CONCEPTUALIZING ARTIFICIAL INTELLIGENCE AS A CATALYST FOR INNOVATIVE PHYSICS PEDAGOGY: A CRITICAL EVALUATION

[1]**BABAJIDE, Veronica Folasade Titilayo, Ph.D**
vbabajide@unilag.edu.ng

[2]**OMOSULE, Sunday Olusegun**
awufungo@gmail.com

[3]**AKINLO, Olabode George**
georgeorizy4reala@yahoo.com

[1 & 2]University of Lagos, Lagos, Nigeria
[3]Robert Gordon University, Aberdeen, Scotland

Corresponding Author: *OMOSULE, Sunday O. (awufungo@gmail.com +2348037096637)*

Abstract

The integration of Artificial Intelligence (AI) into education has no doubts heralded transformative possibilities across disciplines, yet its potential in revolutionizing physics pedagogy remains underexplored. In an attempt to bridge the huge gap, this study critically evaluated the role of AI as a catalyst for innovative teaching and learning strategies in physics education. By way of conceptualizing AI (ChatGPT, and Meta AI), not merely as a tool, but as an epistemic agent, the research investigated how AI-driven technologies, such as intelligent tutoring systems, adaptive learning platforms, and generative models, can reframe instructional design, foster conceptual understanding, and personalize student engagement in physics classrooms. The study adopted a quantitative approach, employing survey method in critically evaluating the role of AI in transforming physics pedagogy, through the lens of teacher perceptions and systemic implications. With a sample size of 141, out of 639 physics teachers being randomly selected for the study, it provided answers to four research questions, and tested two hypotheses. Data collected were analyzed using descriptive and inferential statistics. Drawing theoretical frameworks from constructivist, and experiential learning theories, the study found that sampled teachers have a complex, and multifaceted perception of AI, but still recognize its potential for long-term impact, and transformative power in teaching physics. The paper concluded by proposing a strategic framework for ethically responsible and pedagogically sound AI adoption in physics education, aiming to enhance inquiry-based learning, promote scientific reasoning, and support diverse learner/teacher needs.

Keywords: Artificial Intelligence, Innovative Physics, Pedagogy

Introduction

The integration of Artificial Intelligence (AI) into educational frameworks has emerged as a transformative force, particularly within the realm of physics pedagogy. Its incorporation into teaching enterprise has revolutionized the way subjects are taught and learned, offering new opportunities for innovative pedagogy (Zawacki-Richter et al., 2019; ChunHong, Nan, Xiao YuTing, YuJia, & YuLe, 2025). Physics, as a fundamental science, requires effective teaching methods to help students grasp complex concepts and principles. Traditional physics instruction often contends with conveying abstract concepts and fostering deep comprehension among students, in that it often falls short in engaging learners and promoting profound encounter, thereby leading to misconceptions and lack of interest (Ellermeijer & Tran, 2019). AI technologies, encompassing tools such as intelligent tutoring systems, adaptive learning platforms, and interactive simulations, offer innovative avenues to address these challenges. Recent empirical studies underscore the efficacy of AI in enhancing physics education. For instance, a study by Henze et al. (2024) demonstrated that AI-supported data analysis tools not only improved student motivation but also alleviated stress associated with complex physics problems. Similarly, Rincon-Flores, Castano, Solis, Lopez, Hernández, Lara, and Valdés, 2024) noted that the development of AI-driven tutoring systems, like Physics-STAR, Khan Academy, have been instrumental in providing personalized learning experiences, thereby improving student outcomes in both conceptual understanding and problem-solving efficiency.

Furthermore, initiatives aimed at fostering AI literacy among pre-service physics teachers have been influential in equipping educators with the necessary skills to integrate AI tools effectively into their teaching practices. A notable example is a 2024 training module that combined asynchronous and synchronous learning methods to train future educators in utilizing AI for lesson planning and concept simplification (Rincon-Flores et al., 2024). However, despite these advancements, the implementation of AI in physics education is not without its challenges. For example, Adegoge and Chukwuneke, (2017) noted that issues such as data privacy concerns, algorithmic biases, and the potential erosion of critical thinking skills due to over-reliance on AI tools necessitate a balanced approach to integration. Moreover, there is a pressing need for comprehensive frameworks that guide the ethical and effective incorporation of AI into educational settings. This is because, as AI continues to transform education, it is essential to investigate its impact on student learning outcomes, teacher effectiveness, and the overall physics education landscape (Knight et al., 2018). This study, therefore, explored the potential of AI as a catalyst for innovative physics pedagogy, examining its benefits and challenges, and providing insights into the opportunities and limitations of leveraging AI to enhance physics teaching and learning, within the Nigerian context.

Statement of the Problem

The integration of Artificial Intelligence (AI) into physics pedagogy holds promise for transforming educational practices; however, its implementation faces several challenges. These include infrastructural disparities, such as limited access to technology and unreliable internet connectivity, which hinder equitable access to AI-driven learning tools, particularly in resource-constrained regions like sub-Saharan African countries like Nigeria, Ghana, Kenya, Ethiopia, and others. In addition to this, lack of comprehensive professional development for educators impedes its effective integration into physics curricula, highlighting the need for targeted training programs to equip sub-Saharan physics teachers with the necessary knowledge, skills, and competence.

Research Objectives

The objectives of the research are to:

i. Explore how physics teachers perceive the role of AI in enhancing their pedagogical practices?
ii. Examine the potential benefits and limitations of using AI in physics education?
iii. Determine the implications of AI-driven physics pedagogy for teacher’s professional development?
iv. Determine the potential long-term effects of AI integration on physics education landscape?

Research Questions

1. How do physics teachers perceive the role of AI in enhancing their pedagogical practices?
2. What are the potential benefits and limitations of using AI in physics education?
3. What are the implications of AI-driven physics pedagogy for teacher's professional development?
4. What are the potential long-term effects of AI integration on physics education landscape?

Research Hypotheses

H01: There is no significant difference between the perception of public school physics teachers on the use of artificial intelligence in education, and their counterparts in private schools

H02: There is no significant difference between the perception of teachers who had background in physics education, and their counterparts who digressed into teaching physics for reasons of unemployment on the use of artificial intelligence in education

Literature Review

Conceptualizing Artificial Intelligence in Physics Education

The integration of Artificial Intelligence (AI) in education has no doubts, sparked intense debate among scholars, policymakers, and educators across the globe. In physics education, AI can potentially revolutionize the way students learn and interact with complex concepts. According to Ding (2023), AI-powered adaptive learning systems can tailor instruction to individual students' needs, abilities, and learning styles, promoting more effective learning outcomes. In the same vein, Schunk and Greene (2018) highlight the significance of AI-driven feedback mechanisms in enhancing student motivation and engagement in physics classrooms, just as Jing (2023) explored the role of integrating artificial intelligence and virtual simulation technologies in physics teaching, and submitted that AI-assisted simulations and virtual labs can provide students with immersive and interactive learning experiences, fostering deeper understanding and retention of abstract physics concepts.

Several theoretical frameworks underpin the use of AI in physics education. Social Constructivist Theory (SCT) posits that students construct knowledge through social interactions and experiences (Vygotsky, 1978). AI-powered collaborative tools can facilitate peer-to-peer learning, enabling students to engage in meaningful discussions and share insights (Mahligawati, 2023). In addition to this, Experiential Learning Theory (ELT) emphasizes the role of direct experience and reflection in learning, which AI-facilitated simulations and virtual labs can provide (Kolb, 2014). While AI holds promise for physics education, concerns surrounding its implementation persist. Some scholars argue that over-reliance on AI might lead to diminished critical thinking and problem-solving skills among students (Yongxian, 2020). Moreover, issues of equity, bias, and data privacy in AI-powered educational systems require careful consideration (Krach, 2018). Bairaktarova et al. (2021) highlight the need for teacher training and support in effectively integrating AI-driven tools into physics classrooms. Furthermore, Liang et al. (23) emphasize the importance of contextualizing AI-infused physics education within broader sociocultural and pedagogical frameworks. The literature suggests that AI has the potential to catalyze innovative physics pedagogy, enhancing student engagement, motivation, and learning outcomes. However, critical evaluation of AI's role in physics education is necessary to address concerns surrounding its implementation. Through the process of synthesizing theoretical frameworks and empirical findings, this article aims to contribute to a nuanced understanding of AI's potential as a catalyst for innovative physics pedagogy.

Methodology

This study employed a quantitative research design for data collection and analysis to provide a comprehensive understanding of the role of artificial intelligence (AI) in innovative physics pedagogy. Online survey was carried out on 141 out of 639 physics educators with the use of structured questionnaire, to gather data on their experiences, perceptions, and attitudes towards AI-powered physics pedagogy. Items in the instrument were validated and tested with a reliability coefficient of .79 Cronbach's Alpha. In addition to this, tabular analysis of responses was carried out in order to gather more nuanced and quantitative insights into the benefits and challenges of AI-based physics education, while the data gathered was analyzed using descriptive and inferential statistics to identify significant trends and correlations.

Data Analysis

Table 4.1: ***Demographic Information / Characteristics of Participants***

School Type	Gender		Area of Qualification		Total Number	Percentage (%)
	M	F	Physics Education	Non-Physics Edu.		
Public	17	4	21 (100%)	None	21	14.89
	M	F	Physics Education	Non-Physics Edu.		
Private	102	18	4 (3.33%)	116 (96.67%)	120	85.11
	M	F	Physics Education	Non-Physics Edu.		
Total	119 84.40%	22 15.60%	25 (17.73%)	116 (82.27%)	141	**100** **101** %

The above table shows the demographic information of physics teachers, who participated in the study. As seen on the table, male teachers constitute 84.40%, while their female counterpart constitute 15.60%. This shows that in Ondo State, Nigerian secondary schools, there are more male teachers of physics than their female teachers. However, pathetic is the revelation that show only 25, which is approximately 17.73% of these teachers as holders of degrees in Physics education, while a whooping number of physics teachers constituted 82.27% (116 of 141) out of the sampled teachers. While 21 (14.89%) of the participants belong to public schools, and are all holders of degrees in physics education, the statistics shows that 120 of the participants, constituting 85.11% of the size, belong to the private sector. It is however, disheartening to find that out of the 120 participants from the private sector, only 4 (3.33%) are holders of degrees in the relevant field (physics education), while 116 (96.67%) of them are holders of certificates in physics-related subjects such as Mathematics, Geology, Engineering, and others.

Succinctly put, physics at the Nigerian private secondary school level is being taught, mostly by those who are neither professionally trained, nor academically qualified to do so, due to unemployment, and this would have negative consequences on the future of the Nigerian STEM education.

Research Question 1: Teacher's Perception of AI in Physics Teaching

Table 4.2: Table Showing Teacher's Perception of AI in Physics Teaching

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Perception	141	7.879	3.746	0.316

As seen in the table above (4.2) the calculated mean of 7.879 is significantly lower than the benchmark mean of 12.00 set for the items. This suggests that the physics teachers in the sample generally have a low perception of AI in physics teaching. This, by implications, indicates potential scepticism or lack of confidence in AI's role in enhancing teaching methods.

Research Question 2: Benefits and Limitations of AI in Physics Teaching

Table 4.3: Participants Distribution on Benefits and Limitations of AI in Physics

ITEMS	SA	A	D	SD
AI facilitates personalized learning experiences for physics students	40	36	32	33
Use of AI in physics teaching may lead to over-reliance on technology	39	48	28	26
AI enhances students' understanding of complex physics concepts	36	38	42	25
AI may not be suitable for all practical physics topics	56	41	23	21
The integration of AI in physics teaching is hindered by technical issues	76	39	15	11

The above table (4.3) shows participants distribution on benefits and limitations of A in physics teaching. As seen in the table, participants hold mixed reactions as per the benefits and limitations of using Artificial Intelligence in teaching physics in Ondo State. For instance, while quite a number of participants unanimously agreed that the integration of AI in physics teaching is hindered by technical issues like poor / fluctuating signals (network) and erratic power supply, there is mixed feelings as to whether the use of AI enhances students' understanding of complex physics concepts. In the same vein, participants significantly disagreed that AI can be suitable for all practical physics topics and learning styles. This means that, for these set of teachers, there is a wide gap between their competence in handling AI for physics teaching, and what is in vogue in the western world, where almost every topic in physics is capable of being taught seamlessly online (via AI).

Table 4.4 Research Question 3: Implications for Teacher Professional Development

ITEMS	SA	A	D	SD
AI will require teachers to develop new skills to effectively integrate technology into their practice	78	43	11	9
AI-powered tools can help teachers identify areas where they need professional development	37	49	30	25
Most teachers I know need training on how to effectively use AI-powered tools in their teaching physics	87	41	8	5
Relying on AI for professional development undermines the value of human mentorship	76	61	5	-
AI cannot fully replace the nuanced understanding that human trainers bring to teacher development	79	58	3	1

Table 4.4 shows the implications of adopting Artificial Intelligence for teacher's professional development. As seen on the table, item one of this section is in agreement with the participants' earlier perception on AI in physics teaching. They all agreed that engaging AI in physics teaching will require teachers to develop new skills to effectively integrate the technology into their practice. This is further reflected in their responses to the next item, where a significant number of them strongly agreed that most teachers they know need training on how to effectively use AI-powered tools in their physics teaching. By implication, all stakeholders would need to encourage teachers' professional development, so as to enhance effective transfer of physics learning among senior secondary school students in Ondo State.

Table 4.5 Research Question 4: Long-Term Effects of AI on Physics Teaching Landscape

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Long_Term_Effects	150	14.5133	4.15107	0.33893

The above table (4.5) show the long term effects of AI on physics teaching landscape. As seen in the table, the participants agreed that Artificial Intelligence has a long-term effect in shaping the education sector, though most of them lack the technical/technological know-how. This is seen as the mean score of participants (14.5133) is higher than the benchmark mean of 12.00 set for the items in the section. This means that though their perception is low due to their poor technological competence, however, seeing the trends of global education shift towards Artificial Intelligence, they agreed that AI has a long-term effect on physics teaching landscape.

$H0_1$: There is no significant difference between the perception of public school physics teachers on the use of artificial intelligence in education, and their counterparts in private schools

Table 5.1: Group Statistics on Perception of Participants Based on School Type

Group Statistics

SCHOOL_TYPE		N	Mean	Std. Deviation	Std. Error Mean
Perception	Public	21	7.5238	4.17874	0.91188
	Private	120	7.9417	3.68119	0.33605

Table 5.2: Independent Samples Test on Perception against School Type

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Perception	Equal variances assumed	0.69	0.41	-0.47	139.00	0.64	-0.42	0.89	-2.17	1.34
	Equal variances not assumed			-0.43	25.72	0.67	-0.42	0.97	-2.42	1.58

As seen in table 5.1 above, there is no significant difference between the perception of public school physics teachers on the use of artificial intelligence in education, and their counterparts

in private schools. The table shows that in spite the huge difference in the number of participants in the public schools (21) against those in the private sector (120), their mean score is approximately 8.00 to one significant figure.
Furtherance to this is table 5.2, which shows their mean difference is -0.42, just as the p-value (0.41) is greater than 0.05 level of significance. In that wise, the hypothesis stating that there is no significant difference between the perception of public school physics teachers on the use of artificial intelligence in education, and their counterparts in private schools, is hereby accepted.

$H0_2$: There is no significant difference between the perception of teachers who had background in physics education, and their counterparts who digressed into teaching physics for reasons of unemployment on the use of artificial intelligence in education

Table 6.1: Group Statistics on Perception of Participants Based on Area of Expertise

Group Statistics

Area_of_Expertise		N	Mean	Std. Deviation	Std. Error Mean
Perception	Physics Education	26	13.6923	4.27803	0.83899
	Non-Physics Education	115	6.5652	1.94273	0.18116

Table 6.2: Independent Samples Test of Participants Based on Area of Expertise

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Perception	Equal variances assumed	55.37	0.00	12.99	139.00	0.00	7.13	0.55	6.04	8.21
	Equal variances not assumed			8.30	27.37	0.00	7.13	0.86	5.37	8.89

As seen in table 6.1 above, there is significant difference between the perception of physics education teachers on the use of artificial intelligence in education, and that of their counterparts who are not certified in physics education, but found themselves teaching in Ondo Secondary schools. The table shows that in spite the huge difference in the number of participants who studied physics education (26) against those who did not study physics education (115), the difference in their mean score is 7.1271, with participants who studied physics education as having a mean of 13.6923 against those who did not study physics education as having 6.5652.

Furtherance to this is table 6.2, shows that the p-value is less than 0.05 level of significance. In that wise, the hypothesis stating that there is no significant difference between the perception of teachers who had background in physics education, and their counterparts who digressed into teaching physics for reasons of unemployment on the use of artificial intelligence in education, is hereby rejected, as the results given in the above tables show that there is significant difference between their perception of AI in teaching physics.

Discussion of Findings

The results of Hypothesis One indicated no significant difference between public and private school physics teachers' perceptions of using AI in education. This finding suggested that both public and private school teachers shared similar views on the potential benefits and challenges of integrating AI into physics pedagogy. Several factors could contribute to this similarity such as uniformity in educational goals, exposure to AI technologies, and professional development.

In contrast, the results of Hypothesis Two revealed a significant difference in perceptions between teachers with a background in physics education and those who got into the field due to unemployment or other reasons. Teachers with a specialized background in physics education tend to view AI as a valuable tool for enhancing pedagogy, whereas those without a direct background in physics education are less likely to see its potential benefits. This difference could be attributed to several influences as:

Specialized Knowledge: Teachers with a physics education background may better understand how AI can be leveraged to teach complex physics concepts, making them more receptive to its use.

Pedagogical Training: These teachers are likely to have received training in effective teaching methods specific to physics, allowing them to see how AI can support these methods.

Appreciation for Innovative Tools: Teachers who chose physics education as their primary field might be more open to innovative teaching tools, including AI, and recognize their potential to improve student outcomes, compared to those who got into the teaching profession without any passion and professional qualification.

The findings suggest that while school type (public vs. private) does not influence teachers' perceptions of AI in education, a teacher's background and specialization in physics education do play a crucial role. This highlights the need for targeted professional development programs that focus on AI literacy and its application in physics teaching, particularly for teachers who did not start their careers with a focus on physics education.

Conclusion

This critical evaluation highlights the potential of artificial intelligence as a catalyst for innovative physics pedagogy. Generally, the study found that teachers' perception about the role of AI in enhancing their pedagogical practices, is generally low. On a similar note, the study found that physics teachers hold mixed reactions as per the benefits and limitations of using Artificial Intelligence in teaching physics in Ondo State. This means that, for these set of teachers, there is a wide gap between their competence in handling AI for physics teaching, and what is in vogue in the western world, where almost every topic in physics is capable of being taught seamlessly online (via AI tools).

However, participants generally agreed that Artificial Intelligence has a long-term effect in shaping the education sector, though most of them lack the technical/technological know-how. By leveraging AI-powered tools, it is expected that physics educators would be able to create immersive, personalized, and data-driven learning experiences that can enhance student engagement and understanding in physics

Recommendations

Based on the conclusion drawn from the study, the following recommendations were made:

i. Physics educators should adjust and blend learning facilitation with AI-technology in their instruction, so as to stimulate student interest, and meet the 21st century goals in Ondo State, Nigeria.
ii. All stakeholders in Ondo State should endeavour to foster AI-literacy among physics educators, by providing them with trainings and resources to effectively integrate AI-powered tools into physics pedagogy
iii. Encourage interdisciplinary collaboration among physics educators, AI researchers, and industry experts, so as to develop innovative AI-powered solutions

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