

Enhancing Scientific Literacy in University Physics Teaching: Design and Practice Based on Newton's Laws of Motion

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Abstract

This study investigates the design and practical implementation of teaching strategies aimed at enhancing scientific literacy in university physics education, using Newton's laws of motion as a case study. Through theoretical analysis, student situation surveys, teaching design, and empirical validation, the research examines the significance of scientific literacy in university physics teaching, its design principles, and the outcomes of its implementation. The findings demonstrate that embedding scientific literacy into teaching practices significantly improves students' competencies across four key dimensions: scientific methods, scientific thinking, scientific attitudes, and awareness of science's social impact.

Keywords

University Physics Teaching, Scientific Literacy, Teaching Design, Newton's Laws of Motion, Dimensions of Scientific Literacy

1. Introduction

In an era defined by globalization and rapid technological advancement, scientific literacy has emerged as a critical competency for science and engineering students, enabling them to adapt to societal demands and engage in informed scientific decision-making (Fang & Liu, 2008; Zhang, 2002). As a foundational course for science and engineering disciplines, university physics not only imparts fundamental

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concepts and laws but also serves as a vital platform for fostering students' scientific thinking, practical skills, and innovative capacities. Evaluations of traditional teaching methods reveal that instruction on Newton's laws of motion often restricts students' understanding to rote memorization of formulas, limiting their ability to apply these principles flexibly to real-world problems. Furthermore, students exhibit a weak grasp of the scientific inquiry process and the broader societal implications of physics, resulting in notable deficiencies in comprehending the essence of physics, mastering scientific methods, and recognizing science's societal value.

Scientific literacy encompasses the ability to apply scientific knowledge and methods holistically to address problems, spanning dimensions such as scientific knowledge, process skills, and attitudes. Newton's laws of motion, a cornerstone of classical mechanics, are a central focus in university physics teaching. These laws not only elucidate the fundamental principles governing object motion but also offer an exemplary case for students to explore scientific methods and develop logical reasoning. This study leverages Newton's laws as a starting point to design and implement a teaching model aimed at enhancing scientific literacy. By integrating theoretical insights with practical application, the research seeks to comprehensively elevate students' scientific literacy and provide valuable insights for reforming university physics education.

2. Logical Mapping between University Physics Courses and Scientific Literacy Cultivation

Scientific literacy refers to an individual's capacity to comprehend scientific knowledge, employ scientific methods, utilize scientific thinking, cultivate scientific attitudes, and recognize the societal impacts of science. As a core foundational course for science and engineering students, university physics emphasizes the development of observational skills, experimental proficiency, and logical reasoning—attributes that align closely with the essence of scientific literacy. The teaching objectives of university physics courses correspond seamlessly with the logical framework for cultivating scientific literacy (Zhang & Zhang, 2016; Sun, 2024). Using Newton's laws of motion as an illustrative example, **Table 1** delineates the logical mapping between university physics curricula and scientific literacy cultivation.

3. Student Situation Analysis

In university physics education, cultivating scientific literacy extends beyond knowledge transmission to encompass the development of students' holistic competencies. By designing teaching strategies centered on Newton's laws, scientific literacy can be effectively enhanced across multiple dimensions. Drawing on the learning characteristics and cognitive levels of university students, this study utilized questionnaires, classroom observations, and interviews to identify specific challenges in various scientific literacy dimensions and propose targeted instructional strategies, as outlined in **Table 2**.

Table 1. Logical mapping between university physics courses and scientific literacy cultivation.

Objective	Core Elements of Scientific Literacy	Logic of University Physics Courses in Cultivating Scientific Literacy
Systematic Transmission of Scientific Knowledge	<p>Scientific Knowledge: The ability to understand scientific concepts, principles, and theories. In university physics, students must master the core content of Newton’s laws, such as Newton’s first law (the law of inertia), which describes the conditions under which an object remains at rest or in uniform motion; Newton’s second law ($F = ma$), which quantifies the relationship between force and acceleration; and Newton’s third law (action and reaction), which illustrates the mutual interaction of forces.</p>	<p>University physics courses establish a scientific worldview through a structured knowledge framework. For instance, Newton’s laws not only underpin mechanics but also provide a foundation for subsequent concepts like energy and momentum conservation. In teaching, instructors elucidate the concept of inertia in the first law, the mathematical formulation of the second law ($F = ma$), and the interaction principle of the third law, enabling students to grasp the essentials of classical mechanics.</p>
Experimental Teaching and Training in Scientific Methods	<p>Scientific Methods: The ability to conduct scientific inquiry through observation, experimentation, reasoning, and validation. For example, with Newton’s second law, students can measure mass, force, and acceleration experimentally to verify the theoretical model, thereby mastering the scientific inquiry process.</p>	<p>Physics experiments are pivotal in cultivating scientific methods. In teaching Newton’s laws, students can perform experiments like “verifying Newton’s second law”, designing variable-controlled procedures (e.g., fixing mass and varying force, or vice versa), measuring acceleration, and analyzing data. This process immerses students in the full cycle of hypothesis formulation, experimental design, data analysis, and conclusion validation.</p>
Problem-Solving and Cultivation of Scientific Thinking	<p>Scientific Thinking: Encompasses critical thinking, logical reasoning, and problem-solving skills. When analyzing complex mechanical systems (e.g., a block on an inclined plane), students must apply Newton’s laws to decompose forces, formulate equations, and solve them, fostering the ability to abstract general principles from specific phenomena.</p>	<p>University physics teaching promotes scientific thinking through problem-based learning. Using Newton’s laws, instructors can design scenarios such as “analyzing forces on a passenger in an accelerating elevator” or “calculating the acceleration of a block on a frictional inclined plane”, guiding students to decompose forces, establish coordinate systems, set up equations, and solve them, thereby enhancing their logical reasoning and problem-solving capabilities.</p>
Shaping Scientific Attitudes and Spirit	<p>Scientific Attitudes: Refers to curiosity about science, a commitment to truth-seeking, and a rigorous approach. Newton’s development of the laws of motion through repeated observation and reasoning about falling objects and planetary orbits exemplifies the perseverance of scientific inquiry, serving as a model for students.</p>	<p>By integrating the history of physics and scientists’ research journeys, instructors can ignite students’ enthusiasm for science. For example, Newton’s synthesis of Kepler’s laws with universal gravitation to formulate a unified theory of motion highlights curiosity and rigor, inspiring students to adopt a truth-seeking mindset in their studies.</p>
Reinforcing the Social Impact of Science and Responsibility	<p>Social Impact of Science: The ability to comprehend science and technology’s influence on society, the economy, and the environment. Newton’s laws underpin modern engineering applications, such as car seatbelt design and spacecraft trajectory calculations, enabling students to appreciate physics’ profound contributions to society.</p>	<p>The evolution of physics has significantly shaped human society. Newton’s laws, for instance, are applied in transportation (e.g., braking systems), aerospace (e.g., rocket propulsion), and beyond. Through case studies in teaching, students gain insight into the practical value of scientific knowledge and scientists’ societal responsibilities, fostering their scientific decision-making skills and sense of duty.</p>

Table 2. Student situation analysis.

Cognitive Dimension	Student Issues	Specific Cases	Solutions	Scientific Literacy Goals
Understanding Scientific Knowledge	Students' comprehension of Newton's laws is often limited to formula memorization, lacking depth in physical meaning and application conditions.	Misinterpreting Newton's first law as applying only to stationary objects, overlooking inertia's role in uniform motion.	Introduce real-life scenarios (e.g., a skater gliding at constant speed) and multimedia animations to guide students in deriving laws from phenomena.	Deepen understanding of scientific knowledge and construct a systematic framework.
Application of Scientific Methods	Lack of rigor in experimental procedures, weak awareness of variable control, and limited data analysis skills.	Failing to control friction in experiments verifying Newton's second law, resulting in inaccurate acceleration measurements.	Develop standardized experimental protocols, enhance variable control training (e.g., fixing mass while increasing force), and guide data fitting and error analysis.	Improve the rigor of scientific inquiry and experimental proficiency.
Scientific Thinking Abilities	Insufficient analytical and reasoning skills when applying theory to complex problems, with limited experience in multi-step problem-solving.	Struggling to analyze the motion of a "car on a frictional inclined plane", often neglecting force vector decomposition.	Design progressive problems (e.g., from frictionless to frictional inclined planes), guiding students in force decomposition, modeling, and solution.	Foster logical reasoning and problem-solving skills.
Formation of Scientific Attitudes	Lack of initiative and curiosity in physics learning, with limited critical thinking and passive acceptance of conclusions.	Showing disinterest in the story of "the apple inspiring Newton" and failing to explore its scientific significance.	Incorporate historical scientific cases (e.g., Newton's integration with Kepler's laws) and stimulate interest through discussions.	Ignite curiosity and a truth-seeking spirit.
Social Impact of Science	Vague awareness of Newton's laws' societal value and limited ability to connect knowledge to reality.	Unaware of Newton's third law in rocket launches or the role of inertia in seatbelt design.	Introduce case-based teaching (e.g., spacecraft propulsion and traffic safety design) and facilitate discussions on physics' contributions to technology.	Enhance social responsibility and scientific decision-making abilities.

4. Teaching Design

To achieve comprehensive scientific literacy development, a teaching design centered on Newton's first law is presented in **Table 3**. The instructional process includes an introduction, theoretical explanation, experimental inquiry, case analysis, and summary reflection, targeting enhancement across all scientific literacy dimensions.

Table 3. Teaching design.

Teaching Process	Teaching Content	Teaching Methods	Analysis of Scientific Literacy Dimension Enhancement	Specific Cases	Teaching Evaluation	Correspondence with Student Situation Analysis
Introduction	Introduce inertia phenomena in daily life	Situational creation method	Scientific Knowledge: Use real-life examples (e.g., passengers leaning forward during sudden braking) to spark interest in inertia and provide a preliminary understanding of Newton's first law. Scientific Attitudes: Stimulate curiosity through questioning and observation.	Show a video of passengers leaning forward during sudden braking, asking "Why does this happen?"	Observe student interest and participation	Addresses "superficial understanding of Newton's laws" by linking phenomena to laws through relatable scenarios.

Continued

Theoretical Explanation	Definition and physical significance of Newton's first law	Lecture method + multimedia	Scientific Knowledge: Systematically explain the core of Newton's first law, clarifying motion states without external forces. Scientific Thinking: Use animations to demonstrate inertia, aiding students in abstracting laws from examples and boosting reasoning skills.	Use animations to illustrate "an object remains at rest or in uniform motion without external forces", explaining inertia.	In-class tests (true/false and short-answer)	Addresses "difficulty applying theory to practice" by enhancing theory-reality connections via visuals.
Experimental Inquiry	Verify Newton's first law	Inquiry-based learning + group experiments	Scientific Methods: Through air track experiments, students design steps and record data, mastering inquiry processes. Scientific Attitudes: Foster rigor and teamwork, emphasizing data integrity.	Conduct an "air track experiment" to observe a cart's motion under near-frictionless conditions, recording speed changes.	Experiment reports + skills assessment	Addresses "lack of experimental rigor" by providing clear protocols and guidance.
Case Analysis	Applications of Newton's first law in technology	Case-based teaching + group discussions	Social Impact of Science: Analyze cases like seatbelt design and satellite orbits to highlight physics' societal contributions. Scientific Thinking: Encourage discussion and innovation in application scenarios, enhancing critical thinking.	Analyze "seatbelt design principles" and "satellite orbital motion", discussing their societal value.	Discussion records + analysis reports	Addresses "vague awareness of science's social impact" by reinforcing practical significance through cases.
Summary and Reflection	Review key points, emphasize scientific spirit and responsibility	Reflective teaching + sharing	Scientific Attitudes: Guide reflection on Newton's scientific spirit, fostering a truth-seeking mindset. Social Impact of Science: Discuss science's societal responsibilities, raising decision-making awareness.	Ask "How did Newton's first law shape our understanding of the universe?" to prompt learning insights.	Reflections + literacy questionnaire	Addresses "unclear understanding of scientific literacy" by deepening comprehension through reflection and discussion.

5. Effectiveness of Teaching Practice

To assess the efficacy of the scientific literacy-oriented teaching design, a practical study was conducted within a university physics course at a local applied undergraduate institution. A total of 193 first-year science and engineering students were selected and divided into an experimental group (scientific literacy-oriented teaching, $n = 94$) and a control group (traditional teaching, $n = 99$) using a quasi-experimental design. The groups were comparable in gender, age, and academic background, with no significant pre-experiment differences in academic performance. Both the experimental and control groups were taught by the same lead instructor, which ensured consistency in pedagogical style, content coverage, and teacher-student rapport. The experimental group integrated scientific literacy modules—such as scientific history narratives, inquiry-based experiments, and debates—into traditional lectures to enhance knowledge, methods, thinking, attitudes, and social application skills. The control group followed conventional textbook-based instruction.

As shown in **Table 4**, a 20-item scientific literacy assessment questionnaire was developed, covering five dimensions: scientific knowledge (4 items), scientific methods (4 items), scientific thinking (4 items), scientific attitudes (4 items), and social impact of science (4 items). Each item used a 5-point Likert scale (1 = "strongly disagree", 5 = "strongly agree"), with higher scores indicating stronger

literacy in that dimension. Following the completion of the scientific literacy assessment questionnaire, a small-scale pre-test was conducted to refine and finalize the questionnaire. Post-collection analysis revealed Cronbach's α values exceeding 0.80 for the total scale and each dimension, confirming high internal consistency.

Table 4. The scientific literacy assessment questionnaire.

Dimension	Item No.	Statement
Scientific Knowledge	1	I can accurately explain the meaning of Newton's first law (e.g., "An object remains at rest or in uniform motion in a straight line unless acted upon by an external force")
	2	I am clear about the mathematical expression of Newton's second law, $F = ma$, and its physical meaning
	3	I understand the principle in Newton's third law that "action and reaction forces are equal in magnitude and opposite in direction"
	4	I can apply Newton's laws of motion to analyze simple physical phenomena (e.g., the motion of an object on a horizontal plane)
Scientific Methods	5	I can design an experiment to verify Newton's first law (e.g., using an air track to observe the motion of a cart)
	6	I can control variables in experiments to ensure the accuracy of results (e.g., keeping mass constant while changing the external force)
	7	I can verify Newton's second law by recording and analyzing experimental data
	8	I believe that scientific inquiry requires rigorous steps (such as proposing hypotheses, experimental verification, and drawing conclusions)
Scientific Thinking	9	I can analyze complex physical problems and correctly apply Newton's laws (e.g., the motion of a cart on an inclined plane)
	10	I can solve practical problems involving Newton's third law by decomposing forces and setting up equations
	11	I believe that learning Newton's laws of motion helps improve logical reasoning skills
	12	I can use Newton's laws to solve new problems and come up with innovative ideas
Scientific Attitudes	13	I am curious about learning the principles and applications of Newton's laws of motion
	14	I find the process of verifying Newton's laws through experiments interesting and meaningful
	15	I am willing to spend time exploring the scientific principles behind Newton's laws
	16	I think Newton's persistent scientific spirit is worth learning from and emulating
Social Impact of Science	17	I know the application of Newton's first law in traffic safety (e.g., seatbelt design)
	18	I understand how Newton's third law drives the development of aerospace technology (e.g., rocket launches)
	19	I believe that the discovery of Newton's laws of motion has a profound impact on modern industry and technological progress
	20	I feel that learning Newton's laws makes me more aware of how science improves social life

6. Descriptive Results

Descriptive statistics for the pre-test (control group) and post-test (experimental group) scientific literacy questionnaire are presented in **Table 5**.

Table 5. Descriptive statistics.

Dimension	Control Group (n = 99) Mean ± SD	Experimental Group (n = 94) Mean ± SD	t	p	Cohen's d
Knowledge	3.86 ± 0.71	4.00 ± 0.72	1.317	0.189	0.190
Methods	3.69 ± 0.67	3.93 ± 0.69	2.497	0.013*	0.360
Thinking	3.61 ± 0.72	3.89 ± 0.62	2.845	0.005**	0.410
Attitudes	3.65 ± 0.66	4.02 ± 0.62	3.960	0.000***	0.570
Social Impact	3.86 ± 0.74	4.20 ± 0.67	3.337	0.001**	0.481
Total Score	3.73 ± 0.62	4.01 ± 0.58	3.144	0.002**	0.453

The control group's mean scores ranged from 3.61 to 3.86, with standard deviations of 0.62 - 0.74, while the experimental group's scores ranged from 3.89 to 4.20, with standard deviations of 0.58 - 0.72. The experimental group outperformed the control group across all dimensions and in total score, with the highest scores in "social impact", followed by "knowledge", and the lowest in "thinking". Normality and homogeneity of variance tests confirmed that the data approximated a normal distribution.

Independent samples t-tests revealed significant differences in scientific methods ($t = 2.497$, $p = 0.013$), scientific thinking ($t = 2.845$, $p = 0.005$), scientific attitudes ($t = 3.960$, $p < 0.001$), and social impact ($t = 3.337$, $p = 0.001$) ($p < 0.05$), but not in knowledge ($t = 1.317$, $p = 0.189$). The total scientific literacy score was also significantly higher in the experimental group ($t = 3.144$, $p = 0.002$). Cohen's d effect sizes for significant differences ranged from 0.36 (methods) to 0.57 (attitudes), indicating small to medium effects.

7. Result Analysis

The results confirm that the experimental group significantly outperformed the control group in scientific methods, thinking, attitudes, and social impact, underscoring the effectiveness of the scientific literacy-oriented teaching design in university physics education.

First, the experimental group's superior performance in scientific methods (medium effect size) reflects the efficacy of hands-on activities like designing verification experiments and controlling variables. Teaching logs and observations indicate that the experimental group's increased practical engagement enhanced skills in items like "can design experiments" and "can control variables", unlike the control group's lecture-heavy approach.

Second, the experimental group's lead in scientific thinking complements the methods improvement. By emphasizing real-world applications of Newton's laws and step-by-step problem-solving, the teaching design bolstered logical reasoning and innovation, evident in higher scores on items like "applying laws to solve problems".

Third, the marked improvement in scientific attitudes highlights the design's success in fostering interest and curiosity. Open-ended questions and engaging

experiments, combined with narratives of scientific discovery, elevated scores on items like “learning is interesting” and “willing to explore further”.

Fourth, the experimental group’s gains in social impact awareness stem from connecting physics to societal applications (e.g., seatbelts, rocket launches), improving responses to items like “concern about science’s societal benefits”. The control group’s theoretical focus limited such gains.

Notably, the lack of significant difference in scientific knowledge may reflect the shared curriculum coverage and time constraints diluting knowledge-focused efforts in the experimental group. This suggests a need to balance inquiry-based learning with foundational knowledge reinforcement, such as through flipped classrooms.

8. Conclusion

Using Newton’s laws of motion as a case study, this research explored the design and practice of enhancing scientific literacy in university physics teaching. The findings affirm that integrating the five dimensions of scientific literacy into teaching significantly enhances students’ physics comprehension, inquiry skills, and social responsibility, while inspiring their learning interest and innovative spirit.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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