**AI-Powered Tutoring for Conceptual Clarity in Energy and Momentum among Malaysian Matriculation Physics Students**

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**ABSTRAK**

*Patah perkataan tidak melebihi 200 patah; format italic bersaiz 12; dan justified*. *Jika kertas kajian ditulis dalam Bahasa Melayu, maka abstrak hendaklah ditulis dalam Bahasa Melayu. Jika kertas kajian ditulis dalam Bahasa Inggeris, maka abstrak hendaklah ditulis dalam Bahasa Inggeris*

*Kata Kunci : Tiga hingga lima patah perkataan*

# **INTRODUCTION**

**Research Background**

In my action research, I am investigating 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 & Eylon, 1997; Singh & Schunn, 2009). For instance, my initial diagnostic data and classroom observations confirm widespread student misconceptions; my 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, 1992).

I selected the focus of this study on energy and momentum 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 my 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 et al., 2013; Koedinger et al., 1997). By targeting these specific conceptual gaps, I aim 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 analyzing 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.

**Research Purpose and Importance**

The primary objective of my study is to enhance students’ conceptual understanding of energy and momentum in the Malaysian Matriculation Physics curriculum through AI dialogue-based tutoring tools (ChatGPT, Gemini, DeepSeek). This objective addresses widespread misconceptions identified via diagnostic assessments and student feedback. My study has two specific aims: first, to measure AI-supported dialogue's impact on conceptual understanding through pre- and post-intervention assessments; second, to explore student perspectives on using AI tools as dialogue-based tutors. I will evaluate conceptual gains using the Energy and Momentum Conceptual Survey (EMCS) and explore perspectives via a feedback form, aligning with the study's central focus on leveraging AI to resolve persistent misconceptions.

**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.

McDermott, L. C. (1991). What we teach and what is learned—Closing the gap.

Bagno, E., & Eylon, B. S. (1997). From problem solving to knowledge-structure: An example from the domain of electromagnetism.

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Koedinger, K. R., Anderson, J. R., Hadley, W. H., & Mark, M. A. (1997). Intelligent tutoring systems as effective and efficient learning environments.

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# **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"*

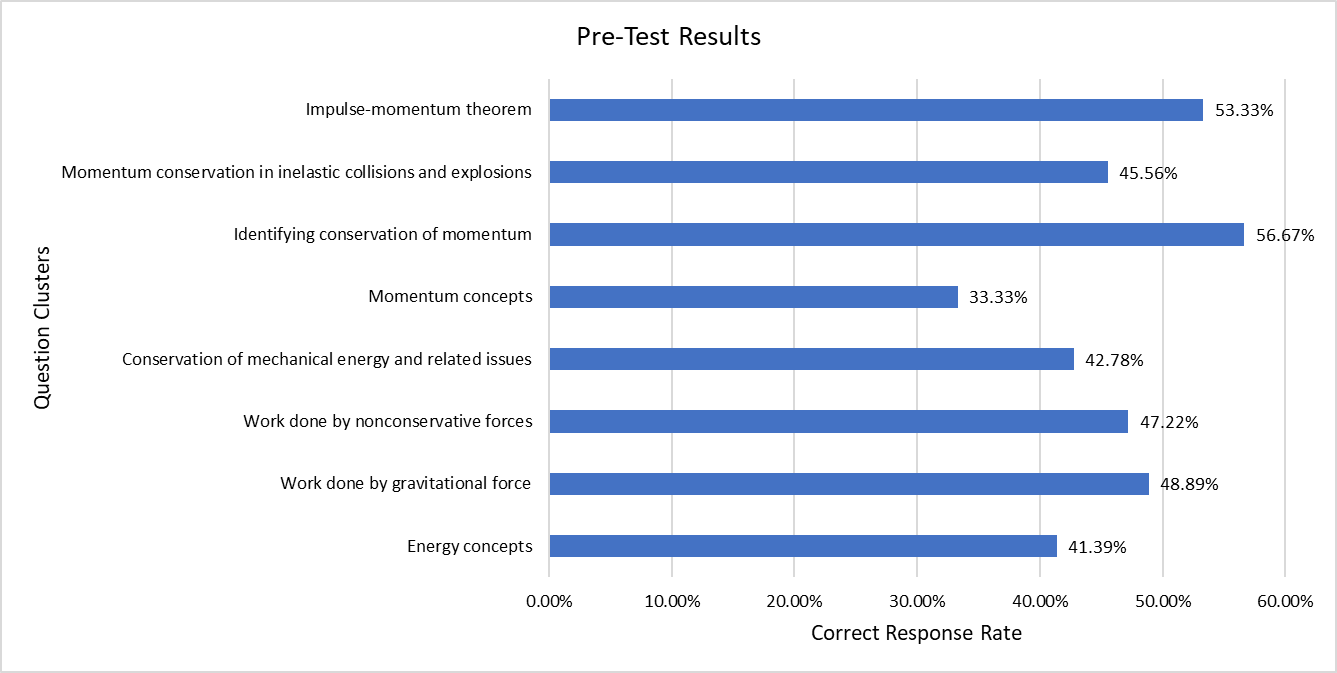
These reflections underscore the need for low-stakes conceptual exploration. While AI cannot replace teachers, it provides scalable, responsive support to address persistent misconceptions.

**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. Firstly, it seeks to measure the extent to which AI-supported dialogue can enhance students’ conceptual understanding, as indicated by improved performance in pre- and post-intervention assessments. Second, it aims to explore students’ perspective on usage of AI tools as tutors for dialogue-based learning.

These objectives are realistic and measurable within the scope of the study. Conceptual gains will be evaluated using items adapted from the Energy and Momentum Conceptual Survey (EMCS), while students’ perspective explored via feedback form on their experience. Collectively, these objectives align closely with the study's central concern: addressing persistent misconceptions by leveraging the unique affordances of AI-based dialogue.

# **5.0 TARGET GROUP**

The target group for this study consists of students enrolled in the Two-Semester System of the Malaysian Matriculation Programme at Sarawak Matriculation College for the 2024/2025 academic session. These students are currently taking Physics as one of their core subjects. The selection was based on early diagnostic data that identified persistent misconceptions in energy and momentum.

The students chosen for this study obtained at least a grade B in Physics in their SPM examination, indicating a foundational understanding of the subject but with room for conceptual improvement. This selection criterion ensures the group is both relevant to the focus of the study and likely to benefit from the intervention. A total of 30 students were identified from two tutorial groups under my supervision. These students were selected to ensure consistency in teaching delivery and access to AI tools during the research period.

The target group includes both male and female students, with a mix of ethnic backgrounds typical of the Malaysian matriculation context. Academically, these students vary in their overall science performance but share a common challenge in mastering abstract physics concepts, particularly those requiring conceptual reasoning beyond memorisation. Their demographic diversity and varied learning styles make them a suitable and representative group for investigating the effectiveness of AI-supported interventions in 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).

Implementation occurred across two instructional cycles featuring: (1) pre-class AI explorations of conceptual prompts (e.g., "Where does collision energy go?"), (2) in-class discussions comparing AI-derived insights, and (3) iterative refinements based on student feedback. 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.

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| 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.

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| **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).

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| **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 analyze 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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