AI-Powered Tutoring for Conceptual Clarity in Energy and Momentum among Sarawak Matriculation College Physics Students

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ABSTRACT

This study addresses persistent conceptual difficulties in energy and momentum among Malaysian Matriculation Physics students, specifically targeting identified misconceptions. An action research methodology was employed with 30 students, integrating AI dialogue-based tutoring tools (ChatGPT, Gemini, DeepSeek). The intervention, structured in two instructional cycles, involved Socratic questioning and ICAP framework application training to foster conceptual distinguishing. AI tools offered immediate, personalized, less intimidating feedback, boosting engagement via mobile devices and collaborative learning. Post-intervention, average test scores significantly improved from 46.67% to 70.76% (normalized gain: 42.94%; Cohen's d:Student perceptions were highly positive (>4.50 on 5-point Likert), particularly for misconception correction (4.77) and explanation clarity (4.70). These findings demonstrate AI's strong potential to resolve core misconceptions and enhance conceptual understanding in physics education..

Keywords : Conceptual Understanding, AI Tutoring, Energy and Momentum, Physics Education, Student Misconceptions

1.0 INTRODUCTION

Research Background

This study investigates persistent conceptual difficulties in energy and momentum within the Malaysian Matriculation Physics curriculum. Research consistently highlights that physics education often faces significant challenges in developing robust conceptual understanding among students (McDermott, 1991). These difficulties are particularly pronounced in foundational topics such as energy and momentum, where learners frequently develop persistent misconceptions that impede their ability to accurately analyze physical systems (Bagno, 1997; Brundage, 2023). For instance, initial diagnostic data and classroom observations confirm widespread student misconceptions; learners often misinterpret energy as being "consumed" rather than merely transformed, and they commonly conflate momentum with mass or force. Such deeply ingrained alternative conceptions are known to resist traditional instructional methods, necessitating innovative pedagogical approaches (Hestenes, 1997).

The focus of this study on energy and momentum was selected based on three key criteria: their importance as foundational, examinable concepts critical for advanced physics understanding; the feasibility of aligning their instruction with syllabus timing and the current capabilities of AI tools like ChatGPT, Gemini, and DeepSeek; and their confirmed relevance as pervasive learning challenges through pre-intervention assessments. The potential of artificial intelligence (AI) in education, particularly through dialogue-based tutoring systems, has shown promise in providing personalized, interactive learning experiences that can address individual student needs and misconceptions (Woolf, 2013; Nwana, 1990). By targeting these specific conceptual gaps, the study aims to examine how AI-based dialogue can effectively address both learning misconceptions and pedagogical constraints inherent in large classroom settings, while remaining focused and scalable for broader implementation.

Researcher's Experience

As a physics educator within the Malaysian Matriculation Programme, I have observed firsthand the pervasive conceptual difficulties students encounter when learning energy and momentum. Through years of teaching these topics, I have consistently noted common patterns in student errors, often stemming from deeply rooted misconceptions rather than mere computational mistakes. My experience includes analysing diagnostic assessments and engaging in extensive classroom observations, which have revealed, for example, students' struggle to differentiate between the transformation and consumption of energy or their tendency to equate momentum solely with mass or force. These recurring challenges in fundamental physics concepts have directly informed my decision to focus this study on these specific areas, seeking innovative ways to foster a more robust conceptual understanding. This is further discussed in section 2.

Research Purpose and Importance

This research addresses persistent conceptual difficulties in energy and momentum within the Malaysian Matriculation Physics curriculum, as these foundational concepts pose significant challenges for students when taught via traditional methods, impacting their understanding, performance, and motivation. Students frequently misinterpret energy as being "consumed" and conflate momentum with mass or force, leading to impaired analysis of physical systems, lower assessment scores, and a potential loss of interest in physics. The importance of this study lies in its aim to develop and examine the effectiveness of AI-based dialogue tutoring to address these specific conceptual gaps, ultimately enhancing student motivation and engagement in learning energy and momentum, and fostering a deeper conceptual understanding of the subject (Chi, 2014).

Researcher's Assumptions, Values, and Beliefs Regarding Teaching and Learning (PdP)

I believe that the integration of AI tools such as ChatGPT, Gemini, and DeepSeek into physics instruction can significantly address misconceptions in energy and momentum concepts. My approach is guided by Kemmis and McTaggart's action research model (Altrichter, 2002), where initial diagnostic assessments are used to identify key conceptual gaps that then inform the design of AI-enhanced activities. It is a core value of mine that students can be empowered through training; therefore, I trained students in question formulation using Socratic questioning techniques (Paul, 2007) and in evaluating responses using the ICAP framework (Chi, 2014), enabling them to distinguish between factual and mechanistic explanations (Tanner, 2005). I hold the belief that AI tools, with their immediate and personalized feedback capabilities, can be less intimidating than teacher queries, thereby increasing student engagement. The implementation of this study, which only requires mobile devices, reinforces my belief that a dialogue-rich and AI-supported learning environment can be created accessibly and collaboratively to foster deeper conceptual development.

2.0 REFLECTION ON PAST TEACHING PRACTICES

Teaching Physics at the Malaysian Matriculation level has revealed persistent conceptual difficulties in energy and momentum. Despite thorough coverage through lectures and tutorials, students maintained fundamental misconceptions - confusing momentum with mass or viewing energy as being "used up". Diagnostic data showed only 45.56% understood momentum conservation in collisions and 42.78% grasped energy transformation, while student reflections revealed struggles connecting equations to phenomena.

This highlighted the need for scalable, dialogic support. AI tools like ChatGPT offer Socratic tutoring and real-time feedback, extending rather than replacing teaching Student journals revealed additional challenges:

"I memorized formulas but couldn't explain why phenomena occur"
"I understand until I try to explain"
"Peer discussions help but I fear wrong answers"

These reflections underscore the need for low-stakes conceptual exploration. While AI cannot replace teachers, it provides scalable, responsive support to address persistent misconceptions.

Early Diagnostic Data

Below is an outline of early diagnostic data collected before the intervention, which supports the need for change:

Table 1. Pre-test Results

Conceptual Area	Correct Response Rate	Common Misconceptions
Energy concepts	41.39%	Energy is always conserved, even when nonconservative forces like friction are present.
Work done by gravitational force	48.89%	The work done by gravity depends on the path taken.
Work done by nonconservative forces	47.22%	No work is done by friction if the object returns to its starting point.
Conservation of mechanical energy and related issues	42.78%	Mechanical energy is conserved in all situations, regardless of external forces like friction or air drag.
Momentum concepts	33.33%	Momentum is only conserved when objects have the same mass or speed.
Identifying conservation of momentum	56.67%	Momentum is not conserved unless the objects collide head-on or have equal mass.
Momentum conservation in inelastic collisions and explosions	45.56%	Kinetic energy is conserved in inelastic collisions.
Impulse-momentum theorem	53.33%	A greater force always leads to a greater momentum change, regardless of how long it acts.

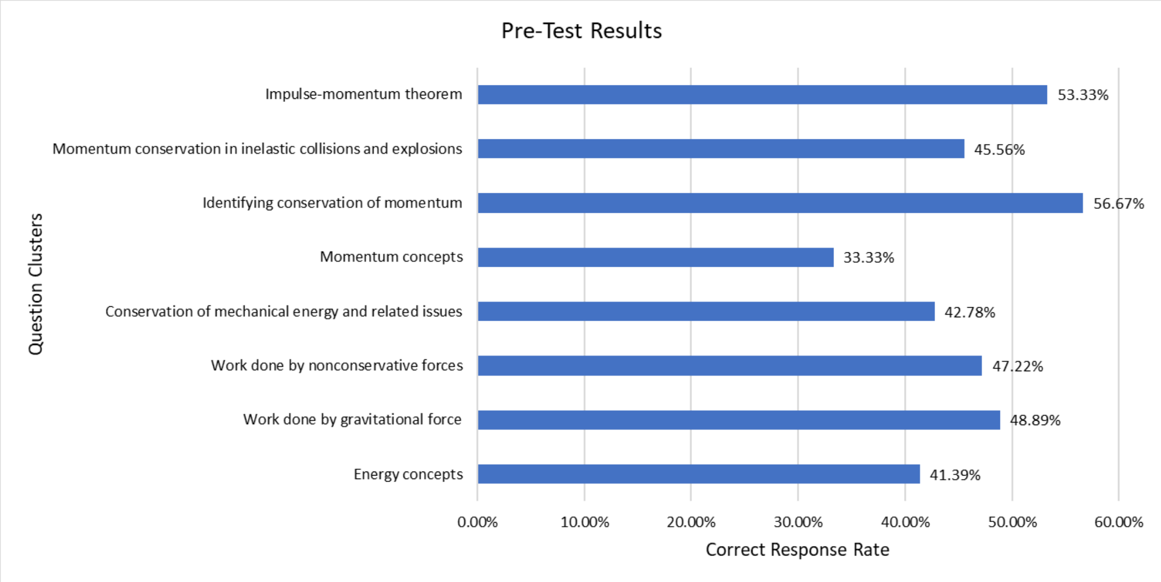

Figure 1: Pretest Results

These data further confirmed the importance of addressing students' underlying reasoning processes, not just their ability to recall formulas.

3.0 RESEARCH FOCUS/ AREA OF CONCERN

This study investigates persistent conceptual difficulties in energy and momentum within the Malaysian Matriculation Physics curriculum, where diagnostic data and classroom observations reveal widespread student misconceptions. Learners frequently misinterpret energy as being "consumed" rather than transformed and conflate momentum with mass or force, impairing their ability to analyse physical systems. The focus was selected based on three criteria: importance (as foundational examinable concepts), feasibility (aligning with syllabus timing and AI tool implementation via ChatGPT/Gemini/DeepSeek), and relevance (confirmed by pre-intervention assessments showing these as pervasive challenges). By targeting these specific conceptual gaps, the study examines how AI-based dialogue can effectively address both learning misconceptions and pedagogical constraints while remaining focused and scalable.

4.0 RESEARCH OBJECTIVES

The primary objective of this study is to improve students' conceptual understanding of energy and momentum in the Malaysian Matriculation Physics curriculum through the integration of AI dialogue-based tutoring tools, specifically ChatGPT, Gemini and DeepSeek. This objective is grounded in the earlier identification of widespread misconceptions in these topics, as revealed through diagnostic assessments and student feedback.

To achieve this, the study aims to pursue two specific objectives:

1. **To quantitatively assess the pedagogical efficacy of AI dialogue-based tutoring systems.**

2. **To systematically investigate learner experiences with AI-mediated conceptual tutoring**

These objectives are realistic and measurable within the scope of the study. Conceptual gains was evaluated using the Energy and Momentum Conceptual Survey (ECMS) while the learner's experiences with AI-mediated conceptual tutoring was explore using questionnaire of based on Likert scale.

5.0 TARGET GROUP

This study's target population comprises 30 students enrolled in the 2024/2025 Malaysian Matriculation Programme (Two-Semester System) at Sarawak Matriculation College, specifically those undertaking Physics as a core subject. Participants were selected from two tutorial groups under my direct supervision to ensure pedagogical consistency and uniform access to AI tools throughout the research period. This selection was primarily based on early diagnostic data identifying persistent misconceptions in energy and momentum, and included students who achieved at least a Grade B in Physics in their SPM examination, indicating a foundational understanding yet substantial room for conceptual enhancement. The group exhibits typical Malaysian matriculation demographic diversity, encompassing both male and female students from varied ethnic backgrounds. While their overall science performance is heterogeneous, they share a common academic challenge in mastering abstract physics concepts requiring conceptual reasoning beyond rote memorization, rendering them a representative and appropriate cohort for investigating AI-supported interventions aimed at improving conceptual understanding.

6.0 ACTION IMPLEMENTATION

This study integrated ChatGPT, Gemini, and DeepSeek into physics instruction to address energy and momentum misconceptions, following Kemmis and McTaggart's action research model (Altrichter, 2002). Diagnostic assessments first identified key conceptual gaps, informing the design of AI-enhanced activities. Students received training in question formulation using Socratic questioning techniques (Paul, 2007) and response evaluation using the ICAP framework (Chi, 2014) , learning to distinguish factual from mechanistic explanations (Tanner, 2005).

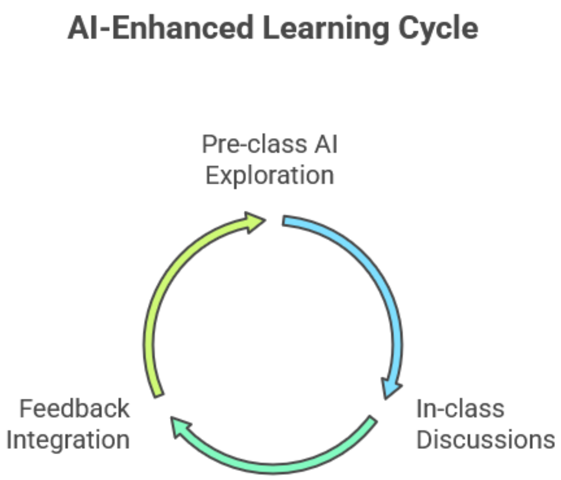

Figure 2: ***Three-phase AI-enhanced learning cycle: Pre-class exploration, feedback refinement, and in-class application.***

The intervention was implemented across two instructional cycles, structured around three core components:

1. **Pre-class AI Conceptual Exploration**
    - Students engaged with AI tools (ChatGPT/Gemini/DeepSeek) to investigate conceptual prompts (e.g., "Where does collision energy go?")
    - Generated responses were documented in digital journals for subsequent analysis
2. **In-class Comparative Discussions**
    - Structured peer debates comparing AI-derived explanations with textbook concepts
    - Teacher-facilitated resolution of conflicting interpretations
3. **Feedback Integration**
    - Collection of student reflections on AI tool effectiveness
    - Adaptive refinement of prompt engineering based on identified misconceptions

The AI tools provided immediate, personalized feedback that students found less intimidating than teacher queries, increasing engagement. The intervention required only mobile devices, combining AI dialogues with collaborative learning to create an accessible, dialogue-rich conceptual development environment.

7.0 Results

Pre and Post Test

The analysis of the student test results from the Energy and Momentum Conceptual Survey reveals substantial learning gains following instruction. The average pre-test score was 46.67%, indicating a moderate level of prior conceptual understanding among students. After instruction, the average post-test score increased significantly to 70.76%, reflecting improved comprehension of the targeted energy and momentum concepts. The normalized gain of 42.94% suggests a medium-to-high level of learning effectiveness, as it falls within the range typically associated with interactive or research-based instructional methods. Notably, the effect size, measured using Cohen’s d, is 1.77, well above the threshold of 0.8 for a large effect. This indicates a strong instructional impact and a substantial improvement in student understanding.

Table 2. Overall Student Test Analysis Results

Metric	Value
Max Possible Score	100.00%
Average Pre-test Score (Overall)	46.67%
Average Post-test Score (Overall)	70.76%
Overall Normalized Gain	42.94%
Effect Size (Cohen's d)	1.77

Overall, these results demonstrate that the teaching intervention had a significant and meaningful effect on students’ conceptual grasp of energy and momentum topics.

The data presented in Table 3 demonstrate significant improvements across all question clusters following the AI-based intervention, reinforcing its efficacy in enhancing conceptual understanding of energy and momentum. Notably, energy-related concepts exhibited a substantial increase from 41.39% to 70.00%, while momentum concepts improved from

33.33% to 67.78%, indicating that the intervention effectively addressed foundational misconceptions.

Table 3. Average Scores by Question Cluster

Question Cluster	Average Pre-test Score	Average Post-test Score
Energy concepts	41.39%	70.00%
Work done by gravitational force	48.89%	70.28%
Work done by nonconservative forces	47.22%	70.00%
Conservation of mechanical energy and related issues	42.78%	68.89%
Momentum concepts	33.33%	67.78%
Identifying conservation of momentum	56.67%	71.67%
Momentum conservation in inelastic collisions and explosions	45.56%	73.89%
Impulse-momentum theorem	53.33%	77.78%

Particularly striking were the gains in traditionally challenging areas, such as momentum conservation in inelastic collisions and explosions (45.56% to 73.89%) and conservation of mechanical energy (42.78% to 68.89%). These results suggest that the AI's Socratic dialogue and real-time feedback mechanisms successfully scaffolded students' reasoning, enabling them to move beyond formulaic recall toward deeper conceptual internalization.

The consistency of improvement, evident even in subtopics with initially higher pre-test performance (e.g., impulse-momentum theorem: 53.33% to 77.78%), further underscores the intervention's broad applicability. These findings align with prior research emphasizing the role of targeted, dialogic feedback in correcting persistent misconceptions.

Feedback Questionnaire

The survey results presented in Table 4 reveal consistently positive student perceptions of the AI tutoring intervention, with all items scoring above 4.50 on a 5-point Likert scale. The highest-rated aspect was the AI's effectiveness in correcting misconceptions about energy and momentum (4.77), indicating its strong utility for conceptual remediation. Students also reported high satisfaction with the clarity of AI explanations (4.70) and expressed greater comfort engaging with the AI tutor compared to traditional classroom discussions (4.57).

Table 4. Overall Student Test Analysis Results

Item	Average Score**
The AI tutor helped me correct my misconceptions about energy and momentum	4.77
The AI's responses challenged me to think more critically about physics concepts.	4.50
The AI provided clear and understandable explanations of physics concepts.	4.70
I felt more comfortable asking questions to the AI tutor than in class discussions.	4.57
I would recommend using AI tutors for learning other physics topics.	4.73

**(1=Strongly disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly agree)

While all dimensions received favourable ratings, the relatively lower score for critical thinking stimulation (4.50) suggests room for improving how the AI challenges students' reasoning. The strong endorsement for using AI in other physics topics (4.73) demonstrates significant potential for broader implementation. These findings collectively suggest that AI dialogue tutors can effectively complement physics instruction by providing accessible, personalized conceptual support, particularly in addressing persistent misconceptions.

8.0 Reflections & Conclusion

The integration of AI tools for tutoring significantly improved students' conceptual understanding of energy and momentum. As shown in Table 2, the average post-test score rose to 70.76% from a pre-test average of 46.67%, with a normalized gain of 42.94% and a large effect size (Cohen's d = 1.77), indicating substantial learning gains beyond traditional instruction.

A detailed breakdown (Table 3) revealed improvements across all subtopics. Notably, energy concepts increased from 41.39% to 70.00%, and momentum concepts improved from 33.33% to 67.78%. Previously challenging areas, such as momentum conservation in inelastic collisions (45.56% → 73.89%) and conservation of mechanical energy (42.78% → 68.89%), demonstrated marked progress, suggesting effective remediation of persistent misconceptions.

The data in Table 4 shows strong student approval of the AI tutor (average scores 4.50-4.77/5), particularly for correcting misconceptions (4.77) and providing clear explanations (4.70). While students preferred AI interactions over classroom questioning (4.57), the slightly lower critical thinking score (4.50) suggests room for improving analytical engagement. The high recommendation rating (4.73) indicates significant potential for broader implementation in physics education. These results confirm the AI tutor's effectiveness as a supplementary learning tool for conceptual understanding.

Strengths and Limitations

The study's key strength lies in its robust quantitative evidence, including pre-post comparisons, normalized gains, and effect sizes, supported by a standardized conceptual assessment (EMCS). This is further reinforced by the overwhelmingly positive student feedback in Table 4, where all AI tutoring aspects scored between 4.50-4.77/5, with the highest ratings for misconception correction (4.77) and explanation clarity (4.70). The intervention directly addressed known student struggles, such as reliance on rote memorization, by fostering self-explanation and conceptual reasoning, as evidenced by students' strong preference for AI interactions over classroom questioning (4.57) and their willingness to recommend the tool (4.73).

However, the absence of a control group limits causal attribution, as confounding factors (such as concurrent instruction) may have contributed to observed gains. While students rated the AI's critical thinking stimulation slightly lower (4.50), suggesting room for refinement, the consistently high scores across all metrics underscore its potential as a supplementary learning tool when interpreted alongside other quantitative measures.

Conclusions and Future Directions

The findings strongly support AI-assisted Socratic dialogue as an effective tool for deepening conceptual understanding in physics, particularly in large-class settings where individualized feedback is challenging. This conclusion is reinforced by the overwhelmingly positive student evaluations in Table 4, where the AI tutor received consistently high ratings (4.50-4.77/5) for correcting misconceptions (4.77), providing clear explanations (4.70), and creating a comfortable learning environment (4.57). The significant post-intervention gains, coupled with students' strong endorsement of the tool (4.73), suggest AI can effectively bridge the gap between algorithmic proficiency and conceptual mastery.

Future research needs to delve deeper into the impact of AI in education to build upon current positive student perceptions. This means adopting controlled experimental designs to pinpoint the exact effects attributable to AI. Given the high immediate effectiveness ratings (4.77), it's crucial to assess the long-term retention of conceptual understanding to see if these benefits persist over time. Additionally, since critical thinking stimulation scored relatively lower (4.50), future studies should analyse AI-student interactions, perhaps through chat logs, to understand the underlying reasons. With students highly valuing both AI's accessibility (4.57) and conceptual support (4.70), it's important to explore optimal teacher-AI integration models. Finally, supported by a strong recommendation score (4.73) for wider implementation, research should examine the broader impacts of AI on problem-solving skills and its scalability within educational settings.

While the study demonstrates promising results through both quantitative gains and positive student feedback (Table 4), further investigation is needed to generalize findings and refine implementation strategies, particularly to enhance the AI's ability to stimulate deeper critical thinking (4.50). The consistently high ratings across all evaluation metrics suggest AI tutoring has significant potential when carefully integrated into physics education.

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REFERENCES

Altrichter, H. a.-S. (2002). The concept of action research. *The learning organization*, 125-131.

Bagno, E. a.-S. (1997). From problem solving to a knowledge structure: An example from the domain of electromagnetism. *American journal of Physics*, 726-736.

Brundage, M. J. (2023). Peer interaction facilitates co-construction of knowledge in quantum mechanics. *Physical Review Physics Education Research*, 020133.

Chi, M. T. (2014). The ICAP framework: Linking cognitive engagement to active learning outcomes. *Educational psychologist*, 219-243.

Hestenes, D. (1997). Modeling methodology for physics teachers. *AIP conference proceedings* (pp. 935-958). American Institute of Physics.

McDermott, L. C. (1991). Millikan Lecture 1990: What we teach and what is learned—Closing the gap. *American journal of physics*, 301-315.

Nwana, H. S. (1990). Intelligent tutoring systems: an overview. *Artificial Intelligence Review*, 251-277.

Paul, R. a. (2007). Critical thinking: The art of Socratic questioning. *Journal of developmental education*, 36.

Tanner, K. a. (2005). Approaches to biology teaching and learning: understanding the wrong answers—teaching toward conceptual change. *Cell biology education*, 112-117.

Woolf, B. P. (2013). AI grand challenges for education. *AI magazine*, 66-84.