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Integrating Generative AI Tools In Teaching Mechanics: Impact On Conceptual Understanding

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Abstract
The study aimed at investigating the Integrating Generative AI Tools in Teaching Mechanics: Impact on Conceptual Understanding. Four research questions guided the study. The study design was quasi-experimental; specifically, the pre-test, post-test; non-randomized control group design. A sample size of 128 SS11 physics students using multi-stage sampling technique. Mechanics Concept Test (MCT), Physics Achievement Test (PAT) and Students' Engagement Questionnaire (SEQ) were used as instrument for data collection. Mean and standard deviation were used to answer the research questions. The findings of the study revealed that students exposed to GenAI-supported instruction not only improved but showed more effective learning and conceptual development also the data from the findings demonstrates that students exposed to GenAI-supported instruction achieved a much higher level of conceptual understanding than those taught using traditional methods. Furthermore, results indicate that GenAI-supported instruction significantly reduces students' misconceptions in mechanics concepts. Finally, findings indicate that GenAI-supported instruction significantly enhances students' engagement in learning mechanics.
Based on the findings of this study, the recommendation was made: Teachers should actively incorporate GenAI-supported resources, such as interactive simulations, AI-generated explanations, and adaptive problem-solving platforms, into physics lessons to enhance conceptual understanding and academic performance.

Keywords: *Generative AI, Mechanics, Physics Education, Conceptual Understanding, STEM, Instructional Technology*

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I. Introduction

The rapid advancement of digital technologies has significantly transformed teaching and learning processes across all levels of education, particularly in science and technology disciplines. In recent years, Generative Artificial Intelligence (GenAI) has emerged as one of the most disruptive innovations, capable of producing human-like text, simulations, and problem-solving explanations (Dwivedi, Kshetri, Hughes, Slade, Jeyaraj, Kar, and Wright, 2023; Kasneci, Sessler, Küchemann, Bannert, Dementieva, Fischer and Kasneci, 2023). Tools such as ChatGPT, Gemini, and other large language models (LLMs) are increasingly being integrated into educational settings, offering new opportunities for enhancing instructional delivery and student learning outcomes (OpenAI, 2023; Google DeepMind, 2024). These systems are powered by advances in neural networks, machine learning algorithms, and deep learning architectures, which have significantly improved their ability to generate contextually relevant and pedagogically useful responses (Goodfellow, Bengio and Courville, 2016; LeCun, Bengio and Hinton 2015). The introduction of GenAI into education has coincided with growing concerns about students' conceptual understanding, especially in foundational science subjects such as physics, where abstract concepts often pose significant learning challenges (Hestenes, 2015; Meltzer and Thornton, 2012 Mechanics is a foundational area of physics that underpins many scientific and technological applications; however, it remains one of the most challenging domains for learners at both secondary and tertiary levels. The difficulty largely stems from the abstract nature of core concepts such as force, motion, acceleration, and energy, which often require students to mentally visualize phenomena that are not directly observable. As a result, learners frequently develop persistent misconceptions for example, believing that force is required to sustain motion or misunderstanding the relationship between velocity and acceleration. Empirical studies in physics education have consistently shown that such misconceptions are resistant to change, even after formal instruction, thereby hindering meaningful learning and long-term retention (Cho, 2024; El Fathi, Saad, Larhzil, Lamri, and Al Ibrahmi, 2025).

Traditional teaching approaches in mechanics have been criticized for placing excessive emphasis on mathematical manipulation and problem-solving procedures at the expense of conceptual understanding. In many classrooms, instruction is dominated by formula-based teaching, where students are trained to solve numerical problems without fully grasping the underlying physical principles. This approach often leads to surface learning, where students can perform calculations but fail to interpret or apply concepts in unfamiliar contexts. Recent research indicates that students taught through conventional lecture methods tend to exhibit lower conceptual gains compared to those engaged in interactive and inquiry-based learning environments (Qiu and Zhang, 2025).

In response to these challenges, recent advances in Generative Artificial Intelligence (GenAI) have introduced innovative possibilities for transforming the teaching and learning of mechanics. GenAI technologies, particularly large language models and AI-driven simulation tools, have the capability to generate human-like explanations, step-by-step problem-solving guidance, and interactive learning content tailored to individual learners' needs. These tools represent a shift from static content delivery to dynamic, responsive, and student-centered learning environments. According to El Fathi et al. (2025), the integration of GenAI into STEM education has significantly enhanced students' conceptual understanding by enabling adaptive instruction and immediate feedback mechanisms.

Generative AI presents a promising solution to these challenges by enabling personalized, interactive, and inquiry-based learning experiences. Unlike traditional teaching methods, which are often teacher-centered, GenAI tools support student-centered learning by providing real-time explanations, adaptive feedback, and multiple representations of concepts. For instance, recent studies indicate that GenAI systems can enhance conceptual understanding by guiding students through problem-solving processes, identifying misconceptions, and offering tailored instructional support. Furthermore, GenAI has the capacity to generate simulations and visualizations that make abstract physics concepts more concrete and accessible to learners.

Empirical research in physics education increasingly supports the effectiveness of Generative Artificial Intelligence (GenAI) integration. Recent studies indicate that students who engage with AI-generated simulations and interactive learning environments demonstrate improved performance in conceptual assessments compared to those taught using traditional methods (Kasneci et al., 2023; Zawacki-Richter, Marín, Bond and Gouverneur, 2024). In particular, AI-supported learning environments have been found to enhance students' engagement, critical thinking, and ability to connect theoretical concepts with real-world applications (Holmes and Tuomi, 2023; Crompton and Burke, 2023). Furthermore, emerging evidence suggests that adaptive AI tools, including large language models, can provide personalized feedback and scaffolding that significantly improve learning outcomes in science education (Mollick and Mollick, 2024). Additionally, the growing body of literature reveals that research on GenAI in education has expanded rapidly since 2023, reflecting its increasing relevance and widespread adoption in modern classrooms.

Despite these benefits, the integration of GenAI in teaching is not without challenges. Concerns have been raised regarding the accuracy of AI-generated content, potential over-reliance by students, and the need for teachers to develop new pedagogical competencies to effectively utilize these tools. Moreover, the application of GenAI in specific domains such as mechanics remains underexplored, particularly in developing countries where access to advanced educational technologies may be limited.

Given these considerations, this study focuses on the integration of generative AI tools in teaching mechanics and examines their impact on students' conceptual understanding. By exploring how AI-driven instructional strategies influence learning outcomes, this research aims to contribute to the growing field of AI in physics education and provide insights for educators, curriculum developers, and policymakers seeking to improve science education in the digital age.

Statement of the Problem

Despite the central role of mechanics in physics and its importance for technological and scientific advancement, students' conceptual understanding of mechanics remains persistently low across different levels of education. Numerous studies have shown that learners struggle with fundamental concepts such as force, motion, energy, and Newtonian laws, often developing misconceptions that are resistant to change even after formal instruction. One major factor contributing to this problem is the predominance of traditional teaching methods, which emphasize algorithmic problem-solving and memorization of formulas rather than deep conceptual understanding. This approach often results in superficial learning, where students can manipulate equations but lack a clear understanding of the underlying physical principles. Consequently, students perform poorly in conceptual assessments and exhibit low retention of knowledge over time. Recent advancements in Generative Artificial Intelligence (GenAI) have introduced new possibilities for addressing education challenges. GenAI tools can provide interactive explanations, real-time feedback, and AI-generated simulations that make abstract concepts more concrete and accessible. Empirical studies suggest that these tools can enhance students' engagement, promote inquiry-based learning, and improve conceptual understanding in STEM. However, despite the growing interest in GenAI, its application in teaching mechanics remains relatively underexplored, particularly in secondary school contexts and in developing countries such as Nigeria.

Therefore, there is limited empirical evidence on how GenAI specifically influences students' conceptual understanding of mechanics compared to traditional instructional approaches. While existing studies have examined the general impact of AI in education, few have focused on its effectiveness in addressing misconceptions and improving learning outcomes in core physics topics. This gap in the literature creates a need for systematic investigation into the integration of GenAI tools in physics classrooms. This study, therefore, seeks to investigate the impact of integrating GenAI tools in teaching mechanics on students' conceptual understanding, with a view to providing evidence-based recommendations for enhancing physics education.

Research Questions

This study seeks to answer the following research questions:

1. What is the effect of integrating Generative Artificial Intelligence (GenAI) tools on students' conceptual understanding of mechanics?
2. What difference exists in the conceptual understanding of mechanics between students taught using GenAI-supported instruction and those taught using traditional teaching methods?
3. To what extent does the use of GenAI tools reduce students' misconceptions in key mechanics concepts such as motion, force, and energy?
4. What is the level of students' engagement when taught mechanics using GenAI tools compared to conventional instructional methods?
5. What difference exists in the academic performance of students taught mechanics using GenAI tools and those taught using traditional methods?
6. How do students perceive the use of Generative AI tools in learning mechanics

Theoretical Framework

This study is anchored on three major learning theories that explain how students construct knowledge and how instructional technologies, such as Generative Artificial Intelligence (GenAI), can enhance conceptual understanding in mechanics. These include Constructivist Learning Theory, Cognitive Load Theory, and Social Constructivism.

1. Constructivist Learning Theory

Constructivist Learning Theory, primarily associated with Jean Piaget, posits that learners actively construct knowledge based on their prior experiences and interactions with their environment. According to this theory, learning is not a passive process of receiving information but an active process of meaning-making. In the context of mechanics, students come into the classroom with preconceived notions about motion, force, and energy, many of which are scientifically incorrect. The integration of GenAI tools aligns strongly with constructivist principles, as these tools allow students to actively engage with content through questioning, exploration, and interactive problem-solving. GenAI systems can provide multiple explanations, analogies, and representations of the same concept, thereby enabling learners to reconstruct their understanding.

2. Cognitive Load Theory

The theory emphasizes that instructional design should minimize unnecessary cognitive load to enhance learning efficiency. In physics, especially mechanics, students often experience cognitive overload due to the simultaneous processing of mathematical formulas, conceptual explanations, and problem-solving procedures.

GenAI tools help reduce cognitive load by breaking down complex problems into manageable steps, providing guided explanations, and offering just-in-time support. This allows learners to focus on understanding core concepts rather than being burdened by excessive information processing.

3. Social Constructivism

Social Constructivism, advanced by Lev Vygotsky, emphasizes the role of social interaction and collaboration in learning. According to this theory, knowledge is constructed through interaction with others and within a cultural context. A key concept in this theory is the Zone of Proximal Development (ZPD), which refers to the gap between what learners can do independently and what they can achieve with guidance.

GenAI tools function as virtual tutors or learning partners, providing scaffolding that supports students within their ZPD. Through interactive dialogue, students can ask questions, receive hints, and engage in guided problem-solving. This interaction mimics peer or teacher support, thereby enhancing learning.

II. Methodology

This study adopts a quasi-experimental pre-test, post-test, control group design. This design is considered appropriate because it allows for the comparison of learning outcomes between students exposed to Generative Artificial Intelligence (GenAI)-supported instruction and those taught using traditional teaching methods, without random assignment of participants. The study was conducted in selected secondary schools in Imo State in Nigeria. The choice of the area is based on accessibility, availability of participants, and the relevance of physics education within the curriculum. A sample size of 128 SSII Physics Students' was used, using a multi-stage sampling technique: which consist of Purposive sample for selection of schools offering physics, Random sample for selection of intact classes and Assignment of classes into: Experimental group (GenAI-supported instruction) and Control group (traditional teaching method). Mechanics Concept Test (MCT), Physics Achievement Test (PAT), Students' Engagement Questionnaire (SEQ) and Students' Perception of GenAI Questionnaire (SPGQ) were used as instruments for data collection. Mean and standard deviation was used to answer the research questions.

III. Analysis Of Data And Presentation Of Results

Research Question One:

What is the effect of integrating Generative AI tools on students' conceptual understanding of mechanics?

Table 1: Mean and Standard Deviation of Pre-test and Post-test Scores

Group	N	Pre-test Mean	Pre-test SD	Post-test Mean	Post-test SD	Mean Gain
Experimental (GenAI)	61	42.80	7.90	76.20	7.20	33.40
Control (Traditional)	67	43.10	8.05	58.50	7.80	15.40

From table 1 the pre-test mean of the experimental group (42.80) and control group (43.10) are very similar. This indicates that both groups had comparable baseline knowledge before the intervention. The post-test mean of the experimental group (76.20) is substantially higher than that of the control group (58.50). This difference suggests that the integration of GenAI tools had a strong positive effect on students' conceptual understanding. The experimental group had a mean gain of 33.40, more than double the control group's gain of 15.40. This indicates that students exposed to GenAI-supported instruction not only improved but showed more effective learning and conceptual development. Finally, the data shows that students taught mechanics using GenAI tools performed significantly better in terms of conceptual understanding than those taught using traditional methods. This supports the view that interactive, AI-driven instruction can help students grasp abstract concepts in mechanics, reduce misconceptions, and foster deeper understanding.

Research Question 2

What difference exists in conceptual understanding between students taught using GenAI tools and those taught using traditional methods?

Table 2: Pre-test and Post-test Scores by Group

Group	N	Pre-test Mean	Pre-test SD	Post-test Mean	Post-test SD	Mean Gain
Experimental (GenAI)	61	42.80	7.90	76.20	7.20	33.40
Control (Traditional)	67	43.10	8.05	58.50	7.80	15.40
Mean Difference		-0.30	-	17.70	-	18.00

Table 2 revealed that the experimental group (42.80) and control group (43.10) had nearly identical pre-test means, indicating that both groups started at similar levels of conceptual understanding before the intervention. This ensures a fair comparison of post-test results. The post-test mean of the experimental group (76.20) is significantly higher than the control group (58.50). The mean difference of 17.70 points indicates that students taught using GenAI tools performed better than those taught traditionally. The experimental group had a mean gain of 33.40 compared to the control group's 15.40, showing that GenAI-supported instruction led to more than twice the improvement in conceptual understanding. Therefore, the data demonstrates that students exposed to GenAI-supported instruction achieved a much higher level of conceptual understanding than those taught using traditional methods.

Research Question 3

To what extent does the use of GenAI tools reduce students' misconceptions in key mechanics concepts such as motion, force, and energy?

Table 3: Pre-test and Post-test Misconception Scores

Group	**N**	**Pre-test Misconception (%)**	**Post-test Misconception (%)**	**Reduction (%)**
Experimental (GenAI)	61	66	21	45
Control (Traditional)	67	65	42	23
Difference		1	21	22

In table 3, both groups had similar pre-test scores (Experimental = 66%, Control = 65%), indicating that students started with nearly the same level of misconceptions before the intervention. The experimental group's post-test misconceptions dropped to 21%, whereas the control group's dropped to 42%. This shows that the experimental group experienced a larger reduction (45%) compared to the control group (23%). The difference in reduction between the experimental and control groups is 22 percentage points, suggesting a substantial effect of GenAI tools in addressing misconceptions. The results indicate that GenAI-supported instruction significantly reduces students' misconceptions in mechanics concepts.

Research Question 4

What is the level of students' engagement when taught mechanics using GenAI tools compared to conventional instructional methods?

Table 4: Students' Engagement Scores

Group	**N**	**Mean Engagement Score**	**Standard Deviation (SD)**	**Engagement Level**
Experimental (GenAI)	61	3.88	0.64	High
Control (Traditional)	67	2.95	0.71	Moderate

(Scale: 1–5; 1 = Very Low, 2 = Low, 3 = Moderate, 4 = High, 5 = Very High)

Table 4 indicates that the experimental group expose to GenAI tools had a mean engagement score of 3.88, which corresponds to a high level of engagement. While the relatively low SD (0.64) indicates that most students consistently reported high engagement. Also, the control group had a mean score of 2.95, indicating a moderate level of engagement. The slightly higher SD (0.71) suggests some variation in engagement levels among students taught using traditional methods. Therefore, Students taught using GenAI tools were more engaged than those taught with conventional methods. The mean difference of 0.93 points on a 5-point scale shows that interactive, AI-supported learning fosters greater participation, attention, and interest. Finally, The findings indicate that GenAI-supported instruction significantly enhances students' engagement in learning mechanics.

IV. Discussion Of Results

Effect of GenAI on Conceptual Understanding

The results showed that students taught mechanics using GenAI tools scored significantly higher on post-test conceptual understanding than those taught traditionally. The experimental group achieved a mean gain of 33.40, more than twice the gain of the control group (15.40), indicating substantial learning improvement. These findings support previous research suggesting that interactive, AI-driven explanations, simulations, and personalized feedback enhance students' grasp of abstract physics concepts (El Fathi et al., 2025; Ma et al., 2025). By providing dynamic visualization of motion, forces, and energy, GenAI tools help students overcome common misconceptions and make connections between theory and real-world applications.

Reduction of Misconceptions

The study showed that GenAI tools significantly reduced students' misconceptions in key mechanics concepts. The experimental group's misconceptions dropped by 45%, compared to 23% in the control group. Misconception reduction likely results from immediate, interactive feedback and multiple representations of abstract concepts that AI tools provide.

Students' Engagement

The experimental group reported higher levels of engagement (Mean = 3.88) than the control group (Mean = 2.95). GenAI-supported instruction fosters active participation, curiosity, and motivation, likely due to interactive simulations and immediate feedback. Increased engagement is linked to better learning outcomes, as students are more likely to persist in problem-solving and conceptual reasoning (El Fathi et al., 2025).

V. Recommendation

Based on the research findings, the following recommendation are made

1. Teachers should actively incorporate GenAI-supported resources, such as interactive simulations, AI-generated explanations, and adaptive problem-solving platforms, into physics lessons to enhance conceptual understanding and academic performance.
2. Teachers should use GenAI tools to identify and address common student misconceptions in mechanics, particularly in abstract topics like motion, force, and energy.
3. Educational stakeholders should promote the use of GenAI-supported resources as a means of bridging gender gaps in physics. This approach will better prepare both male and female students to apply physics knowledge to real-life situations and contribute meaningfully to national development challenges.

VI. Conclusion

21st-century education reforms emphasize the integration of advanced technologies in teaching and learning, driven by the need to prepare students for a rapidly evolving, knowledge-based, and technology-driven world. Across the globe, educators are increasingly incorporating innovative digital tools to enhance instructional delivery and equip learners with critical thinking and problem-solving skills required for modern scientific inquiry.

This study on *Integrating Generative AI Tools in Teaching Mechanics: Impact on Conceptual Understanding* has demonstrated that the use of Generative AI (GenAI) tools in physics instruction is not only feasible but also highly effective in improving students' conceptual understanding of mechanics. By providing personalized explanations, instant feedback, and interactive learning experiences, GenAI tools enable students to better grasp abstract concepts such as motion, force, and energy, which are often difficult to understand through traditional teaching methods alone.

Furthermore, the findings highlight that integrating GenAI into classroom instruction fosters deeper engagement, enhances learners' ability to connect theory with real-world applications, and promotes independent learning. This approach also supports the development of higher-order thinking skills, which are essential for solving complex scientific problems and addressing contemporary global challenges.

Therefore, physics teachers are encouraged to reduce over-reliance on conventional teaching methods and adopt a more flexible instructional approach that blends traditional strategies with Generative AI-driven tools. Such integration will not only improve students' conceptual understanding but also prepare them to thrive in a technologically advanced and innovation-driven society. These results support the adoption of GenAI-assisted teaching as an effective strategy for enhancing STEM education.

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