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Physics teachers' perspectives of roles of mathematics in physics learning in senior high schools

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Abstract

This study explores senior high school physics teachers' perspectives on the role of mathematics in physics education. Through qualitative interviews with five experienced teachers, this research investigates how mathematics supports students' understanding of physics concepts, as well as the challenges teachers face in integrating it effectively. Findings reveal that teachers view mathematics as essential for deepening comprehension, enabling students to analyze, predict, and quantify physical phenomena. However, they also acknowledge the difficulties that students, especially those with weaker math skills, encounter, which can lead to disengagement. To address this, teachers employ adaptive strategies, such as starting with conceptual explanations and using visual aids and real-world examples to make mathematics more accessible. These insights underscore the need for a balanced approach that integrates mathematics in ways that align with students' cognitive readiness, thereby enhancing engagement and comprehension. This study contributes to understanding effective instructional practices in physics education, supporting more accessible and meaningful learning.

Keywords: Physics teachers' perspectives; Mathematics integration, Physics teaching.

1. Introduction

Mathematics plays an essential role in physics teaching, particularly at the senior high school level, where it serves as a critical tool for developing students' understanding of core physical concepts (Bigozzi et al. 2018). Mathematics in physics enables students to describe, analyze, and model various phenomena, providing a language to represent physical laws quantitatively. For example, concepts such as Newton's laws, energy, and electromagnetism often require a solid foundation in algebra, calculus, and trigonometry. Mathematics allows students to move beyond qualitative explanations, giving them the skills to predict outcomes and solve complex problems analytically. In addition to facilitating problem-solving, mathematics supports logical reasoning, enabling students to approach scientific questions systematically. Consequently, mathematics in physics classes not only enhances comprehension but also strengthens students' analytical skills, a benefit that extends across other scientific disciplines and into real-world applications. These skills are invaluable in shaping scientifically literate individuals capable of interpreting and engaging with the world around them.

If physics instruction were to avoid a mathematical approach, the impact on students' understanding would be significant. While conceptual understanding is critical, it is incomplete without the quantitative aspect that mathematics provides. Without mathematics, students may grasp the general principles but struggle to apply these concepts practically or predict real-life outcomes. For instance, understanding acceleration as "a change in velocity over time" conceptually is quite different from calculating it in specific scenarios, such as a car decelerating at a known rate. Removing the mathematical component may also lead to a shallow grasp of fundamental physics laws, as students would lack the skills to analyze or test these laws experimentally (Vanlehn and Van de Sande 2009). Additionally, the absence of a mathematical approach limits students' readiness for further studies in STEM fields, where mathematical skills are foundational. Physics is inherently quantitative, and simplifying it by removing mathematics may detract from its accuracy and depth, potentially resulting in students perceiving physics as disconnected from real-world applications and less rigorous than other sciences.

The primary purpose of this research is to explore physics teachers' perspectives on the role of mathematics in physics instruction at the senior high school level. By examining teachers' viewpoints, this study seeks to understand how they perceive the integration of mathematics in fostering students' comprehension of physics concepts. Additionally, this research aims to identify the perceived challenges teachers face when balancing conceptual explanations with mathematical rigor in physics learning. Analyzing these perspectives could offer insights into potential strategies for aligning mathematical approaches with students' learning needs and addressing challenges related to students' mathematical readiness. This study also investigates teachers' opinions on the possible impacts of a reduced emphasis on mathematics in physics education, which could provide a valuable foundation for curriculum development. Ultimately, the research findings may contribute to refining physics teaching methods, helping teachers optimize their instructional approaches to ensure that students not only grasp conceptual knowledge but also develop the mathematical competencies essential for advanced studies and real-world applications.

2. Literature Review

In this present study, we discussed briefly some literature review related to nature of mathematics in physics teaching, previous research dealing with integration of mathematical approach in physics teaching.

2.1 Nature of mathematics in physics teaching

The integration of mathematics in physics teaching is extensively supported in educational literature, highlighting its role as both a tool and a language for understanding physical phenomena. Mathematics in physics does not simply function as a calculative skill but acts as a structural framework that helps students analyze, predict, and model real-world occurrences (Kuo et al. 2020). It enables students to represent complex physical ideas in a simplified, systematic way, reinforcing the accuracy of scientific principles (Airey and Linder 2009). Studies indicate that mathematical proficiency in physics supports cognitive development by enhancing students' logical reasoning and problem-solving abilities, which are critical in STEM disciplines (Bryant et al. 2016). Furthermore, when mathematical concepts are integrated with physics instruction, students are better prepared to engage with experimental and theoretical physics, as well as interdisciplinary fields that require quantitative skills, such as engineering and data science. This linkage of math and physics cultivates a deeper comprehension, as it allows students to explore and make sense of concepts like force, energy, and motion through equations and quantitative reasoning, rather than solely relying on verbal explanations.

However, research also emphasizes the potential challenges that come with emphasizing mathematics in physics instruction, particularly regarding student accessibility and learning progression. Some studies note that an over-reliance on mathematics can lead to cognitive overload, especially

for students who struggle with mathematical concepts (Tuminaro and Redish 2007). Physics educators often express difficulty in striking a balance between teaching conceptual understanding and mathematical rigor, as students may disengage if they perceive physics as overly mathematical (Kuo et al. 2020). To address this, educational models have been proposed that advocate for a gradual introduction of mathematical complexity, ensuring students develop foundational conceptual insights before tackling advanced quantitative aspects (Riley et al. 2017). Additionally, instructional strategies, such as using visual aids, simulations, and problem-solving frameworks, have shown potential in helping students integrate mathematical knowledge with physical understanding effectively. These studies highlight the need for a thoughtful approach to incorporating mathematics in physics teaching, one that is responsive to students' cognitive needs and that fosters both conceptual and quantitative skills.

2.2 *Prior research dealing with integration of mathematics in physics teaching*

Research on the integration of a mathematical approach in physics teaching underscores its importance in enhancing students' conceptual understanding and problem-solving skills. Studies show that when mathematics is used effectively in physics instruction, it enables students to develop a deeper, more nuanced understanding of complex physical concepts Kuo et al. 2020. Redish (2022) found that embedding mathematical modeling within physics lessons helps students grasp the underlying principles by translating abstract ideas into tangible, analyzable forms. Furthermore, Bryant et al. (2016) emphasized that incorporating mathematics in physics encourages students to engage in higher-order thinking, fostering a systematic approach to scientific inquiry. The use of mathematical equations and models allows students to make predictions, test hypotheses, and validate physical laws, which are essential processes in scientific research and practice. Studies also show that mathematical tools such as calculus, vectors, and algebra can help students overcome misconceptions by challenging them to apply physics principles quantitatively, moving beyond memorization toward meaningful learning (Tuminaro and Redish 2007).

Despite these benefits, research highlights challenges in integrating mathematics effectively in physics classrooms. Tuminaro and Redish (2007) observed that students often struggle with the mathematical rigor required in physics, which can lead to frustration and disengagement if not appropriately scaffolded. Several studies, including those by Kuo et al. (kuo2013students), advocate for instructional strategies that gradually introduce mathematical elements, allowing students to first build a strong conceptual foundation. For instance, the use of visual aids and simulations, as discussed by Holmes et al., helps students form mental models of physical phenomena before they encounter complex equations. Additionally, instructional frameworks like Modeling Instruction have been shown to be effective, as they encourage students to create and test their own models, fostering a natural progression from conceptual understanding to mathematical application (Wells, Hestenes, and Swackhamer 1995). These findings suggest that a balanced approach to integrating mathematics in physics, which aligns with students' cognitive readiness and promotes active engagement, can enhance learning outcomes and better prepare students for advanced studies in STEM fields.

3. Research Method

3.1 *Research design and participants*

This research utilizes a descriptive qualitative design to explore physics teachers' perspectives on the role of mathematics in senior high school physics learning. The qualitative approach is suitable because it allows for an in-depth understanding of teachers' perceptions, experiences, and challenges related to integrating mathematics into physics instruction. Through interviews and open-ended surveys, this study seeks to capture the nuances of teachers' insights and identify common themes that reveal both the benefits and difficulties of using mathematics to teach physics. The data collection includes semi-structured interviews that encourage participants to express their views freely, providing a

comprehensive understanding of their beliefs and instructional strategies. The qualitative approach also facilitates identifying individual and collective perspectives, as teachers' responses are analyzed to discern patterns and unique viewpoints. This design choice aligns well with the study's purpose, as it enables the researcher to gain a detailed perspective on how mathematics is valued and applied in physics classrooms, helping to clarify the influence of mathematical approaches on students' physics understanding.

The study's participants are physics teachers from senior high schools, specifically those teaching physics to grades 10–12. A purposive sampling method is employed to select teachers with varied teaching experiences and academic backgrounds, ensuring a broad range of insights. The sample includes approximately 5 physics teachers from different schools in Garut, both private and public in a city in Indonesia, to capture diverse educational contexts and teaching conditions. The selection criteria also consider teachers who have had substantial experience in integrating mathematics in their physics instruction, as they are likely to provide relevant insights into the challenges and benefits encountered in practice. In addition to gender, experience levels, and teaching location, the participants' familiarity with various instructional strategies is taken into account to ensure a balanced representation of perspectives. These participants' experiences will help inform the study's findings, offering a multifaceted understanding of how mathematics is perceived and applied in high school physics education.

3.2 Instruments and data analysis

Data collection instruments for this study include semi-structured interview guides (Adeoye–Olatunde and Olenik 2021). The interview guide contains questions aimed at eliciting teachers' views on the importance of mathematics in physics, specific challenges they face, and their strategies for integrating mathematical concepts into lessons. These questions are designed to prompt teachers to share personal experiences and reflections, yielding rich, qualitative data. The instruments are validated through pilot testing with a small group of teachers to ensure clarity, relevance, and effectiveness in capturing the intended information. Using multiple instruments enhances data reliability by enabling the researcher to triangulate findings and gather comprehensive information on teachers' perspectives, practices, and perceived impacts of mathematical integration in physics.

The data analysis follows a thematic approach, wherein interview transcripts responses are coded to identify recurring themes and patterns in teachers' perspectives. Initial coding involves reading through the data to develop a list of codes that reflect key concepts, such as "importance of mathematics," "teaching challenges," and "student understanding." These codes are then grouped into broader themes, like perceived benefits and instructional strategies, which are analyzed in depth to understand the roles mathematics plays in physics education. The analysis includes comparing responses across different teacher demographics, such as years of experience and teaching locations, to uncover any variations in perspective. Finally, the findings are cross-referenced with existing literature to contextualize teachers' viewpoints within broader educational discussions on math-physics integration, providing insights into how these perspectives align with or differ from theoretical frameworks.

4. Result of the research and discussion

The integration of mathematics into physics education has long been acknowledged as a crucial factor in developing students' understanding of the physical world. Physics, inherently a quantitative science, relies heavily on mathematical concepts to describe, analyze, and predict physical phenomena. For senior high school physics teachers, the challenge lies not only in teaching the physical concepts but also in ensuring that students can navigate the mathematical frameworks that underlie these concepts. This task becomes even more complex when considering the varying levels of students'

mathematical proficiency and their ability to connect abstract mathematical ideas with real-world applications.

The following data, gathered from interviews with five experienced high school physics teachers, offers valuable insights into their perspectives on the role of mathematics in physics learning. Each teacher recognizes the significance of mathematics in making physics more accessible and precise, yet they also acknowledge the difficulties students face when trying to apply mathematical principles to solve physics problems. The teachers express differing views on how mathematics should be introduced and balanced with conceptual learning. Some emphasize that math is the "language of physics" and is essential for deeper comprehension, while others warn against overloading students with mathematical formulas that might overshadow the physical concepts they are meant to represent.

The data highlights the challenges physics teachers face in balancing the mathematical rigor required in physics with the need to ensure that all students, regardless of their mathematical background, can succeed in understanding core physical principles. These teachers' experiences provide critical insights into the practical implications of integrating mathematics into physics instruction, which can inform future teaching practices, curriculum design, and professional development strategies for physics educators.

Teacher 1: "Mathematics is essential in my physics classes because it allows students to understand abstract concepts more concretely. For instance, without equations, students might understand what acceleration is conceptually, but they won't be able to calculate or apply it in different situations. However, many of my students struggle with the mathematical part, and that can sometimes make them feel disconnected from the subject."

Teacher 2: "I see math as the language of physics. It's the way we translate physical phenomena into something measurable and analyzable. Without math, I feel like I'm only giving my students half the story. At the same time, I have to be careful to balance the math content because if it's too challenging, it might discourage students who are not as confident with numbers."

Teacher 3: "Mathematics helps students see relationships in physics that would otherwise be difficult to grasp. For example, when teaching energy concepts, showing the equations for kinetic and potential energy helps them understand the conservation of energy in a quantitative way. But I've noticed that if students don't have a strong math foundation, they tend to focus on memorizing formulas rather than truly understanding the physics behind them."

Teacher 4: "I believe that math is a tool that helps deepen students' understanding, but it shouldn't overshadow the physics concepts themselves. My goal is to help students understand that physics isn't just about calculations; it's about understanding the world around them. Sometimes, I start with a conceptual explanation and only bring in the math after students have a good grasp of the basic ideas."

Teacher 5: "In my experience, integrating math into physics is a double-edged sword. On one hand, it's necessary for accurate understanding and for students to be able to make predictions. On the other hand, it can be overwhelming. Many students get intimidated by the math, so I try to use visual aids and real-world examples to make the math more approachable and relatable."

The findings from the interviews with senior high school physics teachers emphasize both the pivotal role of mathematics in physics education and the complexity of balancing mathematical

rigor with student accessibility. The teachers universally acknowledge mathematics as a crucial language in physics, necessary for describing, analyzing, and predicting physical phenomena in ways that purely conceptual teaching cannot achieve. As stated by one teacher, without mathematics, students would only gain a superficial understanding of physics concepts, lacking the skills to solve real-world problems or explore physics in depth. This aligns with existing literature which posits that mathematical proficiency strengthens students' abilities to understand scientific laws quantitatively (Redish 2022). The role of mathematics, therefore, is not just supportive but integral to learning physics effectively. However, the teachers' insights also reveal significant challenges, particularly when students lack confidence or foundational skills in mathematics. This challenge resonates with studies that suggest an overemphasis on mathematics can discourage students from engaging fully with physics (Tuminaro and Redish 2007). The teachers in this study indicate that students who struggle with mathematical concepts often face barriers to understanding physics and may resort to rote memorization of formulas instead of meaningful learning. To mitigate this, many teachers adopt a strategy of starting with conceptual explanations before introducing the mathematical aspects, allowing students to grasp the essence of the topic first. Other teachers support mathematical integration with visual aids and relatable real-world examples, making math more approachable and fostering a supportive learning environment (Airey and Linder 2009).

These findings suggest that while mathematics is essential, a flexible, adaptive approach to integrating it into physics is necessary. Teachers' strategies for balancing mathematics with conceptual understanding illustrate a broader pedagogical challenge in physics education: meeting diverse student needs while maintaining instructional rigor. The study points to a need for teacher training programs to focus on developing adaptive instructional strategies that bridge math and physics learning effectively. Furthermore, curriculum developers might consider structuring physics topics in a way that builds mathematical complexity gradually, allowing students to develop confidence alongside conceptual understanding. Ultimately, this approach could lead to improved student engagement and success in physics, helping students appreciate both the practical and theoretical relevance of mathematics in understanding the natural world.

5. Conclusion

In conclusion, this study highlights the complex yet essential role of mathematics in senior high school physics education, as perceived by physics teachers. Mathematics is recognized by teachers as a fundamental tool that enables students to deepen their understanding of physics concepts, facilitating quantitative analysis, prediction, and problem-solving. Without mathematics, students may only achieve a partial understanding of physics, limiting their ability to apply concepts in meaningful, practical ways. However, teachers also face challenges in implementing a mathematical approach, as many students struggle with the mathematical demands of physics, which can lead to disengagement or reliance on rote memorization of formulas.

To address these challenges, teachers employ strategies such as starting with conceptual explanations, incorporating visual aids, and connecting mathematical ideas to real-world examples. These methods help make mathematics more accessible and foster a supportive environment for diverse learners. This study underscores the need for a balanced instructional approach that gradually integrates mathematics with conceptual learning, allowing students to build confidence and comprehension concurrently. By adopting flexible and adaptive teaching strategies, educators can make physics both rigorous and accessible, ultimately improving students' engagement and readiness for further studies in STEM fields.

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