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THE RELATIONSHIP BETWEEN CONCEPTUAL UNDERSTANDING AND PROBLEM-SOLVING ABILITIES IN FORCE AND MOTION AMONG PHYSICS UNDERGRADUATES IN MALAYSIA

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Abstract

This study was conducted to better understand how students' conceptual knowledge influences their ability to solve physics problems, particularly in the topic of force and motion. This study investigates the relationship between conceptual understanding and problem-solving ability in the topic of force and motion among undergraduate physics students at a university in Malaysia. The research aimed to determine the relationship between conceptual understanding, assessed using the Force Concept Inventory (FCI), and problem-solving ability, assessed using the Scholastic Assessment Test (SAT) Physics Practice Test focusing on Newton's Laws. A total of 60 respondents who had completed the Mechanics course participated in this study. Descriptive analysis using frequency distribution was conducted to evaluate the levels of both conceptual understanding and problem-solving ability. The results showed that 41.67% of students demonstrated Partial Understanding, 38.33% had Limited Understanding, 13.33% showed Not Understanding, and only 6.67% achieved Sound Understanding. For problem-solving ability, 50.00% of the students were at the Intermediate level, 26.67% were classified as Expert, and 23.33% as Novice. To determine the relationship between the two variables, Pearson Correlation analysis revealed a moderate negative correlation ($r = -0.488$, $p = 0.049$), indicating a statistically significant inverse relationship between students' conceptual understanding and their problem-solving ability in force and motion. The findings highlight the need for instructional approaches that address conceptual understanding and problem-solving as distinct yet interconnected skills in physics education.

Keywords: Conceptual understanding – problem solving – university undergraduates

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INTRODUCTION

Physics, as a branch of natural science, encompasses the study of energy, forces, motion, and the fundamental principles that govern the universe. Understanding these principles requires not only the ability to solve problems but also the capacity to connect new knowledge with prior understanding. According to Saputra and Mustika [1], conceptual understanding in physics involves organizing and integrating concepts meaningfully for efficient recall and application. It enables students to approach physical phenomena qualitatively and is essential for developing higher-order thinking and solving real-world problems.

In parallel, problem-solving in physics is defined as a cognitive process that involves interpreting information, identifying relevant concepts, and applying appropriate principles to arrive at solutions [2]. This process not only reinforces theoretical knowledge but also bridges it with practical applications. Effective problem-solving requires critical thinking, logical reasoning, and the ability to navigate complex, unfamiliar situations using fundamental physics principles. Consequently, both conceptual understanding and problem-solving are considered foundational competencies in physics education.

Despite their central role in physics instruction, research indicates a persistent gap between students' problem-solving performance and their conceptual comprehension. While many students can perform well on algorithmic or quantitative tasks by memorizing formulas or applying procedures, they often lack a deep understanding of the underlying principles. Docktor et al. [3] observed that students tend to rely on a "means-ends analysis" approach focusing on matching problems to equations rather than understanding the physics concepts involved. This overreliance on mathematical manipulation without conceptual grounding results in a superficial mastery that fails to transfer to novel contexts or conceptual questions.

Introductory physics courses for science and engineering students aim to develop both problem-solving skills and conceptual understanding. However, numerous studies (e.g., [4]) show that these two aspects of learning do not always develop simultaneously. Students may solve computational problems accurately yet struggle with conceptual questions derived from the same topics. For instance, after viewing worked-out animated solutions, students often perform well on similar problems but fail to answer related conceptual questions correctly. This suggests that problem-solving ability alone is not a reliable indicator of deep conceptual knowledge.

Moreover, difficulties in learning physics, especially concepts like force and motion are further compounded by mathematical complexity and persistent misconceptions. Many students enter physics courses with intuitive but incorrect beliefs (e.g., that heavier objects fall faster), and these misconceptions can interfere with learning. When students also face challenges in applying mathematical tools like algebra and calculus, it creates additional barriers to mastering physics [2], [5]. While some students understand the theoretical content, they often struggle to apply this knowledge to solve practical or conceptual problems effectively.

The importance of integrating conceptual understanding with problem-solving is further underscored by recent research. Taqwa et al. [5] emphasized that a strong grasp of basic physics concepts significantly enhances students' problem-solving performance. Students with a solid conceptual foundation are better equipped to analyze situations critically, identify relevant principles, and develop effective solutions. However, many students exhibit poor conceptual understanding despite achieving correct answers in problem-solving tasks, suggesting that their performance may not reflect true comprehension. Therefore, conceptual understanding plays a crucial role in ensuring that problem-solving is meaningful and transferable.

In efforts to address these challenges, educational researchers and practitioners have developed various instructional strategies aimed at promoting both conceptual understanding and problem-solving skills. Active learning techniques, such as classroom response systems and real-time feedback, have shown promise in helping students confront and revise misconceptions [4]. These approaches emphasize engagement and deeper thinking, shifting the instructor's role from information deliverer to learning facilitator. Nevertheless, much of the foundational research exploring the relationship between conceptual understanding and problem-solving in physics stems from studies conducted in the 1980s to early 2010s [6], [7]. Since 2014, there has been a notable decline in published research addressing this relationship, despite ongoing shifts in education technology, pedagogical practices, and student learning behaviors.

Given this research gap, there is a pressing need for updated investigations that reflect the current educational landscape. Recent studies [8] affirm that learning models emphasizing problem-solving can significantly enhance students' conceptual understanding. However, more contemporary data is required to validate these findings and explore how these two dimensions of physics learning interact in today's academic settings.

To address this need, the present study aims to examine the relationship between conceptual understanding and problem-solving abilities in the topic of force and motion among physics undergraduates in Malaysia. The study is guided by the following research questions:

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1. What is the level of conceptual understanding in force and motion among physics undergraduates in Malaysia?
2. What is the level of problem-solving ability in force and motion among physics undergraduates in Malaysia?
3. Is there a significant relationship between conceptual understanding and problem-solving ability in force and motion among physics undergraduates in Malaysia?

By investigating these questions, this study seeks to provide new insights into how conceptual knowledge and problem-solving skills support each other in physics education. Ultimately, the findings aim to contribute to a deeper understanding of the cognitive processes involved in learning physics and to inform more effective instructional approaches for developing both competencies in higher education contexts.

LITERATURE REVIEW

2.1 Level of Conceptual Understanding in Force and Motion among University Physics Undergraduates

Numerous studies have explored the persistent challenges students face in developing a deep conceptual understanding of force and motion in physics. Taqwa et al. [5] conducted a descriptive study involving 86 first-year undergraduate students and found that the overall level of conceptual understanding was low, with an average score of 49.65%. Only 10.46% of the students achieved sound understanding, while many exhibited partial understanding or specific misconceptions. Their findings highlighted the critical role of conceptual clarity in enabling effective problem-solving and emphasized the need for targeted instructional strategies to address prevalent misconceptions in foundational physics topics.

Robertson et al. [9] approached the issue from a qualitative perspective by analyzing students' written responses to five conceptual questions adapted from the Force Concept Inventory (FCI). With data from 1,057 students across four U.S. universities, their study revealed that while students often relied on intuitive reasoning, these ideas were frequently inconsistent or context-dependent. Rather than viewing these as outright misconceptions, the researchers framed them as conceptual resources and partial understandings that educators could refine and build upon. This perspective supports a shift in pedagogical focus toward leveraging students' existing reasoning patterns to promote deeper learning and critical thinking.

In another related study, Saputra and Mustika [1] examined the conceptual understanding of 40 pre-service physics teachers using open-ended questions related to Newton's Laws. The results showed wide variability in understanding, with many students demonstrating theoretical or inappropriate models of reasoning. These findings indicated that even those preparing to teach physics often struggle with core concepts, underscoring the importance of developing more effective strategies to enhance conceptual comprehension. The study advocated for a shift away from memorization-based approaches toward models that foster critical engagement and long-term understanding.

Collectively, these studies highlight a recurring pattern of low conceptual understanding in force and motion, even among students who can solve quantitative problems. Each study used either reasoned multiple-choice items or open-ended questions and applied descriptive analysis particularly frequency distribution analysis to categorize levels of understanding. This analytical approach has proven effective in identifying misconceptions, trends, and performance patterns. Furthermore, the integration of conceptual tools such as the FCI has reinforced the importance of diagnostic assessments in evaluating foundational knowledge, which is crucial for strengthening both conceptual understanding and problem-solving abilities in physics education.

2.2 Level of Problem Solving Ability in Force and Motion among University Physics Undergraduates

The ability to solve problems effectively in physics is a core skill closely linked to students' overall understanding of the subject. Marlina et al. [2] emphasized that improving students' cognitive processes in problem-solving enhances educational outcomes and fosters deeper comprehension of scientific principles. Their literature-based research compared the behaviors of expert and novice problem solvers, revealing that experts apply more strategic approaches such as setting clear goals and monitoring progress while novices tend to rely on surface features and formula-based methods. The study highlights that expert-like strategies, including qualitative analysis and concept-based reasoning, contribute to higher performance in physics, underscoring the importance of teaching these strategies to less experienced students.

Riantoni et al. [10] expanded upon this by conducting a systematic literature review of studies on physics problem-solving over the past two decades. Their analysis identified persistent challenges faced by novice learners, such as an overemphasis on mathematical procedures at the expense of conceptual understanding. The review also highlighted the need for a balanced instructional approach that develops both conceptual insight and quantitative problem-solving skills. Importantly, Riantoni et al. [10] stressed the integration of these two dimensions as critical for fostering effective physics problem-solving and recommended targeted interventions to address students' difficulties with applying theory in practical contexts.

Together, the findings from Marlina et al. [2] and Riantoni et al. [10] support the need for comprehensive assessment tools that go beyond final answers to evaluate the thought processes students engage in while solving problems. Quantitative descriptive analysis, such as frequency distribution analysis, has been widely adopted for this purpose. This method allows educators to analyze performance patterns, identify strengths and weaknesses, and present data in an accessible format using percentages, bar charts, and frequencies. It provides valuable insights into students' problem-solving levels and helps in monitoring progress or comparing outcomes across groups.

Complementing these perspectives, Ince [11] reviewed various methodologies used in physics education research on problem-solving. These included experimental designs with pre- and post-tests, think-aloud protocols, and customized physics achievement tests to measure conceptual application. Self-confidence measures were also used to explore the role of self-efficacy in solving problems. In alignment with this approach, the current study adopts the Scholastic Assessment Test (SAT) Physics Practice Test: Newton's Laws, as outlined by Caputo [3], to assess students' problem-solving abilities in force and motion. Standardized tests like this offer reliable data, allow for cross-group comparisons, and help uncover misconceptions that may hinder problem-solving success further reinforcing the importance of evaluating both conceptual and procedural competence in physics education.

2.3 Relationship between Conceptual Understanding and Problem Solving Ability in Force and Motion among University Physics Undergraduates.

The relationship between conceptual understanding and problem-solving ability in physics especially within the topic of force and motion is complex and multifaceted. Morphew and Mestre [4] emphasized that these two forms of knowledge can develop independently. A student may solve numerical problems correctly without grasping the underlying concepts, or may understand the concepts but struggle with mathematical execution. Conceptual understanding involves grasping fundamental physics principles and their interrelationships, enabling students to interpret and apply knowledge meaningfully across various contexts. Without this foundation, students may face challenges in utilizing problem-solving skills effectively.

Problem-solving in force and motion often emphasizes computational proficiency, such as using formulas and algorithms. While this reflects a student's ability to perform calculations, it may not indicate conceptual comprehension. For example, a student may calculate the net force or tension in a string correctly but fail to understand the physical context or assumptions of the problem [4]. To explore how these two dimensions interact, educational researchers often use statistical tools like the Pearson Correlation Coefficient to examine the relationship between conceptual and procedural performance.

Supporting this, Sijabat et al. [8] and Gaigher et al. [7] both concluded that conceptual understanding provides a strong basis for effective problem-solving. Students with well-developed conceptual knowledge are better at identifying key information, selecting appropriate strategies, and making meaningful connections between ideas. They are also more likely to use advanced problem-solving techniques, such as drawing diagrams and reasoning qualitatively. Conversely, students who depend solely on formulaic approaches may struggle to adapt when faced with unfamiliar or complex problems, due to a lack of conceptual depth.

To investigate this relationship, past studies have used a variety of statistical methods, including two-way ANOVA [8] and the Chi-square test [7]. However, for the present study, the Pearson Correlation Coefficient will be employed as it is effective for measuring the strength and direction of the linear relationship between two continuous variables conceptual understanding and problem-solving ability. This method is ideal for identifying patterns and trends without requiring a predetermined cause-effect relationship, making it a suitable tool for exploring how these competencies interact in undergraduate physics education.

RESEARCH METHOLOGY

3.1 Population and Sampling

The population for this study comprises 60 physics undergraduates from a public university in Malaysia who have completed the Mechanics course. The sample included 25 students from Year 2 (41.7%) and 35 students from Year 4 (58.3%). Using purposive sampling, participants were selected based on their direct experience with the course to ensure relevance to the research objectives. This non-random technique was chosen due to logistical feasibility, limited resources, and the focused scope of the study, making it appropriate for collecting meaningful data on the relationship between conceptual understanding and problem-solving abilities in physics.

3.2 Research Instruments

To measure students' conceptual understanding of force and motion, this study employs the Force Concept Inventory (FCI) developed by Hestenes et al. [12] and sourced from the PhysPort website. The FCI consists of 30 multiple-choice questions designed to assess key concepts such as linear motion, free fall motion, inertia, momentum, force, weight, resultant force, forces in equilibrium, and Newton's three laws of motion. Each question offers five answer choices, allowing for targeted evaluation of students' misconceptions and understanding. The distribution of questions is categorized to ensure comprehensive coverage: for example, linear motion is assessed in seven questions, free fall motion in four, and Newton's laws each with one question. This instrument effectively captures students' conceptual grasp by encouraging application and transfer of knowledge across a variety of physics contexts [5].

To assess problem-solving ability, this study utilizes the Scholastic Assessment Test (SAT) Physics Practice Test: Newton's Laws, developed by Caputo [3] and modified from CrackSAT.net. Composed of 18 multiple-choice questions, this instrument evaluates students' ability to apply Newtonian principles in solving problems related to weight, force resolution, resultant force, linear and free fall motion, impulse, momentum, and forces in equilibrium. Each question includes five answer options and is strategically distributed across topics for instance, four questions assess impulse and impulsive forces, three each for linear and free fall motion, and two each for resultant force and momentum. This test is aligned with the problem-solving framework required in physics education and offers insight into students' ability to apply theoretical knowledge to practical, calculation-based problems [11].

3.3 Validity and Reliability

The evaluator is a senior lecturer at the public university of Malaysia, specializing in physics education. She holds a Doctoral Degree in Physics Education from a public university in Malaysia and is currently conducting research in STEM and Epistemological Beliefs.

To ensure the reliability of the instruments used in this study, a pilot test was conducted involving 30 undergraduates who had completed the Mechanics course. Following the recommendation of Ntumi et al. [13], the Kuder-Richardson Formula 20 (KR-20) was used to assess the internal consistency of both instruments. A KR-20 coefficient of 0.70 or higher indicates acceptable reliability, while an index of discrimination of 0.20 or above is considered effective for distinguishing between high- and low-performing students. This analysis ensures that the test items used are both reliable and valid for measuring conceptual understanding and problem-solving ability in physics.

For the Force Concept Inventory (FCI), the KR-20 analysis yielded a reliability coefficient of 0.754, indicating a strong level of internal consistency. Each of the 30 items was scored dichotomously (1 for correct, 0 for incorrect). Item discrimination analysis showed that all questions met the minimum threshold of 0.20, with five items rated as "Excellent," several rated as "Good," and the rest as "Average." These findings confirm that the FCI is a consistent and dependable instrument for evaluating students' conceptual understanding of force and motion, capable of effectively distinguishing between varying levels of student performance.

For the SAT Physics Practice Test: Newton's Laws, the KR-20 reliability coefficient was found to be 0.705, also within the acceptable range. Like the FCI, each of the 18 SAT items was scored dichotomously. The item discrimination analysis showed that all items exceeded the 0.20 benchmark, with Question 5 rated as "Excellent" and several others, including Questions 2, 4, 10, 14, 15, and 17, rated as "Good." The remaining items were classified as "Average." These results support the SAT test as a reliable tool for assessing students' problem-solving abilities related to Newton's Laws, reinforcing its suitability for use in this study.

3.4 Data Analysis

The quantitative data collected in this study were analyzed using the Statistical Package for Social Sciences (SPSS) to address all three research questions. Descriptive statistical methods, specifically Frequency Distribution Analysis, were used to determine the levels of conceptual understanding and problem-solving ability among university physics undergraduates. To explore the relationship between these two variables, inferential statistics were applied using the Pearson Correlation Coefficient. This combination of analyses provided a comprehensive overview of student performance and the potential connections between conceptual and procedural competencies in physics.

For the Force Concept Inventory (FCI), students' performance was categorized into four levels of conceptual understanding based on the scoring criteria adapted from Taqwa et al. (2022). A total score of 24–30 correct answers (80–100%) indicates Sound Understanding (SU), while 18–23 correct answers (60–79%) fall under Partial Understanding (PU). Scores between 12–17 (40–59%) are classified as Limited Understanding (LU), and 0–11 correct answers (0–39%) are categorized as Not Understanding (NU). This classification enabled the identification of students' depth of conceptual understanding across a broad spectrum of force and motion topics.

For the SAT Physics Practice Test: Newton's Laws, problem-solving ability was categorized into three levels. Students scoring 15–18 correct answers (83–100%) were classified as Experts, indicating high proficiency in solving Newtonian physics problems. Those with 9–14 correct answers (50–82%) were placed in the Intermediate category, while students who scored between 0–8 correct answers (0–49%) were classified as Novices, reflecting limited problem-solving ability. This classification system allowed for a detailed assessment of students' abilities to apply theoretical knowledge to practical problem scenarios.

To examine the relationship between conceptual understanding and problem-solving ability, the Pearson Correlation Coefficient was employed. This test measured the strength and direction of the linear relationship between the two variables. Correlation values (r) range from -1 to +1, with $r = 0$ indicating no correlation, values from 0.1 to 0.3 representing a weak correlation, 0.3 to 0.5 moderate, 0.5 to 0.7 strong, and 0.7 to 1.0 very strong [4]. In addition, the p-value was used to determine the statistical significance of the results, with $p < 0.05$ indicating a significant correlation. A positive r-value alongside a significant p-value suggests that higher conceptual understanding is associated with higher problem-solving ability, while a negative r-value would indicate an inverse relationship. If the r-value is close to zero and $p > 0.05$, it suggests no significant relationship between the two variables. This approach provided a robust analysis of how conceptual comprehension may influence students' ability to solve physics problems effectively.

ANALYSIS AND DISCUSSION

4.1 Level of Conceptual Understanding in Force and Motion

The data was obtained from the Force Concept Inventory (FCI) and descriptive analysis using frequency distribution was conducted to assess the overall level of students' conceptual understanding. Table 1 shows that the conceptual understanding level among the majority of the physics undergraduates fall under Partial Understanding (PU) (41.67%) and Limited Understanding (LU) (38.33%) categories. A smaller portion of students demonstrated Not Understanding (NU) (13.33%), while only 6.67% achieved Sound Understanding (SU). The results suggest that most students possess a moderate grasp of force and motion concepts, with very few displaying a thorough and complete understanding.

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Table 1: Analysis of force and motion conceptual understanding using FCI

Conceptual Understanding Level	**Frequency (n)**	**Percentage (%)**
Not Understanding (NU)	8	13.33
Limited Understanding (LU)	23	38.33
Partial Understanding (PU)	25	41.67
Sound Understanding (SU)	4	6.67
Total	**60**	**100**

While many students possess a basic grasp of Newtonian concepts, only a few have developed a complete and accurate understanding. These findings align with those of Taqwa et al. [5], who also reported low conceptual scores in force and motion topics, with students averaging below 50%. The current study reinforces the notion that many students struggle with conceptual reasoning, possibly due to instructional emphasis on procedural problem-solving rather than conceptual depth. Although multiple-choice tools like the FCI provide a useful measure, they may not fully capture students' conceptual mastery, as some correct responses may result from memorization or guessing. This highlights the need for deeper engagement with the foundational principles of physics to improve students' conceptual understanding.

4.2 Level of Problem Solving Ability

The data was collected using selected items from the Scholastic Assessment Test (SAT) Physics Practice Test focusing on Newton's Laws. Descriptive analysis using frequency distribution was carried out to determine the levels of problem-solving ability. Table 2 reveals that 50.00% of the respondents are at the Intermediate level, indicating a moderate proficiency in applying Newton's Laws to solve physics problems. A notable 26.67% of students reached the Expert level, demonstrating a strong ability to analyse and solve problems effectively. Meanwhile, 23.33% of the respondents were identified as Novice, reflecting limited problem-solving skills in the topic area. These findings suggest that the majority of students possess a reasonable level of problem-solving ability.

Table 2: Analysis of problem-solving ability using SAT

Problem-Solving Ability Level	**Frequency (n)**	**Percentage (%)**
Novice	14	23.33
Intermediate	30	50.00
Expert	16	26.67
Total	60	100

These findings indicate that while most students possess moderate competence in solving physics problems, a notable portion either excels or struggles with applying Newtonian principles effectively. The distribution of problem-solving abilities suggests a range of student preparedness, with some demonstrating strong analytical skills while others still face difficulties in strategy use or conceptual application. This pattern is consistent with prior research by Marlina et al. [2], which highlights the contrast between expert and novice problem-solving approaches. Experts tend to plan methodically and rely on conceptual reasoning before applying formulas, whereas novices often use surface-level features and jump into calculations without qualitative analysis. The current findings, with only a quarter of students reaching Expert status, underscore the continued reliance on procedural strategies among many learners and point to the need for more emphasis on developing concept-driven problem-solving skills.

4.3 Relationship

To address Research Question 3, Pearson Correlation Coefficient was used. The total scores from the FCI and SAT were calculated by assigning 1 point for each correct answer and 0 for incorrect answers. These total scores, representing conceptual understanding and problem-solving ability respectively, were treated as continuous variables and analyzed using SPSS Version 30. This method allowed the study to assess the linear relationship between the two variables.

The analysis shown in Table 3 revealed a moderate negative correlation with a coefficient of $r = -0.488$ and a p-value of 0.049, indicating a statistically significant inverse relationship between conceptual understanding and problem-solving ability. As the p-value is below 0.05, the result is considered statistically significant at the 5% level. This means that as students' conceptual understanding increases, their problem-solving ability tends to decrease, and vice versa. Although unexpected, this inverse relationship suggests a disconnect between students' conceptual grasp and their ability to apply that knowledge in problem-solving contexts.

Table 3: Pearson Correlation Analysis Result

Variables	Sample size (n)	Correlation Coefficient (r)	Significance Value (p-value)	Relationship Strength
Conceptual Understanding Level & Problem-Solving Ability	60	-0.488	0.049	Moderate Negative Correlation

This unexpected finding challenges the assumption that stronger conceptual understanding naturally enhances problem-solving performance. It suggests that students may develop procedural problem-solving skills without fully grasping the underlying concepts, or that those who prioritize conceptual reasoning may engage less with procedural practice. These results align with Morphew and Mestre [4], who found that problem-solving success does not always reflect conceptual mastery. Their study, like the present one, supports the idea that conceptual and procedural knowledge can develop independently, highlighting the complexity of cognitive processes involved in physics learning.

IMPLICATIONS

The findings of this study suggest that conceptual understanding and problem-solving ability in physics may develop as distinct cognitive skills, highlighting the need for instructional approaches that address both areas independently. The moderate negative correlation observed reinforces the importance of using multiple assessment tools, such as the Force Concept Inventory (FCI) and the SAT Physics Practice Test, to capture the full spectrum of students' learning outcomes. Furthermore, conducting item-level analysis proved valuable in identifying specific conceptual or procedural strengths and weaknesses, allowing for more targeted feedback and support. This unexpected inverse relationship also opens new avenues for future research to explore the cognitive and instructional factors contributing to the apparent disconnect between understanding and application in physics problem-solving.

CONCLUSION

Most undergraduate physics students demonstrated only partial or limited conceptual understanding of force and motion, while a moderate level of problem-solving ability was observed. The Pearson Correlation analysis showed a statistically significant moderate negative relationship between conceptual understanding and problem-solving ability, suggesting a disconnect between students' reasoning and application skills. These findings align with previous research highlighting inconsistencies between conceptual and procedural competencies, underscoring the need for instructional strategies that integrate both [2], [5]. This study also recommended future research using mixed methods, larger and more diverse samples, longitudinal studies, and exploration of mediating variables to better understand the interplay between these core physics competencies.

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