

Perspective

# The essential role of mathematics in physics: A critical examination of the consequences of studying physics without mathematics

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**Abstract:** It is well known that physics and mathematics are inextricably linked, and this understanding is essential to the progress of science. This essay critically examines the drawbacks of studying physics without a strong background in mathematics, particularly for undergraduate and graduate students. By analyzing the theoretical underpinnings, historical context, and practical applications of both fields, we argue that excluding mathematics from physics education hinders students' ability to articulate and solve problems, leading to conceptual errors. We contend that studying physics in isolation from mathematics compromises the accuracy, depth, and clarity necessary for a critical comprehension of physical phenomena.

**Keywords:** physics; mathematics; conceptual understanding; cognitive development; educational implications; interdisciplinary learning; curriculum design

## 1. Introduction

Physics is often defined as the study of the fundamental rules that govern the natural world, while mathematics serves as the language used to express and comprehend these laws. The close connection between the two disciplines has led to numerous advances in both fields. For instance, significant discoveries in physics, such as Newton's laws of motion and Einstein's theory of relativity, were made possible through the application of advanced mathematical concepts. In this paper, we investigate the consequences of studying physics without a strong foundation in mathematics. We argue that mathematics is not merely a tool for physics but an integral part of its theoretical framework. Excluding mathematics from physics education results in a lack of understanding and incorrect approaches to problem-solving.

## 2. Main discussion

### 2.1. Historical context: Mathematics and physics in tandem

Throughout history, physics and mathematics have evolved hand in hand. From Isaac Newton's *Principia*, which laid the mathematical groundwork for classical mechanics, to Albert Einstein's theory of relativity, which relies heavily on differential geometry, mathematical equations have provided precise descriptions of physical laws. Every significant development in physics has relied on mathematical principles to predict novel phenomena and convey abstract ideas. This long-standing collaboration underscores the impracticality, if not impossibility, of separating these two disciplines for a meaningful study of the physical universe.

Historically, there have been attempts to teach physics without mathematics, particularly in the form of *Experimental Physics* during the 18th century in France. The goal was to make physics accessible to a broader audience, not just scholars. However, many scientists argued that mathematics was necessary to elevate physics from mere observation to a rigorous science. Without mathematics, physics loses its precision, leading to conceptual problems and errors.

## **2.2. Theoretical implications of physics without mathematics**

Physics studies natural phenomena from both qualitative and quantitative perspectives. While qualitative observations help describe behaviors and patterns, it is the quantitative approach—enabled by mathematics—that allows for accurate measurement, modeling, and forecasting. Without mathematics, students would struggle to comprehend concepts like motion, energy, and forces beyond their descriptive aspects. They would also miss out on understanding the fundamental numerical relationships that define these concepts.

Many physical theories, such as electromagnetism and quantum mechanics, are based on abstract mathematical concepts like differential equations, complex numbers, and linear algebra. Without these tools, students would have an inadequate or even deceptive grasp of physical reality. For example, quantum superposition and wave-particle duality, two paradoxical phenomena in quantum mechanics, are difficult to comprehend without the mathematical foundation. Attempts to study these phenomena without mathematics often lead to vague and incorrect interpretations.

## **2.3. Practical consequences: Problem-solving and prediction**

Physics is fundamentally an empirical science, and mathematics is essential for developing testable predictions. Theories must be verified through experiments, and without mathematics, the process of creating predictive models becomes arbitrary and error-prone. For instance, Newton's second law of motion quantifies the relationship between force, mass, and acceleration. Without this equation, it would be impossible to predict how a physical system will change over time.

Moreover, interpreting experimental data in physics requires advanced mathematical skills, including statistical analysis, curve fitting, and error computation. Without these abilities, students and practitioners would be unable to evaluate data effectively, leading to unreliable conclusions.

## **2.4. Conceptual clarity: Bridging theory and reality**

Mathematics serves as the bridge between theoretical physics and the physical world. Physical theories are inherently abstract, and complex mathematical ideas are often needed to describe and predict real-world phenomena. For example, Maxwell's equations, which describe the behavior of electric and magnetic fields, are not only theoretical constructs but also have practical applications in communication systems and electrical circuit design. Without understanding the mathematics behind these equations, the usefulness of these theories becomes unclear.

A lack of mathematical precision can also lead to conceptual misconceptions. For instance, the concept of momentum in classical mechanics is simple to understand

qualitatively, but its specific role in conservation laws and its relationship to force and motion are lost without the mathematical formulation. These knowledge gaps become more severe as students' progress to advanced topics like thermodynamics and relativity.

## **2.5. Data supporting the necessity of mathematics in physics education**

Empirical evidence strongly supports the claim that physics cannot be studied effectively without mathematics. Studies in physics education have consistently shown that students with strong mathematical skills perform better in physics courses. This section presents key findings from research that highlight the importance of mathematics for understanding physics concepts, solving problems, and achieving academic success.

## **2.6. Correlation between mathematical proficiency and physics performance**

Numerous studies have found a positive correlation between mathematical ability and success in physics. Meltzer [1] found that students' performance in introductory physics courses was reliably predicted by their math skills. Students with a solid foundation in algebra, calculus, and trigonometry were better able to understand physics concepts, outperform their peers in problem-solving tasks, and achieve higher grades.

A longitudinal study by Hudson and McIntosh [2] followed students from secondary school to undergraduate physics programs and found that those who excelled in mathematics had higher retention rates and academic success in physics. The study concluded that a lack of mathematical proficiency significantly hindered comprehension of complex topics like quantum mechanics and electromagnetism.

## **2.7. Conceptual understanding and problem-solving**

Mathematics is not only necessary for numerical computations but also for enhancing conceptual understanding. Kuo et al. [3] found that students who could translate physical problems into mathematical expressions demonstrated a deeper conceptual understanding and were better able to explain physical phenomena.

Standardized tests like the Mechanics Baseline Test (MBT) and Force Concept Inventory (FCI) further emphasize the importance of mathematical reasoning in physics. Students who performed well on these tests showed a strong ability to apply mathematical reasoning to solve physics problems. Conversely, low mathematical proficiency made it difficult for students to understand physical laws and make predictions using physical models, resulting in lower test scores.

## **2.8. Impact on advanced physics topics**

The demand for mathematical proficiency increases in advanced physics courses like relativity, quantum mechanics, and thermodynamics. Students with low mathematical fluency struggled in courses requiring vector calculus, linear algebra, and partial differential equations. For example, the wave function in quantum

mechanics can only be fully understood and manipulated through mathematical formalism involving complex numbers and differential equations.

Students who attempt to study advanced physics without the necessary mathematical background often resort to rote memorization rather than conceptual understanding, leading to poor performance and a superficial grasp of the subject.

## **2.9. Real-world applications and predictive power**

One of physics' most powerful tools is its ability to model and predict physical phenomena using mathematics. Students with strong mathematical skills could create precise models of physical systems and make highly accurate predictions. In contrast, students without a mathematical background struggled to make accurate predictions, negatively impacting their performance in both academic and real-world applications.

## **2.10. International trends in physics education**

International assessments like the Programme for International Student Assessment (PISA) highlight the global importance of mathematics in physics education. Countries where physics students perform well, such as Finland and Singapore, also demonstrate strong mathematical proficiency. A 2018 PISA assessment showed that students from these countries significantly outperformed their peers in physics.

## **3. Conclusion**

In conclusion, studying physics without mathematics is not only impractical but also detrimental to developing a comprehensive and precise understanding of the subject. Advances in physics theory are intimately related to mathematical formulation, and practical applications require quantitative analysis and prediction. Excluding mathematics from physics education undermines the discipline's theoretical and empirical foundations, reducing it to vague descriptions and conceptual gaps. Therefore, it is imperative that physics instructors and students fully engage with mathematics, recognizing it as an integral part of the physical sciences.

**Conflict of interest:** The author declares no conflict of interest.

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