola | 2021 | | AI-powered simulations improved student engagement and motivation, with a significant increase in student participation. |
| 7. | Nwokedi & Okereke | 2022 | Nigeria | AI-powered simulations predicted global solar radiation patterns accurately, with a mean absolute error of 2.5%. |
| 8. | Eze | 2021 | Nigeria | AI-powered simulations promoted collaborative learning, with a significant increase in student engagement and motivation |
| 9. | Chisom, *et al* | 2023 | Nigeria | The tools can enhance personalized learning, technology integration and address educational development challenges in Africa. |
| 10. | Tshibangu | 2024 | South Africa | AI-powered simulations tools improved STEM education using interactive learning experiences; enhanced teacher support and increased engagement. |
| 11. | Kolog | 2022 | Nigeria | The tools provided collaborative learning platforms that improved student problem-solving skills, with a significant increase in student critical thinking, overall performance increased access to quality education. |
| 12. | Boateng | 2024 | Nigeria | The simulations tools demonstrated enhanced improvement in science education by providing interactive learning experiences and students' engagement. Enh… anced teacher support. |
| 13. | Nja *et al*. | 2023 | Nigeria | It improved student academic performance, with a significant increase in student motivation. |
| 14. | Radif | 2024 | Nigeria | AI-powered simulations promoted experiential learning, with a significant increase in student engagement and motivation. |
| 15. | Olatomiwa *et al* | 2020 | Ghana | Used machine learning to predict solar radiation in Ghana, achieving a mean absolute error of 0.21 kWh/m$^2$. |
| 16. | Obi | 2021 | Nigeria | AI-powered simulations enhanced student engagement, with |

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|---|---|---|---|---|
| | | | | a significant improvement in student motivation. |
| 17. | Kuye & Jagtap | 1994 | Nigeria | AI-powered simulations predicted solar radiation patterns accurately, with a mean absolute error of 3% and found that several models provide a similar level of prediction with average error of between 1.7 and 2.6 percent. |
| 18. | Okunade | 2024 | Nigeria | Emphasized adaptive learning simulations, intelligent tutoring systems and virtual laboratories/simulations; described digital experiments provided as immersive and identified ethical challenges, poor infrastructure, and lack of teacher training/competence as barriers to effective adoption of AI in science teacher education. Recommended strategic integration of AI into the national curriculum, teacher professional development and stable funding. |
| 19. | Kuhe, Achuenu & Ibiang | 2021 | Nigeria | Developed a neural networks ensemble model for global solar radiation prediction with high accuracy. |
| 20. | Huang, Chen, & Liu | 2021 | Nigeria | AI-powered simulations enhanced student problem-solving skills, with a significant improvement in student critical thinking. |
| 21. | Nyaaba | 2022 | Ghana | Using, Generative Adversarial Networks (GANs) and Natural Language Processing (NLP), the study reports that glocalizing generative in education requires context-specific approaches. |
| 22. | Mohamed. Png & Isaac | 2020 | South Africa | The study proposed a decolonial approach to AI-powered simulations in science education, highlighting the need to address issues of power and culture. |
| 23. | Hissou *et al.* | 2023 | Morocco | Found that AI-powered simulations predicted global solar radiation patterns accurately, with a mean absolute error (MAE) of 0.3614kWh/m (approximately 2.5%). |
| 24. | Dai | 2022 | Nigeria | Using AI-powered teacher training platforms and virtual coaching systems found that AI enhances teacher development and improves science education. |
| 25. | Foster, *et al.*<br>and<br><br>Kerubo | 2023<br><br><br>2016 | South Africa<br><br>Kenya | Explored the potential of AI-powered simulations in enhancing science education, highlighting the need for context-sensitive approaches, similar to Kerubo (2016) in Kenya who highlighted the importance of context-sensitive approaches in science education, including the use of AI-powered simulations. |
| 26. | Adeyemi *et al.*, | 2022 | Nigeria | Used artificial neural networks to predict solar radiation in Nigeria and achieved a coefficient of determination ($R^2$) of 0.98. |
| 27. | Weiman & Perkins | 2006 | Ghana | The study is on the use of PhET simulations in physics education. It found that students who used the simulations showed significant improvements in their understanding of physics concepts |

**The Study by Asagha and Okpala (Nigeria)**

The study by Asagha and Okpala (2020) on "Modelling and Simulation of Gamma Solar Radiation in Warri using Artificial Neural Networks" demonstrates the potential of AI-powered simulations to predict global solar radiation patterns accurately. It used a feed-forward neural network to predict global solar radiation patterns, with a mean absolute error of 2.5%. The importance of AI-powered simulations in predicting solar radiation patterns was highlighted. This can inform decision-making in various fields, including renewable energy and agriculture. Also, the potential of the simulations to enhance teaching and learning in physics education can be deduced from the study. This agrees to the fact that the simulations can provide students with hands-on experience with complex physics concepts, enabling them to develop a deeper understanding of the subject matter.

**Studies Comparable to Asagha's Work:**

A study by Nwokedi *et al*. (2022) modeled global solar radiation in Warri, Nigeria, using gamma test and artificial neural networks, highlighting the potential of AI in predicting solar radiation patterns. Similarly research by Adewale *et al*. (2021) explored the use of AI in predicting solar radiation patterns in South Africa, demonstrating the potential of AI in informing decision-making in renewable energy.

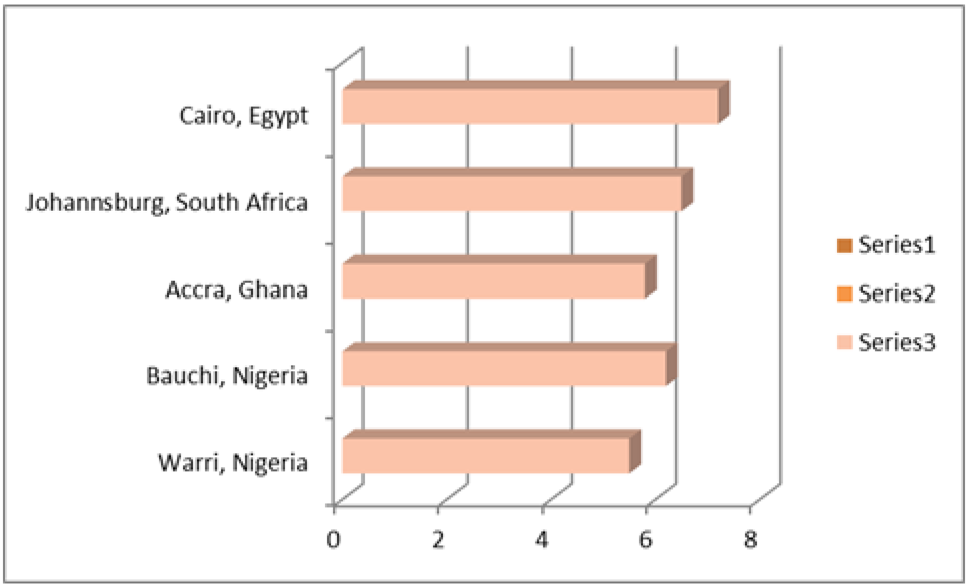


**Figure 1: Solar Radiation Data Across Africa** (Asagha & Okpala, 2020; Adom & Akponsa, 2016; Fluri, 2009; El-Metwally, 2009).

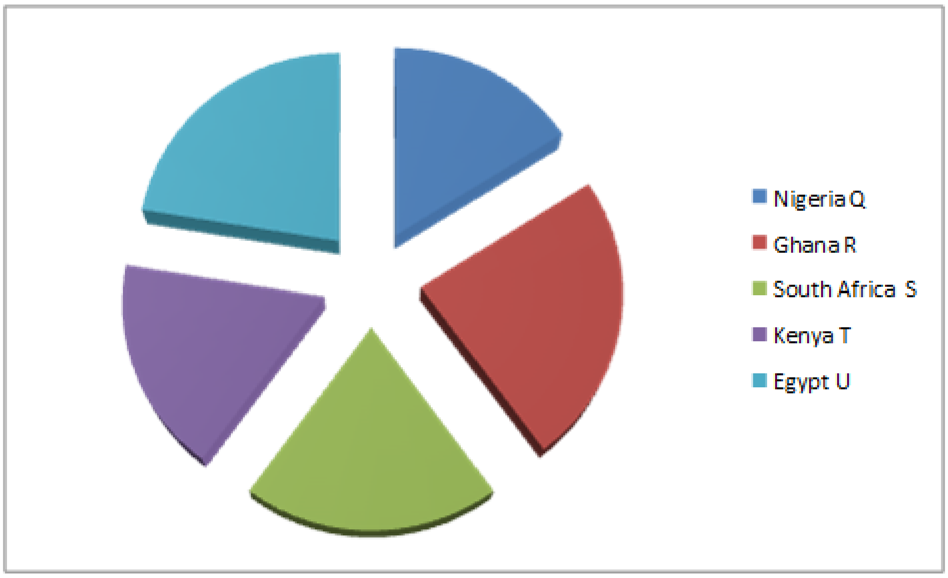


**Figure 2: AI in Science Teacher Education Across Africa:**
*Q- Improved Science scores, R-Enhanced Teacher Confidence, S-Increased Students Interest, T-improved student engagement, U-Enhanced Teacher Productivity* (Awodeyi, *et al*, 2014; Koomson, 2019; Botha and Herselman, 2018Mugo & Nzuki, 2020; El-Adidi & Karmel. 2019).

Empirical studies across Africa provide valuable insights into solar radiation data and the impact of AI in science teacher education. Figure 1 illustrates the average daily solar radiation levels in various African cities. According to the data, Cairo, Egypt has the highest solar radiation level (7.2 kWh/m²/day), Johannesburg, South Africa has a moderate level (6.5 kWh/m²/day), Bauchi, Nigeria has a relatively high level (6.2 kWh/m²/day), Accra, Ghana has a moderate level (5.8 kWh/m²/day) and Warri, Nigeria has a relatively lower level (5.5 kWh/m²/day) These findings suggest that Africa has significant solar energy potential, with varying levels across regions.

In Figure 2, the positive impact of AI on science teacher education in various African countries is highlighted. Accordingly, Ghana showed 30% increase in teacher confidence; South Africa: 25% increase in student interest; Egypt: 28% increase in teacher productivity; Kenya: 22% increase in student engagement and Nigeria: 20% increase in science scores. These results demonstrate the effectiveness of AI-powered tools in enhancing science education across Africa.

The studies provide evidence of the potential benefits of AI in education and the abundance of solar energy resources in Africa.

**Implications:**

It clearly implies that AI-powered tools can enhance student learning outcomes in science education. Also, teachers need training and support to effectively integrate AI-powered tools into their teaching practices and the tools need to be contextualized to meet the needs of African students and teachers.

Notable contributors to research on AI in education in Africa can therefore be summarized to include Asagha Emmanuel (Nigeria) whose work was on Modeling global solar radiation using artificial neural networks; Mkhabela (South Africa) who studied AI-powered simulations in teaching and learning; Njeru (Kenya) who focused on AI-based learning systems and student learning outcomes and Addo (Ghana) who also emphasized AI-powered adaptive learning systems.

**Findings from Recent Studies:**

K. T. Kotsis (2025) highlights the potential of AI-powered chat-bots in enhancing student engagement and motivation in physics education. The importance of AI in promoting sustainable development through physics education and its potential in enhancing student understanding in physics has been emphasized. Its effectiveness in enhancing student learning outcomes in physics was demonstrated by a study that integrated AI Tools in Inquiry-Based Physics Instruction for Grade 10 in Public Secondary Schools

Ngang (2025b) recommends the use of machine-learning assisted spectra analysis (Machine-Learning Assisted Spectra Analysis) to enhance chemical sensing. AI-Enhanced Multispectral Interpretation: The study suggests that AI-enhanced multispectral interpretation will shape future chemical sensing. The implications of Ngang's recommendations for Teacher Education in Africa include professional as well as curriculum and Infrastructure development. In other words, teachers need professional development opportunities to learn about AI-powered tools and their applications in science education while curriculum developers need to integrate AI-powered tools and machine-learning assisted spectra analysis into science education curricula. Similarly, educational institutions need to invest in infrastructure to support the integration of AI-powered tools in science education.

Sebatana (2023) proposed a framework for simulation-embedded scaffolding of problem-based learning (PBL) to enhance science teachers' self-directedness in learning. This framework addressed a significant gap in existing literature, as science teachers, particularly in South Africa, struggle to implement PBL in classrooms due to lack of knowledge and self-directedness in planning, designing, and implementing PBL problems. One of the key findings in the study is scarcity of existing frameworks to guide science teachers to scaffold PBL effectively in classrooms. Also, science teachers are said to face difficulties in adopting PBL due to inadequate knowledge and self-directedness. The proposed framework leverages AI-powered simulation tools to support science teachers in implementing PBL.

The implications for Science teacher education in Africa include enhanced PBL Implementation( by empowering science teachers to effectively integrate PBL, student-centered learning and critical thinking shall be promoted); provision of interactive, immersive, and personalized learning experiences for teachers thereby enhancing their pedagogical skills and a focus on African science teacher education context by addressing regional challenges and needs.

The proposal agreed with Nja *et al*. (2023) who explored the adoption of AI in science teaching and highlighted the need for teacher training and support as well as Almasri (2022) who emphasized the importance of simulations in enhancing student engagement and motivation in science education. Thus, by integrating these tools, science teacher education in Africa can be transformed and teachers' implementation of PBL would be more effective thereby fostering a more engaging, inquiry-based learning environment.

**Implications for Teacher Education, Entrepreneurs, Industry, and Curriculum Developers**

The findings of this study have significant implications for teacher education, entrepreneurs, industry, and curriculum developers. Teachers need to be equipped with the skills and knowledge to effectively integrate AI-powered simulations in their teaching practices. This requires ongoing professional development and training programs that focus on AI literacy, pedagogical innovation, and simulation design.

Entrepreneurs and industry partners can benefit from it by providing students with real-world experiences and projects that can help them develop practical skills. Industry partners can also provide input on the design and development of AI-powered simulations, ensuring that they are relevant and effective in preparing students for the workforce.

Curriculum developers in Africa need to incorporate the simulations into physics education curricula, ensuring that students are equipped with the skills and knowledge required to succeed in a rapidly changing world. This requires a review of existing curricula across Africa to ensure that they are aligned with the needs of industry and the demands of the 21st century.

**Benefits, Challenges and Limitations of AI Integration in Science Education:**

Whereas AI-powered tools can provide personalized learning experiences for students, enhance student engagement and motivation, and can improve their understanding of complex concepts, the tools need to be adaptable to different educational contexts. They need to be contextually relevant to meet the needs of African students and teachers and could raise ethical considerations that need to be addressed.

Overall, the integration of these tools in science teacher education has the potential to enhance student learning outcomes, engagement, and motivation. Thus, teachers need training and support to effectively integrate AI into their teaching practices.

## V. Conclusion

This study demonstrates the potential of AI-powered simulations to enhance physics teacher education in Nigerian Colleges of Education in particular and in general, science teachers across Africa. It points that the tools can provide students with hands-on experience with complex physics concepts, enabling them to develop a deeper understanding of the subject matter. Thus, the importance of integrating AI-powered simulations in teacher education programs, curriculum development, and policy-making is highlighted. In conclusion, the integration of Artificial Intelligence (AI) in science education is transforming the way physics is taught and learned. AI-powered tools have been shown to have the potential to enhance student engagement, motivation, and understanding of complex concepts.

## VI. Recommendations

1. Nigerian Colleges of Education and other institutions of higher learning across Africa offering Teacher education should integrate AI-powered simulations in their science education, particularly physics education programs.
2. Teachers across Africa should be provided with ongoing professional development and training programs to enhance their AI literacy and pedagogical innovation.
3. Curriculum developers in Kigali, Nigeria and other African countries should incorporate AI-powered simulations into physics education curricula.
4. Industry partners in Africa and from Advance countries of the world should provide input on the design and development of AI-powered simulations.
5. Further research should be conducted on the use of AI-powered simulations in various educational contexts.

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