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ORIGINAL RESEARCH PAPER

Enhancing Learning of Motion Concepts through Conceptual Frameworks

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ABSTRACT

Drawing on recent advances in physics education research as well as practical insights from classroom experiences, the article proposes a set of strategies for effective implementation. These include contextualizing learning within real-world phenomena, integrating interactive technologies into instruction, and designing inquiry-based learning activities that promote active engagement. A central contribution of this work lies in its dual theoretical and practical orientation. The article not only identifies the pedagogical significance of conceptual tools but also demonstrates how their structured integration can be systematically applied to the teaching of motion. This structured approach represents the main novelty of the study, as it provides teachers with a clear framework for bridging theory and classroom practice. The discussion further addresses common challenges faced in physics instruction, such as persistent misconceptions and limited student engagement. In response, it offers strategies grounded in both educational theory and empirical practice, ensuring that the suggested frameworks are both conceptually sound and practically applicable. In conclusion, the article emphasizes that prioritizing conceptual understanding over purely procedural knowledge can significantly improve student motivation, retention of core ideas, and scientific reasoning skills. Such a shift underscores the transformative potential of conceptual frameworks in advancing the teaching and learning of motion.

Keywords:
Motion in physics, conceptual frameworks, physics education, motion concepts, interactive learning, improving physics education.

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1. INTRODUCTION

A deep understanding of motion concepts (position, displacement, velocity, acceleration, and Newton's laws) is essential for developing students' reasoning and problem-solving skills. However, research shows that learning these concepts is hindered by their abstract nature, overreliance on traditional teaching methods, and lack of connection to real-life contexts. To address these challenges, recent studies emphasize the role of conceptual tools (concept maps, mental models, simulations, and visual representations) in promoting deeper comprehension and correcting misconceptions.

Despite its foundational importance, students ranging from secondary school learners to university undergraduates frequently struggle with motion-related concepts. Research has consistently shown that these difficulties often arise from the abstract nature of motion, inadequate integration of real-life contexts, and a reliance on traditional teaching methods that emphasize rote memorization over conceptual understanding. Misconceptions such as believing that a continuous force is required to sustain motion or that heavier objects fall faster persist even after formal instruction and can significantly hinder students' ability to engage with more complex physical systems.

To address these challenges, recent studies in physics education have emphasized the role of conceptual frameworks—such as simulations, mental models, and visual representations—as tools for promoting deeper understanding, addressing misconceptions, and supporting cognitive engagement.

These frameworks include concept maps, mental models, dynamic simulations, and other representational tools that help students visualize, organize, and relate physical concepts in meaningful ways (Novak, 2010; Chi, 2009; Linn & Eylon, 2011). Unlike conventional approaches that often isolate concepts and prioritize computational fluency, conceptual frameworks aim to integrate knowledge, support metacognitive reflection, and strengthen cognitive connections across topics.

While prior studies have addressed conceptual tools in general physics instruction, fewer works have focused specifically on their integration in teaching motion. This article seeks to fill that gap by examining the pedagogical use of such tools in enhancing students' understanding of motion.

Furthermore, integrating recent learning theories—such as Conceptual Change Theory, Constructivism, and Cognitive Load Theory—into instruction provides a foundation for designing learning experiences that support conceptual restructuring and durable knowledge.

This article presents a theoretical-practical exploration of how conceptual frameworks can be systematically employed to improve student learning of motion concepts. It outlines key motion principles, contrasts traditional and conceptually driven pedagogy, and provides practical classroom strategies—drawn from both educational theory and reflective teaching experience. In doing so, it bridges the gap between research and practice.

Despite several studies exploring conceptual tools in physics education, this paper targets a specific research gap: (a) the lack of an integrated and sequenced framework that combines multiple conceptual tools (concept maps, mental models, simulations, and motion diagrams) specifically for teaching motion; (b) this gap matters because persistent misconceptions in motion directly affect students' problem-solving ability and long-term scientific reasoning; and (c) the contribution of this article lies in presenting a structured framework that connects learning theories to teacher-facing strategies and assessment criteria — going beyond scattered prior studies.
This article represents a theoretical-practical contribution. Its primary novelty lies in the structured integration of multiple conceptual tools—such as concept maps, mental models, and simulations—specifically applied to motion instruction.

2. Fundamental Concepts of Motion in Physics

Motion is one of the most essential and pervasive phenomena in the physical world, forming a core component of both classical mechanics and modern theoretical physics. Understanding motion requires the precise definition and interrelation of several key concepts, such as position, displacement, velocity, and acceleration, as well as a solid grasp of Newton's laws, which govern the dynamics of objects under the influence of forces. This section provides a foundational overview of the types of motion and their associated quantities, forming the basis for exploring more advanced instructional approaches.

2.1 Types of Motion

Motion in physics can be broadly classified into three main categories, each with distinct characteristics and applications: linear motion, rotational motion, and oscillatory motion.

Linear (Rectilinear) Motion involves an object moving along a straight path, either at a constant velocity or under acceleration. Examples include a car traveling on a highway or a falling object under the influence of gravity. This type of motion is typically analyzed using kinematic equations that describe the relationship between displacement, velocity, acceleration, and time (Serway & Jewett, 2018).

Rotational Motion occurs when an object rotates around a fixed axis. This type of motion is observed in systems ranging from spinning wheels to planetary rotation. Key quantities in rotational motion include angular displacement, angular velocity, angular acceleration, and torque (Young & Freedman, 2020).

Oscillatory Motion refers to periodic back-and-forth movement around an equilibrium point, as seen in pendulums, springs, or sound waves. Fundamental parameters such as amplitude, frequency, period, and phase characterize these systems, particularly in simple harmonic motion (Tipler & Mosca, 2008).

2.2 Key Kinematic and Dynamic Quantities

The motion of an object is described using several interrelated physical quantities, each playing a distinct role in analysis and prediction.

Position denotes the spatial location of an object relative to a reference frame. It is often represented using Cartesian or polar coordinates and varies as a function of time (Knight, 2017).

Displacement is the vector quantity representing the change in position over a specified time interval. Unlike distance, displacement conveys both magnitude and direction (Giancoli, 2018).

Velocity refers to the rate of change of displacement with respect to time. It can be expressed as average velocity over an interval or instantaneous velocity at a specific point in time. Understanding velocity is crucial for analyzing uniform and accelerated motion (Serway & Jewett, 2018).

Acceleration is defined as the rate of change of velocity over time. It can be constant (uniform acceleration) or variable, and it plays a central role in the study of dynamics. Acceleration is also a vector, meaning that changes in either magnitude or direction constitute acceleration (Young & Freedman, 2020).

2.3 Applications and Relevance

The concepts of motion have extensive relevance across scientific and technological domains:

In mechanical engineering, analyzing the motion of components informs the design of machines and structures.

In astronomy, understanding planetary and orbital motion enables accurate predictions of celestial events.

In biomechanics, motion analysis helps in understanding the movement patterns of organisms and enhancing performance in sports or rehabilitation.

In transportation and robotics, precise motion modeling is essential for control systems and safety mechanisms.

Establishing a strong conceptual foundation in these motion principles is critical not only for succeeding in physics education but also for applying scientific knowledge in real-world problem-solving. This foundation also prepares students to explore more advanced topics in mechanics, electromagnetism, and thermodynamics.

3. Conceptual Frameworks and Their Role in Teaching Motion

Conceptual frameworks have emerged as transformative tools in science education, offering structured approaches to facilitate students' understanding of complex and abstract ideas. In the context of motion, a domain where misconceptions are persistent and often resistant to traditional instruction, conceptual frameworks help learners build coherent mental models, integrate knowledge, and develop deep conceptual insight.

The effectiveness of these frameworks is grounded in cognitive theories of learning.

Conceptual Change Theory explains how students replace intuitive but incorrect beliefs with scientific ones when faced with cognitive conflict. Constructivist perspectives highlight the importance of active engagement and scaffolding new knowledge on prior understanding. Moreover, Cognitive Load Theory supports the structured use of visual tools and simplified representations to reduce working memory overload. These theories provide a strong foundation for using conceptual frameworks in motion instruction Fyfe, McNeil, Son, and Goldstone (2014) argue that concreteness fading—starting with concrete materials and gradually transitioning to abstract representations—can enhance science learning by grounding abstract thinking in perceptual experiences and promoting generalizable conceptual understanding.

Mental models are internal cognitive structures that learners use to interpret and predict physical phenomena. For example, some students hold an 'impetus-like model' of motion, assuming that continuous force is required to sustain motion, which contrasts with the Newtonian model of inertia. Such models have been extensively studied in conceptual change research [1].

3.1 Defining Conceptual Frameworks in Physics Education

Conceptual frameworks refer to a set of cognitive tools, instructional strategies, and visual representations that support the organization and assimilation of scientific knowledge. Rather than presenting information in isolated fragments, these frameworks foster holistic thinking by emphasizing the relationships among concepts and anchoring new knowledge in prior understanding.

In physics education, key components of conceptual frameworks include:

Concept Maps: Graphical tools that visually represent the hierarchical and relational connections between concepts. These maps assist students in identifying linkages between foundational ideas such as force, velocity, and acceleration.

Mental Models: Internal cognitive structures that students use to interpret and predict physical phenomena. They function as simplified mental representations of reality, enabling learners to explain events, anticipate outcomes, and make decisions in problem-solving contexts. In physics education, students often rely on mental models that may diverge from scientific principles, such as the "impetus model," where motion is incorrectly believed to require a continuous force. Accurate mental modeling is particularly crucial when grappling with Newtonian mechanics, because students must transition from intuitive, everyday conceptions of force and motion to formalized scientific models based on inertia, acceleration, and Newton's laws. Identifying, confronting, and reconstructing these mental models are therefore essential steps in fostering conceptual change and achieving a deeper understanding of motion.

Computer Simulations: Interactive digital environments that allow learners to manipulate variables and observe real-time outcomes. Simulations make invisible forces and motion observable and testable.

Visual Representations: Diagrams, graphs, and schematic illustrations (e.g., free-body diagrams, motion graphs) that translate abstract quantitative relationships into accessible visual formats.

These tools support conceptual learning by enabling students to organize knowledge meaningfully, challenge existing misconceptions, and develop scientifically accurate understandings. Kokkonen and Schalk (2021) argue that while the concreteness fading instructional sequence is appealing, its effectiveness is highly dependent on the nature of the domain-specific representations and instructional goals, particularly in science subjects such as physics.

3.2 Traditional Instruction vs. Conceptual Frameworks

Traditional physics instruction often emphasizes algorithmic problem-solving and formula memorization, with limited attention to the conceptual underpinnings of physical laws. While this approach may yield short-term procedural competence, it frequently fails to cultivate transferable understanding or long-term retention.

In contrast, instruction grounded in conceptual frameworks prioritizes:

Concept discovery over rote memorization

Cognitive engagement over passive reception

Relational understanding over fragmented facts

Table 1 presents a comparative summary of these two approaches under the title "Comparison of Traditional and Conceptual Instruction in Physics", outlining their main characteristics and pedagogical implications:

Table 1 "Comparison of Traditional and Conceptual Instruction in Physics"

Feature	Traditional Instruction	Conceptual Frameworks
Emphasis on memorizing equations	High	Low
Use of visual and interactive tools	Minimal	Extensive
Encouragement of conceptual reasoning	Low	High
Facilitation of cross-concept integration	Limited	Strong
Impact on student engagement	Often low	High

These shifts align with modern theories of meaningful learning and support the use of scaffolding strategies to promote integrative thinking**.**

3.3 Applications of Conceptual Frameworks in Teaching Motion

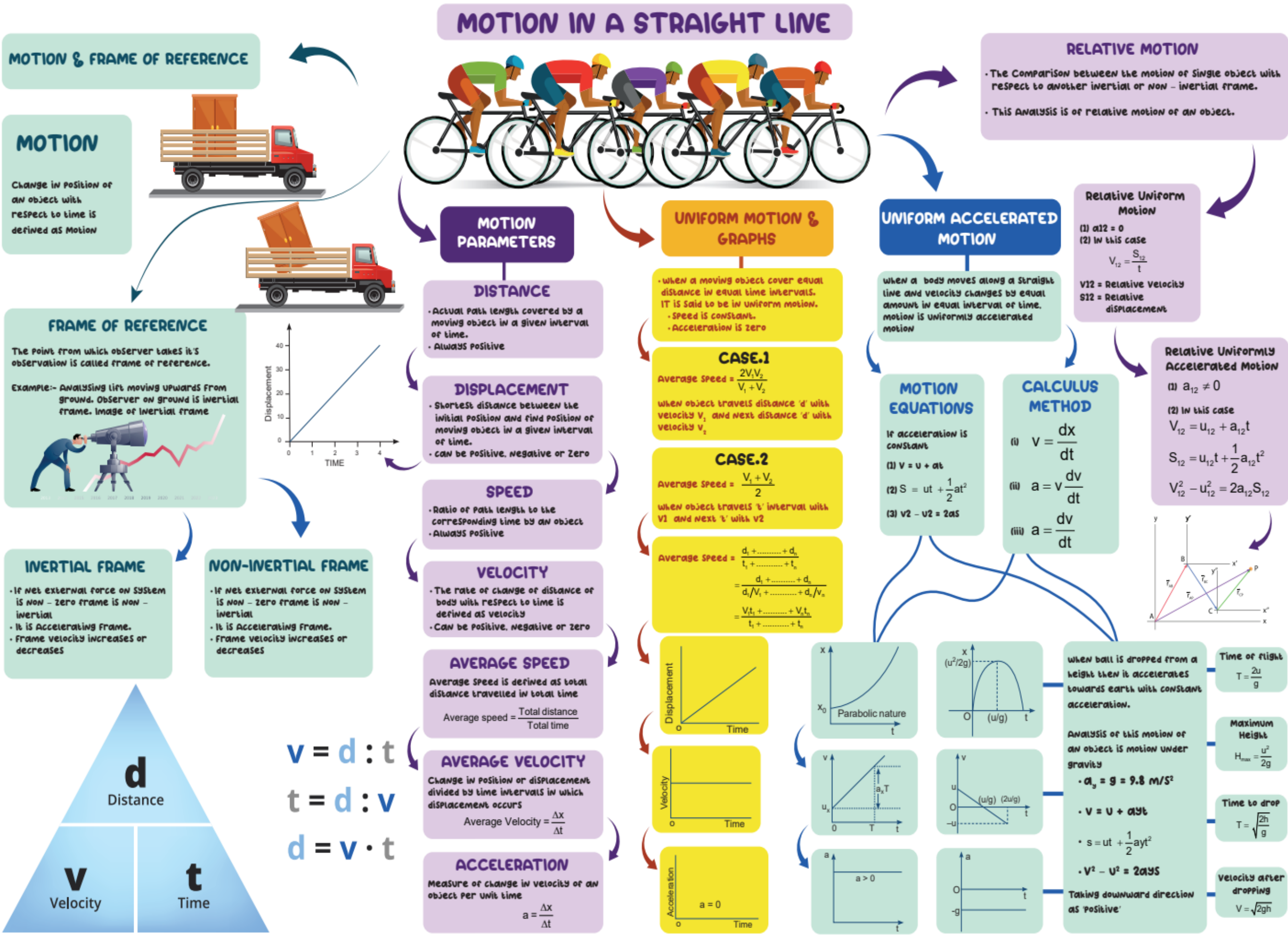
The following instructional tools exemplify the use of conceptual frameworks to teach motion more effectively:

- Motion Diagrams: Visual sequences depicting an object's position, velocity, and acceleration over time. These diagrams help clarify differences between uniform and accelerated motion and support the analysis of kinematic graphs.
- Mathematical Modeling: Encouraging students to derive and apply motion equations based on experimental data fosters both procedural fluency and conceptual understanding. This approach deepens students' grasp of Newton's laws and projectile motion. Recent experimental research has demonstrated that Conceptual Problem Solving (CPS) techniques significantly enhance students'

conceptual understanding of Newton's laws compared to traditional direct instruction (Diyana & Sutopo, 2024).

- Interactive Simulations: Tools such as PhET allow students to manipulate variables like mass and force in real-time. These simulations provide immediate feedback and make abstract relationships tangible. Recent studies suggest that animations grounded in conceptual metaphors and embodied cognition can significantly enhance students' understanding of complex physical concepts, particularly when algebraic reasoning is involved (Oosterwijk, 2022).

Concept Maps: For example, a concept map linking force, mass, and acceleration can reinforce Newton's second law and help correct common misconceptions. Figure 1 illustrates a conceptual map applied to the topic of motion in a straight line.



.Figure 1- An Example of a Concept Map in Physics Learning

These frameworks do not merely supplement instruction; they reshape how students think about physics. By encouraging inquiry, reflection, and knowledge integration, conceptual frameworks move learners beyond superficial familiarity toward genuine understanding.

Although this article does not present new empirical data, the selection and categorization of strategies are grounded in two main sources: (1) a systematic review of literature and empirical evidence on physics concept learning, and (2) classroom-based implementation experiences and feedback. Specifically, the strategies draw on tested approaches such as

Model Analysis [1], the concreteness fading sequence (Fyfe et al., 2014), embodied learning (Lindgren et al., 2016), and studies on simulations and video analysis (Oosterwijk, 2022; Linn & Eylon, 2011). In the manuscript, each strategy is supported with relevant references and classroom-based examples.

To maintain transparency, it is important to clarify how the conceptual strategies presented in this article were selected. These approaches are derived from a combination of the authors' classroom teaching experience, analysis of successful instructional practices, and synthesis of relevant findings in physics education literature. Although the article does not present new empirical data, its recommendations are built upon tested methods and documented research.

4. Practical Strategies for Effective Teaching of Motion

Effectively teaching motion requires pedagogical strategies that bridge abstract theoretical concepts with students' lived experiences and cognitive frameworks. Given the persistent conceptual difficulties learners face in understanding motion—particularly in areas such as velocity, acceleration, Newtonian dynamics, and projectile motion—it is essential to employ diverse, evidence-based instructional approaches.

This section outlines multiple evidence-informed strategies—drawn from instructional practice and literature synthesis—that can help educators improve students' conceptual understanding of motion.

4.1 Connecting Motion Concepts to Real-World Phenomena

Grounding abstract concepts in everyday experiences can significantly improve students' ability to relate to and internalize physical principles. By drawing from familiar contexts, instructors can make motion concepts more accessible and engaging. Table 2 provides an overview of real-life examples and suggested classroom activities that can be used to support the teaching of motion concepts. The table links key physical principles—such as velocity and acceleration, projectile motion, oscillatory motion, and friction—to both experimental classroom practices and familiar everyday contexts, thereby helping students connect theoretical knowledge with practical experiences.

Table 2: Real-Life Examples and Suggested Activities for Teaching Motion

Physical Concept	Classroom Activity	Real-World Example
Velocity and Acceleration	Analyze video clips showing vehicles changing speed under different conditions.	A cyclist accelerating, a car breaking on a highway
Projectile Motion	Perform ball toss experiments from varying heights and measure the trajectory.	Kicking a soccer ball, throwing a stone into a pond
Oscillatory Motion	Use pendulums to investigate amplitude and period	Swinging on a playground swing, the motion of a clock pendulum
Friction	Explore how different surfaces affect motion using inclined planes	Sliding a shoe on carpet, wood, or ice

These contextualized activities align with constructivist learning principles, helping students anchor formal physics content in prior experience and everyday intuition. Such contextualized activities not only improve comprehension but also reinforce the relevance of physics to daily life, thereby boosting students' motivation and retention.

4.2 Utilizing Educational Technologies and Simulation Tools

Digital technologies offer powerful affordances for visualizing and experimenting with motion concepts in ways that are otherwise difficult to replicate in a typical classroom. Interactive simulations allow for repeated experimentation under controlled and idealized conditions. Recent studies have shown that integrating embodied scaffoldings within interactive learning environments can improve conceptual learning and spatial reasoning, particularly when learners interact with abstract scientific content (Zeng et al., 2025). Table 3 summarizes recommended simulation software for teaching motion, outlining their key features and instructional applications. These tools range from accessible web-based modules to advanced modeling platforms, enabling teachers to illustrate motion concepts through interactive experiments, video analysis, and high-precision simulations.

Table 3: Recommended Simulation Software for Teaching Motion

Software	Key Features	Instructional Applications
PhET Simulations	Free, web-based, interactive modules for physics learning	Investigate Newton's laws, forces, and motion in two dimensions
Algodoo	User-friendly platform for simulating physical interactions	Design and explore custom motion scenarios and interactions
Tracker	Video analysis software for kinematic studies	Extract real-time velocity and acceleration data from recorded experiments
COMSOL Multiphysics	Advanced physics modeling tool	Simulate real-world systems with high precision

The integration of these tools supports inquiry-based learning, enhances students' visual-spatial reasoning, and facilitates the exploration of motion principles within interactive, low-risk environments. Moreover, by offering dynamic visual representations of otherwise abstract or invisible forces, such tools can help reduce cognitive load and promote deeper conceptual understanding.

4.3 Integrating Laboratory Experiments and Physics Workshops

Hands-on experimentation remains one of the most effective methods for reinforcing conceptual understanding. Physical experiments provide direct experience with forces and motion, enabling students to connect theoretical models with observable outcomes. Table 4 compares physical experiments and virtual simulations, highlighting their differences in interaction, accuracy, cost, and replicability. This comparison illustrates the complementary role of both approaches in supporting effective physics instruction.

Table 4: Comparing Physical Experiments and Virtual Simulations

Feature	Physical Experiments	Virtual Simulations
Interaction with physical materials	High	None
Accuracy and control of variables	Limited (subject to physical error)	High (idealized conditions)
Cost and resource requirements	High	Low or free
Replicability and consistency	Moderate	Very high

Blending physical and virtual methods can create a synergistic learning environment. For example, students may conduct a simple pendulum experiment in class, and then use a simulation to explore how altering gravity or string length affects motion variables that may not be feasible to change physically.A blended approach that combines physical experimentation with virtual tools can optimize both realism and conceptual clarity.

4.4 Integrated Implementation Framework for Motion Instruction

To support teachers in implementing the above strategies in a coherent way, we propose the following step-by-step framework:

Diagnose Preconceptions: Use diagnostic questions or short quizzes to uncover misconceptions.

Introduce Concepts through Context: Connect motion principles to real-world phenomena.

Explore through Simulations: Use PhET, Tracker, or Algodoo to manipulate variables and visualize motion.

Reinforce with Concept Mapping: Create visual maps linking forces, acceleration, and kinematics.

Consolidate with Hands-on Activities: Conduct simple classroom experiments or project-based workshops.

Assess Conceptual Change: Use qualitative and quantitative tools to evaluate student understanding.

This sequence can be adapted flexibly to suit different levels, curricula, or resource constraints.

5. Challenges and Solutions in Teaching Motion with Conceptual Frameworks

Teaching motion concepts using conceptual frameworks offers significant pedagogical advantages, yet it also presents a set of practical challenges that educators must navigate to ensure effective implementation. This section examines prevalent obstacles including student misconceptions, curriculum constraints, and resource limitations, and proposes evidence-based strategies to address them.

5.1 Common Student Misconceptions and Instructional Interventions

Students frequently enter physics courses harboring entrenched misconceptions about motion, such as the belief that a continuous force is necessary to sustain motion or that heavier objects fall faster than lighter ones. These misconceptions can significantly impede conceptual change and the acquisition of scientifically accurate understanding. Table 5 presents common misconceptions about motion alongside their scientific explanations and suggested intervention strategies. This alignment helps educators address students' misunderstandings effectively and reinforce accurate conceptual understanding.

Table 5: Common Misconceptions and Suggested Interventions

Misconception	Scientific Reality	Recommended Correction Strategy
Objects require a force to keep moving	Newton's First Law states that objects maintain motion unless acted upon	Use frictionless surface experiments to demonstrate inertia
Heavier objects fall faster than lighter ones	In a vacuum, all objects experience the same acceleration due to gravity	Conduct Galileo-style dropping experiments or use simulations
Acceleration always aligns with the direction of motion	Acceleration can oppose motion direction (e.g., braking)	Analyze projectile motion and vector components of acceleration

Correcting these misconceptions requires not just content delivery, but conceptual conflict and active engagement. Framework-based strategies—such as guided inquiry, simulations, and discussion—can help students restructure their internal models.

5.2 Instructional and Structural Barriers

Despite their potential, conceptual frameworks often face implementation challenges at both the classroom and institutional level. These include:

- Limited instructional time restricts opportunities for in-depth conceptual exploration.
- Insufficient access to laboratory equipment hampers the ability to conduct hands-on experiments.
- Teacher preparedness gaps result in inconsistent application of conceptual methods.
- Additionally, shifting from familiar rote learning approaches to student-centered conceptual instruction can initially cause discomfort or disengagement, especially if students are not used to inquiry-based learning.

5.3 Strategies for Overcoming Challenges

- Addressing these challenges requires both strategic planning and system-level support. The following approaches are recommended:

- Integrate concise, targeted conceptual activities that fit within existing time constraints, such as focused group discussions or brief inquiry prompts.
- Leverage free and accessible digital simulations (e.g., PhET) to supplement or replace physical experiments where resources are limited.
- Provide professional development and workshops to enhance teachers' knowledge and confidence in conceptual pedagogy.
- Cultivate a classroom culture that encourages questioning and reflection, easing student transition to active learning modes.
- Furthermore, embedding conceptual frameworks systematically within the curriculum through inquiry-based tasks, interdisciplinary projects, and collaborative learning can foster sustainable instructional transformation. Table 6 outlines common barriers to the conceptual teaching of motion and proposes practical solutions to overcome them. By addressing constraints such as time, resources, teacher preparation, and student resistance, the table highlights

strategies that can make conceptual instruction more feasible and effective in classroom settings.

- Table 6: "Barriers and Solutions in Conceptual Teaching of Motion"

• Barrier	• Practical Solution
• Limited time	• Use short, focused conceptual tasks within routine lessons (e.g., 10-minute discussions, mini-experiments)
• Lack of lab resources	• Leverage free simulations (e.g., PhET, Tracker) to supplement or replace physical experiments
• Insufficient teacher training	• Offer professional development, peer coaching, and access to practical instructional guides
• Student resistance	• Build gradual exposure to conceptual tools; combine with familiar formats to ease transition

- In addition, school systems should provide structured support such as integrated curriculum models, shared simulation libraries, and time allocated specifically for concept-based learning.
- Sustained implementation also requires a classroom culture that values inquiry, tolerates error, and encourages collaborative reasoning.

5.4 Toward Systemic Integration

For long-term success, the use of conceptual frameworks should be embedded into curriculum design—not treated as optional supplements. This includes aligning assessments with conceptual goals, training pre-service teachers in these methods, and engaging administrators in supporting pedagogical innovation.When applied systematically, conceptual frameworks not only improve understanding of motion but also foster transferable scientific thinking.

Conclusion

Teaching motion in physics is a foundational component of science education that significantly shapes students' understanding of natural laws. However, the persistence of misconceptions about motion, coupled with pedagogical and implementation challenges in classroom settings, often impedes effective learning. As this article has shown, persistent student misconceptions—such as those related to inertia, free fall, and acceleration—necessitate instructional strategies rooted in conceptual understanding rather than rote memorization. Embodied learning environments that engage sensorimotor systems have been shown to significantly improve retention of conceptual physics knowledge and reduce persistent misconceptions about motion, such as the "circular impetus" model associated with centripetal force (Lindgren et al., 2016).

This article has presented a theoretical-practical approach that synthesizes conceptual tools—such as simulations, concept maps, mental models, and motion diagrams—with classroom-tested strategies. Grounded in cognitive learning theories, these tools can foster meaningful understanding of motion by addressing misconceptions, supporting visual reasoning, and promoting active knowledge construction.

Incorporating conceptual frameworks into motion instruction offers a powerful means to engage learners, support cognitive development, and promote retention of core physical principles .Successful implementation requires more than just access to tools—it involves redesigning classroom practices, aligning assessments, and preparing educators through professional development.

The primary contribution of this paper lies in offering a structured and theory-informed model for integrating multiple conceptual tools specifically within the context of motion instruction in physics education.

Future Research Directions

While this paper offers practical and theoretical guidance, further empirical studies are needed to assess the long-term effects of conceptual frameworks on student learning. Future research could explore:

- The effectiveness of these frameworks across different learning styles (e.g., visual, kinesthetic, analytical learners)
- Comparative studies in diverse cultural or curricular contexts
- Longitudinal studies to track conceptual retention over time
- The role of teacher training in the successful adoption of these methods
- Integration of AI-based adaptive simulations in motion education

Such research would help strengthen the evidence base and guide future instructional design in physics education.

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ORIGINAL RESEARCH PAPER

Content Analysis of the Physics Section of the Sixth Grade Elementary Science Textbook (2024 Edition)

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ABSTRACT

The aim of this study is to analyze the content of the physics section of the sixth-grade elementary science textbook (2024 edition) to evaluate the level of student engagement based on William Rumi's method. Data were collected from the text, questions, and exercises of lessons 6, 7, 8, 9, and 14 and analyzed from both active and passive perspectives. The findings indicate an overall engagement coefficient of 0.62, suggesting a moderate level of active learning promoted by this section of the textbook. A more detailed analysis reveals that the text has a high engagement coefficient of 1.2, and the questions, with a coefficient of 0.42, also play an active role in encouraging student participation. However, the images section shows a low engagement coefficient of 0.25, indicating a weaker contribution to active engagement. The results underscore the importance of revisiting textbook content design to enhance educational quality and promote active student involvement.

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INTRODUCTION

Textbooks are essential tools designed to achieve educational goals. They include various components such as textual content, images, and questions [1]. To enhance educational quality, many countries continuously conduct research focused on improving their textbooks to meet higher teaching and learning standards. This is based on the understanding that improving textbook quality significantly optimizes the teaching–learning process and facilitates deeper, more effective student learning. Consequently, ongoing review and revision of instructional content have become key strategies in advanced education systems.

The importance of textbooks is highlighted by studies showing that approximately 50% of science teachers worldwide heavily rely on textbooks during instruction [1]. Therefore, developing effective textbooks capable of fostering positive behavioral and attitudinal changes in students requires comprehensive research to ensure the learning process is implemented efficiently [2] Furthermore, textbooks are considered one of the primary sources of student motivation, which plays a critical role in learning, especially in centralized educational systems where it demands special attention [3-4].

Textbooks also act as the primary link between educational systems and learners. Their content profoundly influences students' personality development, shaping their identities and future roles [5]. based on scientific principles, and responsive to current societal needs. This is particularly true in centralized systems such as Iran's, where most teaching components are designed around textbooks, underscoring the need for comprehensive, accurate, and pedagogically sound content [6]. Such resources should aim to nurture innovative, committed, and creative individuals capable of adapting effectively to societal changes [7].

Content analysis of textbooks is a powerful tool for identifying strengths and weaknesses in educational materials. It provides a clear picture of the current status of textbook content and aids in the continuous improvement and refinement of these resources, ultimately supporting educational objectives [8].

To better understand the impact of active curricula on education, one can refer to Comparative studies, such as those analyzing chemistry curricula in Japan and Iran, show that Japan’s education system emphasizes student engagement and activity-based learning, leading to deeper and more practical learning experiences. Conversely, the Iranian curriculum’s lack of such approaches is cited as a major factor in lower academic performance and student engagement [9]. This highlights the necessity for textbooks to be designed based on participatory and activity-oriented frameworks to actively involve students in the learning process [10].

Primary education lays the foundation for lifelong learning and profoundly influences adulthood. Therefore, fostering the right kind of thinking during this stage is crucial. Access to dynamic, effective, and engaging textbooks that satisfy students’ curiosity is essential for sound decision-making in later life and academic success in higher education [4]. Accordingly, curriculum developers must ensure that textbooks—particularly those directly related to real-life contexts, such as science—are structured to maximize student engagement.

The present study aims to evaluate the physics section of the sixth-grade elementary science textbook in Iran, specifically the 2024 edition, to determine the extent to which it supports active versus passive learning based on William Romy's content analysis model.

Literature Review

Any academic research must be grounded in a thorough review of prior studies related to the subject. In this section, several relevant studies are presented, focusing on both the physical structure of textbooks and the degree of active versus passive learning content based on William Romy's methodology:

Nourian (2008) emphasized that textbooks at lower educational levels should include more visual content and less written text. This structure better supports young learners in understanding concepts. As students' progress to higher levels, the inclusion of more complex written content becomes more appropriate [11].

In a comparative study by Sharafi et al. (2019) titled "A Comparative Study of Chemistry Curricula in Iran and Japan at the Upper Secondary Level", the authors argue that hands-on activities should be a fundamental component of science education. They highlight Japan's educational advancement as largely due to students' strong engagement in active learning processes [9].

In a content analysis study by Khadami and Ghoreishi-Nasab (2016) titled "Analysis of the Sixth Grade Science Textbook from the Perspective of Active and Passive Learning Based on William Romy's Method", the interaction coefficient of the textbook text was calculated as 1.49, indicating an active text. The images in the textbook were also found to be active with an engagement coefficient of 1, while the questions showed an even higher coefficient of 3.5, suggesting that students are encouraged to engage in activities even in the absence of detailed textual explanations [2].

Ramazani and Dashti (2021), in their study "Content Analysis of the Sixth Grade Elementary Science Textbook Using William Romy's Technique", found the text engagement coefficient to be 0.34, which is below the desirable threshold and indicates that the textual content is relatively passive. However, the coefficients for questions (1.7) and images (0.8) demonstrated a more active role in stimulating student curiosity and critical thinking. These results highlight the need for textual revisions and the use of active teaching strategies to improve learning outcomes [12].

In a more recent study, Chandool (2023) analyzed the fourth-grade science textbook using Romy's method and found that, while the textual content met engagement standards, images and activities needed improvement to enhance student participation in the learning process [13].

Similarly, Ahmadi et al. (2021) conducted a study titled "Content Analysis of Biological Topics in Fifth and Sixth Grade Elementary Science Textbooks Using William Romy's Technique". Their findings indicated that the biological content and related visuals were moderately active, though still below optimal levels [14].

In another study by Goudarzi (2016) analyzing the sixth-grade science textbook, the text engagement coefficient was reported as 0.67, indicating a moderately active text. The question coefficient was 1.27, showing good levels of student engagement, whereas the coefficient for images and tables was only 0.38, highlighting their passive nature and limited role in promoting interaction [15].

METHODOLOGY

This study employs a quantitative descriptive content analysis methodology, focusing on the science textbook for sixth-grade elementary students published in the 2024–2025 academic year (1403 in the Iranian calendar). To allow for a more targeted analysis, only the physics section of the textbook was selected for examination.

The analysis is grounded in William Romey's content analysis model, which classifies textbook content into three categories based on their potential to engage students: active, passive, and neutral elements.

- **Active elements** include sentences, questions, or illustrations that prompt students to engage in investigative, experimental, inquiry-based, or discussion-oriented activities. These are designed to foster cognitive involvement and hands-on learning.
- **Passive elements** present information without requiring any student interaction or response, thereby limiting engagement.
- **Neutral elements** neither contribute to the instructional content nor stimulate cognitive or practical involvement—for example, decorative images or non-instructional statements.

To assess the level of learner engagement, a Content Engagement Index was calculated for each element type (text, questions, and images) using the formula proposed by Romey:

$$\text{Engagement Index} = \frac{\text{Number of Active Elements}}{\text{Number of Passive Elements}}$$

engaging (i.e., active) content level. Values below 0.4 or above 1.5 suggest that the content may be insufficiently or excessively stimulating, potentially undermining effective learner engagement.

All sentences, questions, and illustrations within the selected content were independently coded by two trained raters. Inter-rater reliability was assessed using Cohen's kappa coefficient to ensure consistency in coding. Finally, the categorized data were analyzed using descriptive statistics, to determine the degree of engagement across each category.

Sampling Procedure

To conduct the content analysis, the entire physics section of the sixth-grade elementary science textbook—including lesson texts, illustrations, and questions—was initially reviewed. To ensure analytical clarity and manageability, a subset of content was selected through random sampling.

Specifically, 10 pages were randomly chosen from the physics section using a random number table. This method was designed to achieve a representative distribution of content across the entire section. The selected pages spanned the full range of the physics material—from the beginning to the end of the section—with at least one or two pages included from each chapter.

From these same 10 randomly selected pages, 10 questions (from both in-text and end-of-lesson exercises) and 10 instructional images were extracted. This ensured that all samples—texts, questions, and images—originated from a consistent and representative subset of the physics content.

These selected elements served as the units of analysis for subsequent coding and evaluation.

Research Objectives

The primary objective of this study is to evaluate the level of student engagement within the physics section of the sixth-grade elementary science textbook for the 2024–2025 academic year. Specifically, the research investigates the extent to which the textbook content promotes active student participation across three modalities: text, images, and questions. The study aims to determine how effectively the textbook supports an interactive and learner-centered environment by encouraging cognitive and practical engagement. Ultimately, it seeks to assess whether the textbook offers a pedagogical framework that aligns with active teaching and learning principles.

Research Questions

1. To what extent is the textual content of the sixth-grade science textbook (in the physics section) active and capable of engaging students in the learning process?
2. To what extent are the questions included in the physics section of the textbook active and effective in promoting student engagement?
3. To what extent are the images and illustrations in the physics section of the textbook active and capable of stimulating student involvement in the learning process?

Population and Sample

The target population of this study is the sixth-grade elementary science textbook used in the 2024–2025 academic year, which comprises four main content areas: chemistry, physics, biology, and earth sciences. Given the breadth and diversity of these disciplines, analyzing all sections within a single study would compromise the depth and focus of the analysis. Therefore, to ensure analytical clarity and manageability, the study focuses exclusively on the physics section of the textbook.

The physics content is presented across five lessons, as follows:

- Lesson 6: Motion and Force I
- Lesson 7: Motion and Force II
- Lesson 8: Let's Design and Build
- Lesson 9: The Journey of Energy
- Lesson 14: From Past to Future

According to a preliminary content audit (see Table 1), the physics section spans 37 pages, making it the most extensive section in terms of page count. This indicates its substantial weight in the overall science curriculum.

Sampling was conducted using a random selection method to ensure a representative subset of the physics content. Selected samples included lesson texts, instructional images, and exercises, distributed across the entire section to capture a wide range of topics and presentation styles. This approach strengthens the generalizability and reliability of the findings by reflecting the diversity of the section as a whole.

Table 1. Statistical Overview of the Physics Section by Lesson Components

lessons / Sections	Lesson 6 **Sports and Force (1)**		Lesson 7 **Sports and Force (2)**		Lesson 8 **Let's Design and Build**		Lesson 9 **Energy Journey**		Lesson 14 **From the Past to the Future**		**Total**	
	Pages	**Images**	**Pages**	**Images**	**Pages**	**Images**	**Pages**	**Images**	**Pages**	**Images**	**Pages**	**Images**
Lesson Text	8	12	12	9	6	7	8	13	3	10	**37**	**51**
Experiment	1	3	5	11	0	0	2	2	0	0	**8**	**16**
Inquiry	1	1	1	6	2	17	0	6	0	3	**4**	**33**
Think About It	2	5	6	5	0	0	4	2	0	0	**12**	**12**
Information gathering	0	0	1	0	0	0	0	0	0	2	**1**	**2**
Discussion	1	0	2	2	1	0	2	1	1	0	**7**	**3**

Science and Life	2	2	1	4	0	0	1	0	1	0	**5**	**6**
Activity	2	0	2	0	1	0	0	0	0	0	**5**	**0**
Wonders of creation	1	0	2	1	0	0	1	1	0	0	**4**	**2**
Warnings	0	0	0	0	0	0	1	0		0	**1**	**0**
total		23		38		24		25		15		**125**

FINDINGS

Text Content Analysis

To examine the level of engagement in the textual content of the sixth-grade science textbook, ten pages from the physics section were randomly selected and analyzed. In accordance with William Romy's framework, as described in the methodology section, a total of 87 sentences were identified and categorized into three groups: active, passive, and neutral. The **passive** categories included:

- *Category a*: statements presenting established scientific facts
- *Category b*: statements linking two propositions
- *Category c*: definitional statements
- *Category d*: immediate answers to questions

The **active** categories consisted of:

- *Category e*: analytical interpretations of data
- *Category f*: prompts encouraging students to draw conclusions
- *Category g*: invitations to perform specific activities
- *Category h*: open-ended questions raised in the text without being directly answered

The **neutral** category was represented by *Category I*, encompassing sentences that were neither clearly active nor passive in their engagement with the learner.

A total of 89 sentences were identified across the selected pages. Among them, 37 sentences were classified as active, 30 as passive, and 22 as neutral. According to William Romy's formula for calculating the engagement index:

$$\text{Engagement Index} = \frac{37}{30} \approx 1.2$$

The resulting index of 1.2 indicates a relatively high level of student engagement in the textual content of this section. This suggests that the text effectively encourages students to think critically, ask questions, and participate in active learning processes.

However, the presence of 22 neutral sentences (approximately 25% of the total) is noteworthy. These may represent areas of the content that are less pedagogically effective or that warrant revision to enhance their educational value. Detailed results are presented in Table 2.

Table 2. Content Analysis of the Sixth Grade Science Textbook (Physics Section) Based on the Text Engagement Index

Categories / pages	Passive				active				Neutral
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**I**
40	2	1	1	---	1	---	---	---	1
45	---	---	---	---	4	1	---	1	5
48	3	4	1	---	2	---	---	---	---

52	1	1	---	---	3	---	4	2	4
58	2	1	1	---	---	1	1	---	---
60	---	---	---	1	---	1	1	---	5
63	---	---	---	---	---	1	1	---	3
67	3	2	---	3	3	1	---	1	---
71	3	---	---	---	2	1	1	1	4
103	---	---	---	---	2	---	---	1	1
	14	9	3	4	17	6	8	6	22
Total Passive Categories					Total Active Categories				Total Neutral Categories
30					37				22
1.2					Engagement Index				

Analysis of Question Content

To examine the level of engagement elicited by the questions in the physics section of the sixth-grade science textbook—specifically those framed as activities, experiments, information gathering, and discussions—10 questions were randomly selected from the previously identified 10 pages of this section and analyzed.

Based on William Romy's framework, each question was categorized as either passive or active:

- Passive questions were labeled as:
  - (a) Questions requiring minimal effort to answer
  - (b) Questions related to definitions
- Active questions were labeled as:
  - (c) Questions related to lesson comprehension
  - (d) Questions that lead to problem-solving

The analysis results, presented in Table 3, showed that out of the 10 questions analyzed (3 active and 7 passive), the engagement index was calculated as 0.42. This value indicates that the questions in this section demonstrate a moderate level of engagement, meaning they only partially involve students actively in the learning process.

The engagement index was calculated using the following formula:

$$\text{Engagement Index} = \frac{3}{7} \approx 0.42$$

Table 3. Content Analysis of the Questions in the Sixth Grade Science Textbook (Physics Section) Based on the Question Engagement Index

Categories / pages	Passive		active	
	a	b	c	d
40	*	---	---	---
45	*	---	---	---
48	---	*	---	---
52	*	---	---	---
58	---	*	---	---
60	*	---	---	---

63	---	---	---	*
67	---	*	---	---
71	---	---	---	*
103	---	---	*	--
	4	3	1	2
Total Passive Categories			Total Active Categories	
7			3	
0.42			Engagement Index	

Analysis of Visual Content

To evaluate the level of student engagement through visual elements in the physics section of the sixth-grade science textbook, 10 images were randomly selected from a total of 125 and analyzed according to William Romy's framework. These images comprised drawings, charts, photographs, and other visual materials related to the instructional content. Using William Romy's engagement index, the images were classified into two categories: active and passive. The passive category (a) included images primarily used for further explanation and interpretation of the text, while the active category (b) consisted of images that prompted activities, questions, or student responses, as detailed in Table 4. The analysis revealed that out of the 10 images, 2 were active and 8 were passive. The engagement index was calculated using the following formula:

$$\text{Engagement Index} = \frac{2}{8} \approx 0.25$$

This low engagement index suggests that the instructional images in this section are mostly passive and have limited potential to stimulate critical thinking, interaction, or hands-on activities among students.

Table 4. Content Analysis of the Images in the Sixth Grade Science Textbook (Physics Section) Based on the Image Engagement Index

Categories pages	Passive	active
	a	b
40	*	---
45	*	---
48	*	---
52	*	---
58	*	---
60	*	---
63	*	---
67	---	*
71	*	---
103	---	*
Total Passive Categories		Total Active Categories
8		2

0.25	Engagement Index

Final Summary and Statistical Conclusion

Based on the content analysis conducted using William Romi's method, Table 5 summarizes the engagement coefficients across three key components of the sixth-grade science textbook (Physics section): textual content, questions, and images. The text demonstrated the highest level of student engagement, with a coefficient of 1.2, indicating that the written content frequently prompts student activity, inquiry, or practical involvement. The engagement coefficient for the questions was 0.42, reflecting a moderate level of interactivity, while the images scored the lowest at 0.25, suggesting a largely passive visual presentation.

The overall mean engagement coefficient across all components was calculated to be 0.62, placing the textbook in the range of moderate engagement. This suggests that while the textbook succeeds in promoting active learning through its textual content, it falls short in utilizing images and questions to the same extent. These results highlight the potential for improving the visual and interrogative aspects of the textbook to foster deeper cognitive and practical engagement in students.

Table 5. Engagement Index of the Sixth Grade Science Textbook (Academic Year 2024–2025)

Textbook	**Average Engagement Index**	**Image Engagement Index**	**Question Engagement Index**	**Text Engagement Index**
Sixth Grade Science Textbook (2024–25)	1.2	0.25	0.42	0.62

DISCUSSION AND CONCLUSION

Science education in the elementary years plays a crucial role in enhancing students' scientific thinking skills, problem-solving abilities, and fostering their interest in learning. Therefore, the content of textbooks at this stage should be designed to actively engage students in the teaching-learning process. This study analyzed the cognitive engagement of sixth-grade physics content in the 2024 edition of the elementary science textbook using William Romi's method. The findings revealed that the engagement coefficient for the text was 1.2, indicating active written content, while the engagement coefficient for questions was 0.42, suggesting borderline activity that requires further improvement. However, the engagement coefficient for images was 0.25, demonstrating inactivity. The overall average engagement coefficient was 0.62, reflecting a moderate level of student engagement.

These results align with previous studies, such as Chandool [13], who found similar patterns of active text but inactive images and questions in fourth-grade science textbooks, highlighting a recurring issue at the elementary level that demands attention. In contrast, Atabak et al. [16] reported higher engagement coefficients across text, images, and questions in a sixth-grade science textbook, which may be due to differences in publication year, scope, and analytical approach. Similarly, Ramzani and Dashti [12] evaluated the entire sixth-grade science textbook (2019 edition) and reported higher image engagement, possibly due to the comprehensive nature of their study and updates made in the 2024 edition analyzed here. Ahmadi et al. [14] also emphasized the relative activity of biological content and images in fifth and sixth-grade science books but acknowledged a gap from optimal standards. Moreover, the perspectives of Nourian [11] and Sharafi et al. [9] underline the importance of increased imagery in lower grades and the essential role of hands-on activities, highlighting the need for content design that aligns with developmental and pedagogical considerations.

Accordingly, to improve learning quality and promote active student participation, it is recommended that educational images be designed not only to illustrate scientific concepts but also to encourage analysis, comparison, and inference. Questions should be revised to target higher-order cognitive skills beyond mere recall. Teacher training should emphasize active teaching strategies, and a comprehensive teacher's guide based on active learning principles should be developed. Additionally, periodic content revisions aligned with global scientific advances and successful international educational practices are essential. Implementing these measures can significantly enhance the teaching-learning process and improve educational outcomes in elementary science education.

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ORIGINAL RESEARCH PAPER

Enhancing Conceptual Understanding in Magnetism through AI-Powered Tools: A Mixed-Methods Study with High School Students

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Keywords:
Physics education, magnetism, artificial intelligence, cognitive load theory, multimedia learning, mixed methods

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ABSTRACT

This research examines the influence of artificial intelligence (AI)-enabled instruments on comprehension, engagement, and retention of knowledge within high school physics education, particularly emphasizing the topic of magnetism. A mixed-methods methodology was utilized, merging a validated questionnaire distributed to 100 eleventh-grade pupils with qualitative analyses of open-ended responses alongside the practical application of selected AI instruments. The intervention comprised the employment of AI chatbots (e.g., ChatGPT), interactive simulations (PhET, Mozaik), concept mapping (Mindomo), and AI-generated educational music (Suno.ai). Quantitative findings demonstrated a significant consensus (78–85%) among students regarding perceived enhancements in understanding and engagement. Qualitative assessment indicated that chatbots and simulations were especially efficacious in elucidating misconceptions and facilitating the visualization of abstract concepts. A theoretical framework grounded in cognitive load theory and principles of multimedia learning is incorporated to elucidate the findings. Notwithstanding limitations pertaining to generalizability and access to technology, the research posits that a deliberate integration of AI tools can augment student-centered learning within the domain of physics. Suggestions for educators and avenues for future research are elaborated upon.

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1. INTRODUCTION

Magnetism is a conceptually challenging topic in high school physics, often associated with persistent misconceptions such as the belief that all metals are magnetic or confusion about field lines and forces on moving charges (Singh, 2005; Maloney et al., 2001). Traditional teaching methods, while foundational, may not sufficiently address these conceptual barriers, particularly in promoting deep understanding and long-term retention.

Recent advances in artificial intelligence (AI), particularly in natural language processing and adaptive learning systems, offer new opportunities to support physics education. Unlike general educational technologies, true AI tools—such as large language models (LLMs) and intelligent tutoring systems—can provide personalized feedback, real-time Q&A, and adaptive scaffolding, aligning with principles of constructivist and student-centered learning [1, 2].

While virtual labs like PhET have been widely studied in physics education research (Wieman et al., 2008), the integration of generative AI tools (e.g., chatbots, AI music generators) in high school magnetism instruction remains underexplored. This study addresses this gap by examining how a combination of AI-powered tools influences students' conceptual understanding, engagement, and retention. It also explores the pedagogical mechanisms through which these tools operate, using cognitive load theory (Sweller, 1988) [3] and Mayer's multimedia learning theory (2009) [4] as analytical frameworks.

The research question guiding this study is:

How do AI-powered tools influence students' conceptual understanding, engagement, and retention in high school magnetism education?

1.1 Theoretical Framework

This study is grounded in two well-established theories of learning: Cognitive Load Theory (CLT) (Sweller, 1988) and Mayer's Cognitive Theory of Multimedia Learning (2009).

CLT posits that learners have limited working memory capacity, and effective instruction should minimize extraneous load while supporting germane load. AI tools such as chatbots and simulations can reduce cognitive load by providing just-in-time explanations, visualizing abstract concepts, and offering immediate feedback, thus allowing students to focus on schema construction.

Mayer's theory emphasizes that people learn better from words and pictures than from words alone, especially when design principles such as coherence, signaling, and personalization are applied. AI-generated content—such as narrated simulations, concept maps, and educational music—can be designed to align with these principles, enhancing dual-channel processing and meaningful learning.

Furthermore, AI chatbots can function as scaffolding agents (Vygotsky, 1978) [5], providing adaptive support that fades as student competence increases. This dynamic interaction supports a constructivist approach to learning, where students actively build knowledge through dialogue and exploration [6-10].

2. METHODOLOGY

2.1. Research Design

A mixed-methods explanatory sequential design was employed. First, quantitative data were collected via an online questionnaire to assess students' perceptions of AI tools. This was followed by qualitative analysis of open-ended responses to explore underlying reasons and experiences.

2.2. Participants

One hundred eleventh-grade students (ages 16–17) from three physics classes at a public high school in Iran participated voluntarily. The sample included 58 female and 42 male students. All had prior exposure to magnetism in their curriculum.

2.3. Intervention and Tools

Students were introduced to five AI-powered tools over a one-week period:

- ChatGPT: For Q&A on magnetism concepts.
- PhET & Mozaik: For interactive simulations of magnetic fields and induction. To illustrate the concept of magnetic fields, we utilized the PhET Interactive Simulations platform, which provides an interactive environment for visualizing magnetic phenomena. As depicted in Figure. 1, the simulation shows magnetic field lines around a bar magnet, with a compass needle aligning itself along these lines to demonstrate the direction and strength of the field at various points.

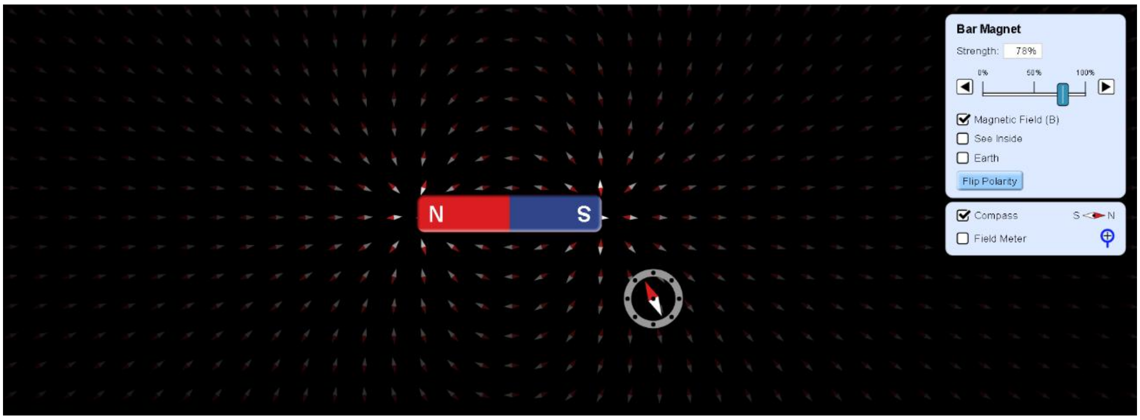

Figure 1. Visualization of magnetic field lines around a bar magnet using PhET Interactive Simulations. The compass needle aligns with the magnetic field, demonstrating the direction and strength of the field at different points.

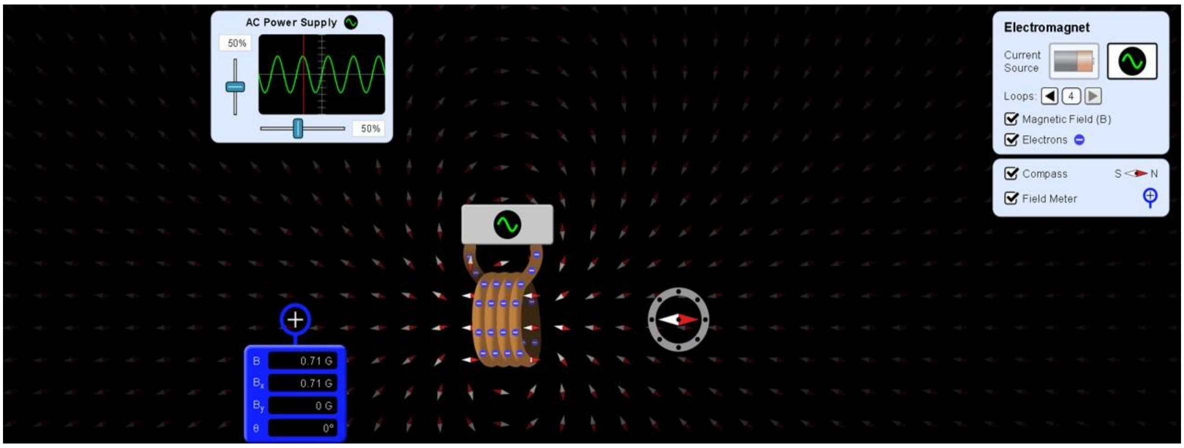

Figure. 2 Faraday's experiment in PhET

As shown in Figure. 2, interactive simulations like those provided by PhET allow students to visualize complex phenomena such as electromagnetic induction. The simulation demonstrates how an alternating current (AC) generates a magnetic field around an electromagnet, with tools like the compass and field meter providing real-time feedback on field strength and direction. This hands-on approach enhances conceptual understanding and engagement, as evidenced by student responses in our study.

As part of the AI-powered tools used in this study, interactive digital activities were employed to reinforce key concepts. For instance, Figure 3 shows a matching activity where students classified materials into ferromagnetic, diamagnetic, and paramagnetic categories. The task involved matching materials such as platinum, lead, and iron with their corresponding magnetic properties. Such interactive exercises were found to significantly improve student engagement and conceptual understanding.

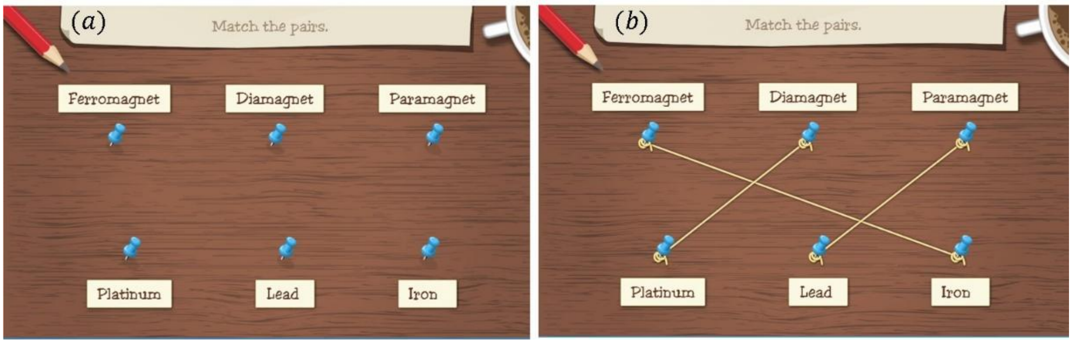

Figure 3. Interactive Matching Activity for Classifying Magnetic Materials; Part (a) showing the initial setup where students are asked to match materials such as platinum, lead, and iron with their corresponding magnetic properties. Part (b) displaying the correct answers.

- Mindomo: For creating concept maps of magnetism topics. As shown in Figure. 4, magnetic materials can be classified into three main categories: ferromagnetic, paramagnetic, and diamagnetic

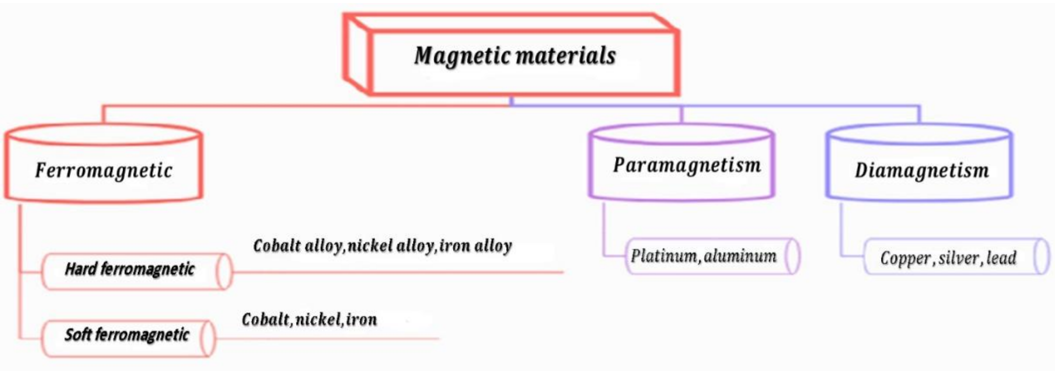

Figure 4. Classification of Magnetic Materials

This figure illustrates the classification of magnetic materials based on their response to external magnetic fields. Ferromagnetic materials, such as cobalt alloys, nickel alloys, and iron alloys, are further divided into hard ferromagnets (e.g., cobalt alloy) and soft ferromagnets (e.g., pure cobalt). Paramagnetic materials, including platinum and aluminum, show a weak attraction to magnetic fields, while diamagnetic materials like copper, silver, and lead exhibit a slight repulsion. This categorization is fundamental in understanding the behavior of materials in magnetic fields.

- Suno.ai: For generating educational music on key principles.

Each tool was demonstrated, and students were given guided activities (e.g., "Use ChatGPT to explain why aluminum is not magnetic").

2.4. Data Collection

An 8-item Likert-scale questionnaire (5-point: Strongly Disagree to Strongly Agree) was administered online. Items addressed understanding, engagement, retention, and usability. An open-ended question asked: *"Which tool impacted your learning the most, and why?"*

The questionnaire was pilot-tested with 10 students and revised for clarity. Content validity was confirmed by two physics education experts. Cronbach's alpha was calculated to assess internal consistency ($\alpha = 0.82$), indicating acceptable reliability.

2.5. Data Analysis

Quantitative data were analyzed using descriptive statistics (frequencies, percentages). Qualitative responses were analyzed using thematic analysis (Braun & Clarke, 2006) to identify recurring patterns (e.g., "visualization," "immediate feedback," "engagement through music").

Appendix A are pie charts displaying responses to each of the 8 main questions. Question 1: Using AI tools increased my understanding of magnetism.

Question 2: Interactive simulations like PhET made concepts more tangible.

Question 3: Multimedia tools like Mozaik aided visual learning.

Question 4: Educational chatbots like ChatGPT provided quick, accurate answers.

Question 5: Creating concept maps with Mindomo helped organize ideas.

Question 6: Educational music (e.g., Suno.ai) improved memory retention.

Question 7: These tools made learning more engaging and personalized.

Question 8: I would prefer using AI tools if studying this topic again.

3. RESULTS AND DISCUSSION

3.1. Quantitative Findings

As shown in Figure 5, 82% of students agreed or strongly agreed that AI tools improved their understanding of magnetism. PhET and ChatGPT received the highest agreement (85% and 83%, respectively). Suno.ai and Mindomo also showed strong positive responses (76% and 74%). Over 90% reported increased engagement (Table. 1).

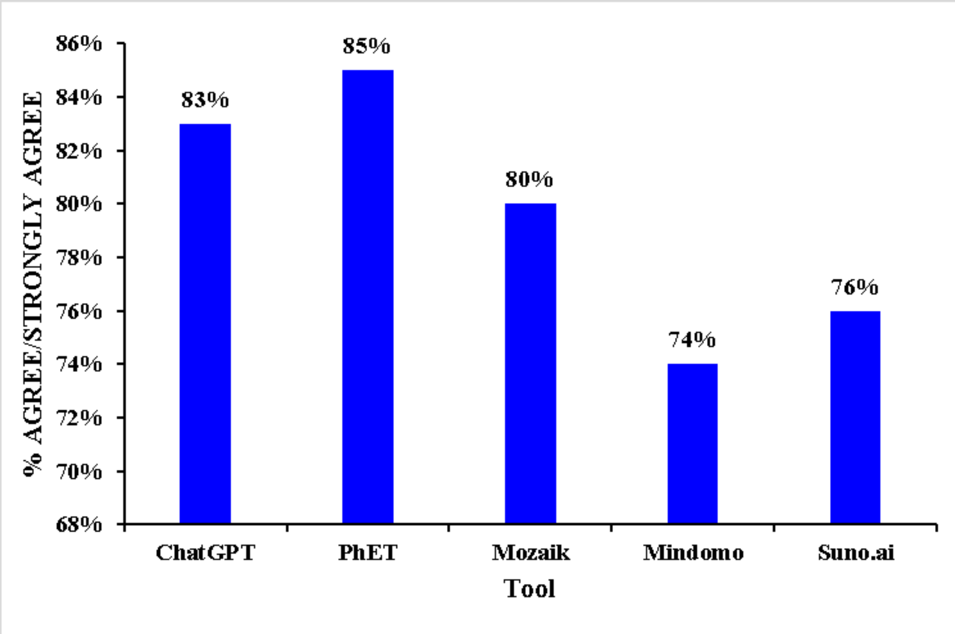

Figure 5. Student agreement on the impact of AI tools on understanding magnetism (N = 100).

Table 1. Percentage of students agreeing on the effectiveness of each AI tool.

TOOL	% AGREE/STRONGLY AGREE
ChatGPT	83%
PhET	85%
Mozaik	80%
Mindomo	74%
Suno.ai	76%

3.2. Qualitative Findings

Thematic analysis of open-ended responses revealed three main themes:

1. Conceptual Clarity: Students appreciated ChatGPT's ability to explain misconceptions (e.g., *"I finally understood why not all metals are magnetic"*).
2. Visualization and Interaction: PhET and Mozaik were praised for making invisible fields "visible" and "interactive."
3. Emotional Engagement: Many noted that music (Suno.ai) made learning "fun" and "memorable," especially for rote concepts like right-hand rules.

"The song helped me remember the right-hand rule without even trying. I was humming it during the test!"— Student 47

The below table compares tools like PhET, Mozaik, ChatGPT, Suno.ai, and Mindomo based on interactivity, content diversity, ease of use, learning impact, question-answering, simulation, and content generation capabilities.

Table. 2 Comparison of AI Tools in Teaching Magnetism Concepts

Feature	PhET	Mozaik	ChatGPT	Suno.ai	Mindomo
Interactivity	Very high	High	Medium	Low	Top
Content diversity	Scientific simulation	Multimedia (video, image)	Textual	Audio	Textual-visual (concept maps)
Ease of use	Easy	Average	Very easy	Average	Easy
Impact on learning	Strengthens conceptual understanding	Increases visual appeal	Facilitates understanding of concepts	Increases retention	Mental order and connection of concepts
Answering questions	No	No	Yes	No	No
Simulation	Yes	Limited	No	No	No
Possibility of content production	No	Yes	Yes	Yes	Yes (concept map)

4. Discussion

The findings suggest that AI tools, particularly chatbots and simulations, can play a meaningful role in enhancing magnetism education by reducing cognitive load, providing immediate feedback, and increasing engagement. These results align with Mayer’s (2009) multimedia principles and Sweller’s (1988) cognitive load theory, supporting the idea that well-designed AI tools can support dual coding and schema formation.

The high impact of educational music is noteworthy, as it reflects the role of affective and rhythmic processing in memory retention (Jäncke & Sandmann, 2010). However, this may be more effective for factual recall than deep conceptual understanding.

Our results are consistent with prior studies on virtual labs (Wieman et al., 2008), but extend them by incorporating generative AI tools like chatbots and AI music generators, which have not been systematically studied in high school physics contexts.

Limitations

- The sample is limited to one school and grade level.
- No pre/post conceptual test was administered.
- Self-reported data may be subject to bias.
- Internet access and device availability varied among students.

Implications for Practice

- Teachers should consider integrating AI chatbots for Q&A and misconception correction.
- Simulations should be used to visualize abstract concepts.
- Creative tools like AI music can enhance motivation and retention.

Future Research

- Longitudinal studies with control groups.
- Integration of AI with standardized assessments (e.g., CSEM).
- Development of localized AI tools for non-English educational systems.

5. CONCLUSION

This study demonstrates that AI-powered tools can positively influence high school students' learning of magnetism when integrated thoughtfully. By aligning tool use with cognitive and multimedia learning theories, educators can enhance conceptual understanding, engagement, and retention. While challenges related to access and infrastructure remain, the pedagogical potential of AI in physics education is significant and warrants further exploration.

6. Recommendations

- Train physics teachers in the effective use of AI tools.
- Develop open-access AI platforms tailored to national curricula.
- Conduct larger-scale studies with control groups and conceptual assessments.
- Encourage interdisciplinary collaboration between physicists, educators, and AI developers.

7. Acknowledgments

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Appendix A:

Table A.1: Status of Responses to Questions

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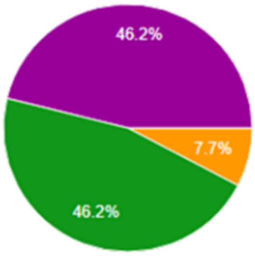
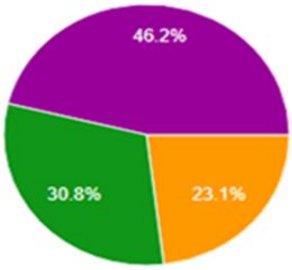
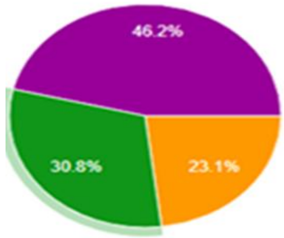
<tr><td>
</td><td>
</td><td>
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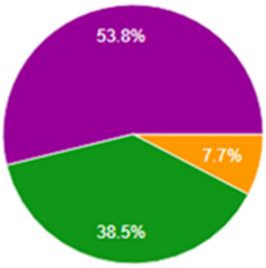
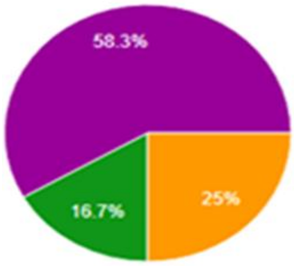
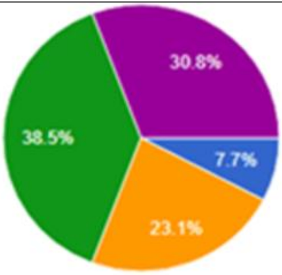
<tr><td>
</td><td>
</td><td>
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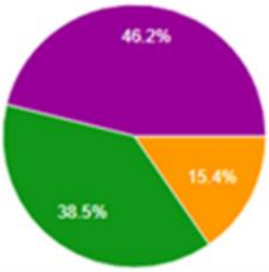
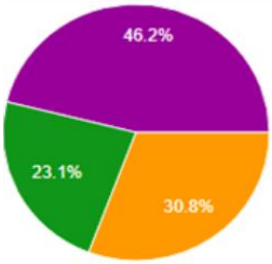
<tr><td></td><td>
</td><td>
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<tr><td></td><td>Question 8</td><td>Question7</td></tr>
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ORIGINAL RESEARCH PAPER

Reimagining Physics Education in Iran: From Memorization to Meaningful Learning

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Keywords:
Rote learning, inquiry-based learning, active learning, curriculum reform, pedagogical strategies

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ABSTRACT

Physics education in Iran has traditionally emphasized rote memorization and exam preparation, often at the expense of conceptual understanding and scientific reasoning. This teacher-centered model limits student engagement and intellectual growth. This paper advocates for a shift toward a learner-centered approach that fosters student agency, critical thinking, and meaningful engagement with physics. It aims to reimagine classrooms as spaces for inquiry, collaboration, and cognitive development. Drawing on pedagogical research and classroom evidence, the paper critiques the limitations of conventional instruction and proposes a human-centered framework informed by Self-Determination Theory, Constructivism, and Cognitive Load Theory. It emphasizes inclusive learning environments, explicit instruction in thinking skills, and active learning strategies. A sample lesson on Bernoulli's Principle demonstrates how abstract concepts can be taught through experiential, inquiry-based methods. By aligning teaching practices with students' psychological needs and cognitive capacities, educators can enhance motivation, deepen understanding, and prepare learners to think scientifically. This framework supports curriculum reform in Iran, equipping students with the skills to explore creatively, reason critically, and engage meaningfully with the world of science

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INTRODUCTION

Despite decades of curricular reform, physics education in Iran remains predominantly traditional, characterized by rote memorization, algorithmic problem-solving, and exam-oriented instruction [1]. This pedagogical model has led to a systemic disconnect between students' procedural proficiency and their conceptual understanding of physics. Empirical observations and interviews with high-achieving students in national entrance exams reveal a troubling pattern: while they demonstrate technical competence in solving textbook problems, they often lack the ability to contextualize physical principles, articulate their historical development, or relate them to everyday phenomena. This suggests a deeper epistemological issue—physics is taught as a set of abstract rules rather than as a coherent, inquiry-driven discipline. International research has consistently shown that active learning strategies—such as peer instruction, diagnostic assessment, and collaborative problem-solving—can significantly improve conceptual understanding and student engagement [2–6]. Studies by Hake [7] and Freeman et al. [8] provide robust evidence that interactive engagement yields higher learning gains across STEM disciplines. These findings have informed global efforts to shift physics education toward constructivist models that emphasize reasoning, reflection, and conceptual change. However, while the efficacy of active learning is well-documented, there is limited research on how these approaches can be adapted to culturally specific contexts like Iran, where entrenched pedagogical norms and systemic constraints pose unique challenges. Existing literature tends to focus on Western implementations, leaving a gap in understanding how conceptual reform can be localized within Iranian educational structures. This study addresses that gap by critically examining the structural and cultural barriers to reform in Iran's physics education system and proposing context-sensitive strategies for transformation.

The paper begins by articulating a human-centered philosophy of physics education rooted in inquiry and conceptual coherence. It then identifies key principles for designing collaborative learning environments, fostering student motivation, and supporting teachers in transitioning from authoritative instruction to facilitative practice. The final sections offer practical guidance for lesson design and present a classroom-ready example—a physics lesson on Bernoulli's Principle—that embodies the proposed framework.

Throughout this paper, terms such as *human-centered framework*, *inclusive learning environments*, and *alignment with cognitive development* are used to describe the proposed transformation in physics education. To ensure conceptual clarity and theoretical grounding, it is important to define these terms and connect them to established educational theories. A human-centered framework refers to an instructional approach that prioritizes students' psychological needs, autonomy, and personal agency. This concept is rooted in Self-Determination Theory (SDT) [9], which emphasizes the importance of autonomy, competence, and relatedness in fostering intrinsic motivation and meaningful learning. Inclusive learning enviro**nments** are informed by Constructivist theory [10] which posits that learners construct knowledge through social interaction and personal experience. Inclusivity in this context means recognizing diverse backgrounds, prior knowledge, and learning styles, and creating equitable opportunities for all students to engage in scientific inquiry. Alignment with cognitive development draws from Cognitive Load Theory [11], which highlights the importance of managing the complexity of instructional content to avoid overwhelming students' working memory. In physics education, this involves scaffolding abstract concepts, using visual representations, and sequencing tasks to support progressive understanding.

By explicitly linking these pedagogical principles to SDT, Constructivism, and Cognitive Load Theory, this paper provides a robust theoretical foundation for its proposed reforms and clarifies the rationale behind its instructional strategies.

Cultivating a Human-Centered Approach to Physics Education

Creating a positive and enriching atmosphere in the physics classroom requires far more than delivering equations and scientific facts. It demands the intentional cultivation of a space where intellectual curiosity, emotional safety, and meaningful human connection can thrive. In this context, the physics teacher plays a pivotal role—not only as a facilitator of conceptual understanding but as a model of scientific thinking, ethical behavior, and inclusive values.

To align classroom practice with the deeper goals of physics education, educators must reflect on questions that go beyond pedagogy:

- **Do I embody the habits of mind I hope my students will adopt?** A physics teacher's conduct—whether in reasoning through a problem or engaging in classroom dialogue—serves as a living example. Precision, integrity, and enthusiasm for discovery should be evident not just in instruction, but in everyday interactions [12].
- **Do I genuinely care about my students—not only as learners, but as individuals?** Effective physics education begins with empathy. When students feel seen and respected, they are more likely to engage with complex ideas. Recognizing their emotional and personal needs builds trust and fosters motivation, especially in a subject often perceived as abstract or intimidating [13].
- **Am I doing everything within my capacity to support their learning?** Professional commitment in physics teaching means continuously refining instructional strategies, responding thoughtfully to questions, and offering diverse opportunities for exploration—whether through experiments, simulations, or real-world applications. This dedication reflects a teacher's responsibility to nurture both understanding and confidence [14].
- **Do I see all my students, or only a select few?** Equity in physics education requires that every student—regardless of prior achievement or background—be acknowledged and supported. Each learner deserves access to the tools of scientific inquiry and the chance to experience the joy of discovery.

By engaging honestly with these questions, physics educators can begin to transform their classrooms into spaces where physics is not only taught, but lived—where students are empowered to question, investigate, and connect the laws of nature to the world around them. In such environments, physics becomes more than a subject; it becomes a lens through which students learn to think critically, act ethically, and imagine boldly.

Humanistic Foundations for a Collaborative and Reflective Physics Classroom

A meaningful physics education is not limited to the transmission of scientific content—it is a human-centered endeavor that nurtures curiosity, intellectual courage, and mutual respect. In this view, learning is not merely cognitive but deeply relational, shaped by the emotional and social dynamics of the classroom. Two essential components of such an environment are the teacher's epistemic stance and the norms that guide classroom interactions. Together, they create the cognitive and emotional conditions in which students begin to think and act like physicists. To foster deep engagement, scientific reasoning, and collaborative inquiry, the physics classroom must be intentionally designed—both physically and socially—as a space that encourages dialogue, reflection, and shared responsibility for learning [15]. Within this humanistic framework, students are not passive recipients of knowledge but active participants in a community of inquiry. The following principles offer a foundation for cultivating such a space—one where students learn physics by engaging with ideas, with each other, and with the broader human experience of making sense of the natural world. The following principles offer a humanistic framework for cultivating a physics classroom where students not only learn scientific concepts but also develop the reflective, inquisitive, and collaborative mindset of physicists.

1. Seating in a Circle

Arranging students in a circle or semi-circle can significantly enhance the dynamics of physics instruction by breaking down traditional hierarchical structures and fostering a sense of equality among participants. Unlike rows of desks that position the teacher as the central authority, circular seating promotes a more democratic and dialogic atmosphere. In this layout, students are more likely to make eye contact, listen actively, and engage in thoughtful exchanges with both peers and the instructor. This physical reconfiguration is especially powerful during conceptual discussions [16], whether exploring the nuances of energy conservation, debating the implications of quantum paradoxes, or unpacking the philosophical foundations of relativity. It encourages students to voice their ideas, question assumptions, and build on each other's insights. The classroom becomes a community of inquiry, where learning is co-constructed through dialogue rather than passively received. In physics, where abstract concepts often require deep reflection and multiple perspectives, such an environment can be transformative.

2. Reading Aloud in Turn

Having students read aloud from physics textbooks, problem statements, or excerpts from scientific papers fosters a sense of shared ownership over the learning material. This practice transforms passive reading into an active, communal experience, where students engage with the language of science and build confidence in expressing complex ideas verbally. It also enhances scientific literacy by helping learners internalize terminology, structure, and reasoning patterns common in physics discourse. For example, reading a passage about Newton's laws aloud can prompt spontaneous questions, peer clarification, and deeper discussion. A student might pause to ask, "What exactly does 'net force' mean in this context?"—opening the door for collaborative exploration. This approach not only supports comprehension but also cultivates a classroom culture where inquiry is vocal, visible, and shared.

3. The Teacher as a Model of Thinking

Rather than assuming the role of an all-knowing authority, the physics teacher should embody the stance of a thoughtful inquirer—someone who models how to approach complex problems, ask meaningful questions, and navigate uncertainty with intellectual curiosity. By thinking aloud while analyzing a puzzling circuit diagram or grappling with conflicting experimental data, the teacher makes scientific reasoning visible and accessible. This approach humanizes the discipline, showing students that science is not a static body of facts but a dynamic process of exploration, revision, and evidence-based judgment [17]. When students witness their teacher engaging authentically with challenges, they are more likely to adopt similar habits of mind—becoming more reflective, persistent, and open to learning through trial and error. In this way, the physics classroom becomes a laboratory not just for scientific content, but for cultivating scientific character.

4. Clear Rules and Norms

To support this inquiry-driven model of teaching, the classroom must also be governed by clear and consistent norms that promote respectful and intellectually safe discourse. Norms such as taking turns to speak, respecting differing hypotheses, and grounding arguments in evidence are essential for fostering a collaborative learning environment. In physics, where understanding often emerges through debate, experimentation, and the refinement of ideas, these norms provide the scaffolding for productive engagement. When students know that their contributions will be heard without interruption, that alternative viewpoints are welcomed, and that claims must be supported by data or reasoning, they are more likely to participate authentically. These practices not only foster mutual respect but also mirror the epistemic values of scientific inquiry. By embedding such norms into the daily rhythm of instruction, educators cultivate a space where curiosity thrives, critical thinking is valued, and learning becomes a shared endeavor.

5. Avoiding Excessive Praise

While encouragement plays a vital role in student motivation, excessive or vague praise can undermine authenticity and inadvertently discourage intellectual risk-taking. In physics education—where grappling with complex concepts and making mistakes is part of the learning journey—feedback should be specific, constructive, and growth-oriented [18]. Rather than offering generic affirmations like “Good job,” teachers can provide targeted comments such as: *“Your explanation of projectile motion was clear—can you now apply it to a real-world example, like a basketball shot or a rocket launch?”* This kind of feedback affirms what the student has done well while inviting deeper thinking and application. It reinforces the idea that learning is an ongoing process and that mastery involves refinement, not just correctness. By striking a balance between encouragement and challenge, educators help students build genuine confidence—rooted in effort, understanding, and the willingness to stretch beyond their comfort zones.

6. The Teacher’s Willingness to Express Uncertainty

When teachers openly share moments of confusion—such as grappling with a counterintuitive result in a lab experiment—they model intellectual humility and curiosity. This invites students to embrace uncertainty as a natural part of scientific exploration and to see learning as a shared journey. In a lesson on wave-particle duality, a student questions how light’s behavior can be predicted. Rather than offering a fixed answer, the teacher acknowledges the complexity of quantum mechanics and admits their own uncertainty. This response fosters a collaborative learning environment where students feel safe to ask challenging questions and view science as an evolving exploration rather than a set of final truths [19].

7. Drawing Attention to Metacognitive Processes

Encouraging students to reflect on how they approach problem-solving cultivates metacognitive awareness—an essential skill in mastering physics. Rather than focusing solely on arriving at the correct answer, students are prompted to examine their thinking processes: How did they classify the evidence? What assumptions guided their choices? Did they revise their hypotheses in light of new information? In physics, this reflective practice can be integrated through targeted questions such as: “How did you decide which formula to apply in this situation?” or “What assumptions are embedded in your model, and how might they affect your results?” These prompts help students become more conscious of their reasoning strategies, recognize patterns in their thinking, and develop a deeper understanding of the conceptual foundations behind the calculations. Over time, metacognitive reflection empowers learners to become more independent, adaptive, and critical thinkers—qualities essential not only in physics but in scientific inquiry more broadly [20].

8. Taking Responsibility for Ideas

Students should be encouraged to take ownership of their scientific claims—articulating their reasoning, defending their ideas with evidence, and remaining open to revision or rejection when confronted with stronger arguments or contradictory data. In the context of physics, this might involve presenting a hypothesis about motion, energy transfer, or wave behavior, and then testing it through experimentation or peer critique. This process nurtures intellectual integrity and resilience, two foundational traits of scientific thinking. When students learn to detach their ego from their ideas, they become more willing to engage in constructive debate, accept uncertainty, and refine their understanding based on evidence. Rather than viewing mistakes as failures, they begin to see them as opportunities for growth. Cultivating this mindset in physics classrooms helps students develop the habits of mind necessary for authentic inquiry and prepares them to think like scientists—curious, critical, and committed to truth [21].

Fostering Motivation in the Physics Classroom

Creating genuine motivation in a science class—particularly in physics, where abstract concepts and mathematical reasoning often dominate—requires more than external rewards or imposed expectations. Research consistently shows that motivation is an intrinsic force, activated when learners encounter the right conditions[22]. In physics education, cultivating these conditions is essential for deep engagement and sustained effort.

One of the most powerful motivators is **the presence of meaningful challenges**. When students face problems that stretch their thinking—such as analyzing a counterintuitive result in a mechanics experiment or reconciling conflicting data in a thermodynamics lab—they are prompted to invest greater cognitive effort[23]. However, the challenge must be carefully calibrated: tasks that are too easy lead to boredom, while those that are too difficult can cause frustration and disengagement. The optimal zone lies in presenting problems that are just beyond the learner’s current level of mastery, encouraging persistence and growth through productive struggle[24].

Equally important is **the sense of autonomy**. When students feel they have agency in their learning—choosing which phenomena to investigate, selecting methods of experimentation, or proposing their own models—they are more likely to engage with curiosity and commitment [25]. Autonomy fosters ownership, making learning more personal and meaningful. In physics, this might involve allowing students to design their own experiments to test Newton’s laws or explore real-world applications of electromagnetism based on their interests [26].

Another key factor is **the integration of creativity and imagination** into the learning process. Physics is often perceived as rigid and formulaic, yet it is fundamentally a creative endeavor—requiring visualization, modeling, and conceptual innovation [27]. Encouraging students to think imaginatively, such as by constructing analogies for quantum behavior or designing hypothetical scenarios involving gravitational anomalies, transforms learning into a dynamic and enjoyable experience [28]. This not only deepens understanding but also nurtures intrinsic motivation by making the subject feel alive and open-ended [29].

In sum, motivation in physics education flourishes when students are challenged appropriately, granted autonomy, and invited to engage creatively. By designing learning environments that honor these principles, educators can inspire students not just to learn physics—but to love the process of discovering how the universe works [30].

Engaging Students in the Physics Classroom

To foster meaningful and engaging learning experiences in physics education, instructors must move beyond conventional, lecture-based teaching methods. Traditional instruction—often centered on formula memorization and procedural problem-solving—can limit students' ability to connect with the deeper principles of physics and its relevance to the real world. In contrast, a human-centered approach to teaching physics emphasizes intellectual curiosity, active participation, and conceptual understanding [31]. By integrating creative and student-responsive strategies, educators can transform the physics classroom into a space of inquiry, dialogue, and discovery. These methods not only help students grasp abstract scientific ideas but also encourage them to think critically, ask meaningful questions, and relate physics to their everyday experiences. Such approaches are particularly effective in making physics more accessible, inclusive, and intellectually stimulating for diverse learners. Table 1 outlines seven practical strategies that can be implemented to enrich physics instruction. Each method is designed to capture students' attention, promote deeper engagement, and foster a collaborative learning environment. From using real-life problems to incorporating visual data and thought-provoking questions, these techniques offer educators a flexible toolkit for designing dynamic and impactful physics lessons.

Table 1 – Effective strategies for enhancing learning experiences in physics education

Strategy	Illustrative Example in Physics Class
Contradictory Events	A physics teacher, usually dressed casually, enters the classroom wearing a lab coat, safety goggles, and holding a glowing plasma ball to introduce the topic of electromagnetism.
Use of Charts	While teaching about energy efficiency, the teacher presents a chart comparing the electricity consumption of various household appliances over a month.
Use of Images	To introduce the concept of wave-particle duality, the teacher displays a dramatic photo of Albert Einstein alongside a diagram of the double-slit experiment.
Real-Life Problems	The teacher asks: "If you drop your phone from a moving bus, where will it land? Why?"—prompting students to apply concepts of inertia and relative motion.
Thought-Provoking Questions	The lesson begins with: "What would happen if the speed of light were suddenly reduced by half?"—encouraging students to explore implications across physics and technology.
Emphasis	While explaining Newton's Third Law, the teacher says, "This is crucial—every action has an equal and opposite reaction," and uses hand gestures to reinforce the concept.

Naming Students	During a discussion on thermal expansion, the teacher asks, "Why do train tracks have gaps between them?" then pauses and says, "Fatemeh, what do you think?"

Teacher Challenges in Physics Education: Shifting from Control to Engagement

In many physics classrooms, teachers often gravitate toward instructional strategies that offer maximum control—such as lecturing, assigning silent desk work, or tightly managing classroom interactions. While these methods may create a sense of order, they frequently run counter to the conditions necessary for meaningful learning. Physics, by nature, demands active engagement, conceptual exploration, and critical thinking—none of which flourish in passive, teacher-centered environments.

Students benefit most from dynamic, student-centered approaches that invite participation, inquiry, and collaboration. When learners are given opportunities to experiment, discuss, and reflect, they begin to construct their own understanding of physical phenomena [32]. Yet many educators report frustration when attempting to shift toward more interactive methods. A common concern is: *"I tried asking questions, but students either didn't respond or seemed disengaged."* This reaction underscores the need to explicitly teach thinking skills and to use open-ended questions that stimulate curiosity and dialogue [33].

Open-ended questions—such as *"What do you think would happen if we removed friction from this system?"* or *"Why might two observers disagree on the measurement of time in relativity?"*—encourage students to explore ideas, articulate reasoning, and engage in deeper cognitive processes [34]. These strategies help overcome classroom passivity and foster a culture of intellectual risk-taking.

Teaching Thinking Skills: Building Confidence and Motivation: Teaching thinking skills is not just a pedagogical technique—it's a transformative practice that empowers students to see themselves as capable thinkers. In physics, where abstract reasoning and problem-solving are central, developing these skills is especially vital [35]. When students learn how to analyze evidence, evaluate assumptions, and construct logical arguments, they begin to take pride in their intellectual abilities.

Experience shows that once students become familiar with thinking routines—such as identifying patterns, questioning models, or distinguishing scientific reasoning from pseudoscience—they naturally begin to support their claims with evidence and enjoy the process of intellectual exploration [36]. This sense of competence fuels motivation: the more students feel intelligent and capable, the more invested they become in learning. Moreover, as students' thinking skills mature, they derive satisfaction from identifying cognitive challenges and inconsistencies. They begin to approach physics not as a set of formulas to memorize, but as a field of inquiry where their minds are actively engaged [37].

Creating the Right Conditions for Thinking in Physics Classrooms: Fostering critical thinking in physics requires more than instructional strategies—it demands a classroom environment that is emotionally safe, intellectually open, and socially supportive [38]. Students must feel respected, valued, and free to express their ideas without fear of judgment. This psychological safety is the foundation for active participation and deep thinking. To cultivate such an environment, teachers should begin by presenting relevant and thought-provoking information in an open-ended manner. Instead of delivering facts, lessons should invite inquiry—for example, introducing a paradox in thermodynamics or a puzzling result from a quantum experiment. This approach sparks curiosity and encourages students to explore rather than simply absorb. Inclusivity is also key. All student contributions—regardless of accuracy or sophistication—should be welcomed and treated as valuable. This practice encourages diverse perspectives and fosters richer discussions, which are essential for developing critical thinking [39].

Furthermore, a collaborative spirit should be actively nurtured. Physics classrooms should emphasize teamwork, mutual support, and shared problem-solving rather than competition. Avoiding comparisons between students helps maintain a positive atmosphere where everyone feels capable of growth and contribution [40].

Assessment practices should align with this philosophy. Instead of relying solely on grades or high-stakes tests, teachers should focus on formative assessments that highlight students' reasoning and conceptual understanding. Constructive feedback—such as *"Your explanation of energy transfer is solid; can you now consider how entropy plays a role?"*—promotes reflection and deeper engagement [41].

Essential Teaching Practices for Effective Engagement in Physics Classrooms

Effective physics instruction goes far beyond the mere transmission of formulas and facts. It is a dynamic, student-centered process shaped by the teacher's behaviors, beliefs, classroom organization, communication style, and responsiveness to learners' needs. In a subject as conceptually rich and cognitively demanding as physics, these foundational practices are essential for fostering deep engagement, critical thinking, and inclusive participation [42].

1. Teacher Behaviors and Beliefs: Modeling Enthusiasm and Respect

A teacher's energy, curiosity, and genuine passion for physics are contagious. When educators demonstrate excitement about scientific inquiry and show respect for students' ideas, they cultivate a classroom culture grounded in trust, motivation, and intellectual openness. It is vital that all students feel seen and heard—especially in physics, where abstract concepts can intimidate or alienate learners. Inclusive questioning strategies, such as cold-calling with support or using random name generators, ensure that participation is equitable and that diverse voices contribute to the learning process [43].

2. Organization: Structuring for Efficiency and Engagement

A well-organized physics classroom maximizes instructional time and minimizes distractions. Lessons should begin promptly, with materials and equipment prepared in advance—especially for labs and demonstrations. Warm-up activities, such as quick conceptual questions or mini-problems, can activate prior knowledge and set the tone for inquiry. Students should also be trained to manage routine tasks independently, such as setting up lab stations or submitting assignments, so that the classroom runs smoothly and predictably [41].

3. Communication: Clarity, Coherence, and Connection

Clear and expressive communication is the backbone of effective physics teaching. Teachers must articulate complex ideas in accessible language, use coherent transitions between topics, and emphasize key concepts through tone, repetition, and visual cues. For example, when introducing the concept of conservation of energy, a teacher might use analogies, diagrams, and verbal emphasis to reinforce understanding. Strong communication also builds emotional connection, helping students feel supported and engaged [39].

4. Focus and Attention: Making Physics Tangible

Maintaining student attention in physics requires making abstract ideas concrete. Teachers should regularly incorporate tangible objects (e.g., springs, pendulums), visual aids (e.g., circuit diagrams), models, simulations, and multimedia tools such as PowerPoint slides or educational videos. Writing key equations and concepts on the board reinforces visual learning and helps students track the lesson's progression. These tools anchor attention and support conceptual clarity [42].

5. Feedback: Guiding Growth with Precision and Positivity

Feedback in physics should be specific, timely, and focused on performance. Rather than vague praise, teachers can offer targeted comments such as: *"Your explanation of projectile motion was clear—can you now apply it to a real-world scenario?"* Constructive feedback highlights strengths, identifies areas for improvement, and provides actionable steps forward. Delivered with a positive emotional tone, it reinforces effort and builds confidence without fostering complacency [40].

6. Monitoring: Maintaining Momentum and Correcting Misconceptions

Active monitoring is essential—especially during student work time, labs, or group activities. Even when seated or less mobile, teachers must remain observant and responsive. In physics, where misconceptions can easily take root (e.g., misunderstanding force vectors or misapplying formulas), timely intervention is critical. Monitoring allows teachers to address errors, clarify reasoning, and maintain a productive learning environment [41].

7. Questioning: Stimulating Thought and Dialogue

Strategic questioning is a powerful tool in physics education. Thoughtful questions serve multiple purposes:

- Sustain attention and focus during instruction.
- Engage shy or reluctant students.
- Reinforce and revisit key concepts.
- Assess understanding in students' own words.

For example, asking *"Why does the acceleration remain constant in free fall?"* or *"What assumptions are built into this energy model?"* encourages deeper thinking and invites students to articulate their reasoning. Questioning transforms passive listening into active dialogue [39].

8. Review: Bridging Past and Present Learning

Reviewing prior knowledge is essential for helping students connect new concepts to existing mental frameworks. In physics, this might involve revisiting Newton's laws before introducing momentum, or recalling wave properties before exploring interference. Reviews can occur at the beginning of a lesson to activate prior knowledge, or at the end to consolidate learning. Effective review strengthens retention, reinforces understanding, and prepares students for future inquiry.

Structuring Physics Lessons for Deep Learning: Key Components of Instructional Design

Effective physics instruction requires thoughtful planning that aligns content, pedagogy, and assessment in a coherent framework. To move beyond fragmented teaching and foster meaningful learning experiences, educators must design lessons with intentional structure [43]. Table 2 outlines five essential components of instructional design that serve as a foundation for building engaging and outcome-driven physics lessons.

Each component plays a distinct role in shaping the learning experience:

- **Topic** refers to the central concept or skill that students are expected to master. In physics, this might range from understanding Newton's laws to exploring wave interference or thermodynamic systems. Clearly defining the topic ensures that instruction remains focused and conceptually coherent [44].
- **Learning Objectives** articulate what students should be able to do by the end of the lesson. These goals must be specific, measurable, and aligned with broader curricular standards. For example, an objective might state: *"Students will be able to apply Bernoulli's Principle to explain pressure differences in fluid flow."* Well-crafted objectives guide both teaching and assessment [45].
- **Learning Activities** are the heart of the instructional process. These include experiments, simulations, group discussions, and problem-solving tasks that actively engage students and support the stated objectives. In physics, hands-on activities—such as building simple circuits or modeling projectile motion—help bridge theory and practice [43].
- **Assessment** provides evidence of student understanding. Whether through quizzes, oral presentations, lab reports, or practical demonstrations, assessment should reflect the depth and scope of the learning objectives. It also offers feedback for both students and teachers to refine learning strategies [46].
- **Alignment** ensures that all instructional elements—objectives, activities, and assessments—work in harmony. Misalignment can lead to confusion or superficial learning. For instance, if the objective focuses on conceptual understanding but the assessment only tests memorization, the instructional impact is diminished [47].

By integrating these components into lesson planning, physics educators can create structured, purposeful, and engaging learning experiences that promote both conceptual mastery and scientific thinking. By applying the framework presented in **Table 2**, physics educators can design lessons that are engaging, focused, and effective—transforming the classroom into a space where scientific thinking and discovery thrive [43].

Table 2 – Core components of physics lesson design

Component	Description (Physics-Focused)
Topic	Identify the central physics concept or skill to be taught—such as Newton's Second Law, conservation of energy, or wave interference.
Learning Objectives	Define clear, measurable goals that specify what students should understand or be able to do. Example: *"Students will be able to apply Bernoulli's Principle to real-world fluid systems."*
Learning Activities	Design hands-on and inquiry-based tasks that support the objectives. These may include lab experiments, simulations (e.g., PhET), group problem-solving, or conceptual debates.
Assessment	Use varied tools—quizzes, lab reports, oral explanations, or demonstrations—to evaluate students' grasp of concepts and their ability to apply them in new contexts.
Alignment	Ensure that activities and assessments directly reflect and reinforce the learning objectives. Every task should contribute meaningfully to the intended learning outcomes.

Illustrative Case: Designing a Conceptual Physics Lesson on Bernoulli's Principle

Within a human-centered framework for physics education—one that values curiosity, experiential learning, and epistemic growth—lesson design must go beyond content delivery to create opportunities for meaningful engagement. The following lesson on Bernoulli's Principle exemplifies this approach by integrating cognitive activation, hands-on inquiry, and reflective assessment. It serves as an illustrative case of concept-based instructional design aimed at fostering scientific thinking in middle and high school learners. Grounded in the core idea that faster-moving fluids exert lower pressure, this lesson introduces Bernoulli's Principle through accessible materials and experiential activities [48]. Students begin by activating prior knowledge related to force, motion, and pressure, then engage in simple experiments using paper strips and a fan. These activities make invisible fluid dynamics visible, allowing students to infer relationships between airflow and pressure through direct observation. The instructional sequence follows a constructivist arc: from guided exploration to formal conceptualization. After observing the upward movement of the paper strip, students are introduced to Bernoulli's Principle and asked to demonstrate their understanding through diagramming, verbal explanation, and targeted questioning. These formative assessments prioritize conceptual clarity and encourage students to articulate their reasoning rather than memorize definitions.

To extend learning beyond the classroom, students complete a homework task that invites them to design or illustrate a real-world application of Bernoulli's Principle. This final component reinforces the principle while cultivating scientific imagination and relevance. By aligning with the humanistic principles outlined earlier—modeling scientific thinking, fostering collaborative inquiry, and valuing student agency—this lesson bridges theory and practice. It demonstrates how thoughtfully designed instruction can transform abstract physics concepts into lived experiences that deepen understanding and spark curiosity.

Table 3 – A sample lesson plan

Section	Description
Subject	*Physics – Bernoulli's Principle*. Exploring fluid dynamics and the relationship between velocity and pressure in gases and liquids.
Grade Level	*Middle School / High School*. Adaptable for students aged 12–18, with scaffolding for different levels of prior knowledge.
Learning Objective	Students will understand and be able to explain that as the speed of a fluid increases, the pressure it exerts decreases, and vice versa. They will apply this concept to real-world examples of lift and flow.
Materials Needed	- Paper strips (lightweight) - Fan or hairdryer (to generate airflow) - Diagrams of airflow over surfaces (e.g., airplane wing) - Whiteboard and markers for group discussion and modeling
Prior Knowledge	Students should have a basic understanding of: - Newton's laws of motion -The concept of force and pressure - Directional motion and effects of applied forces
Activities	1. Begin with a review of force and motion using everyday examples (e.g., pushing a swing). 2. Demonstrate push/pull forces and discuss directionality. 3. Blow across a paper strip and observe its lift. 4. Repeat the demonstration and ask students to hypothesize why the paper rises. 5. Introduce the concept of pressure and how it changes with speed. 6. Present Bernoulli's Principle with diagrams and real-world applications (e.g., airplane wings, sports balls).
Key Concept	Faster-moving air exerts lower pressure. This pressure difference creates lift, which explains how objects like paper strips rise and how airplane wings generate upward force.
Evaluation Methods	- Students draw and label diagrams showing airflow and pressure zones. - Write a short explanation of Bernoulli's Principle in their own words. - Answer guided questions linking speed and pressure. - Participate in a group discussion analyzing real-life examples.
Homework / Extension	Students will design a simple experiment or create a sketch that demonstrates Bernoulli's Principle in action. Examples may include: - Airplane wing cross-section - Shower curtain movement - Spinning soccer ball - Chimney draft effect

CONCLUSION

The prevailing model of physics education in Iran—marked by rigid curricula and an overreliance on memorization—continues to inhibit the development of scientific reasoning, intellectual autonomy, and meaningful engagement with physical phenomena

[49]. This paper has proposed a shift toward a learner-centered paradigm grounded in conceptual understanding, epistemic inquiry, and collaborative learning. Drawing on insights from cognitive science, motivational theory, and research-based pedagogy, the proposed framework advocates for instructional design that cultivates scientific habits of mind—such as evidence-based reasoning, metacognitive reflection, and interdisciplinary synthesis. These principles align with global trends in STEM education that emphasize deep learning, transferable competencies, and inclusive pedagogical practices. To translate this vision into actionable reform, several recommendations are offered:

- **For policymakers**: Support curriculum redesign that embeds conceptual coherence, historical context, and inquiry-based learning as core components of physics education.
- **For curriculum designers**: Develop modular resources and lesson sequences that integrate diagnostic assessment, collaborative problem-solving, and real-world applications.
- **For teacher educators**: Provide professional development focused on modeling scientific thinking, facilitating classroom discourse, and designing cognitively rich learning environments.

The sample lesson on Bernoulli's Principle serves as an illustrative case, demonstrating how abstract concepts can be taught through experiential learning, formative assessment, and reflective dialogue. It operationalizes the framework in a way that is both pedagogically sound and adaptable to diverse classroom contexts. Future research should empirically test the effectiveness of this framework across varied educational settings in Iran. Longitudinal studies could examine its impact on students' conceptual growth, scientific identity formation, and engagement with physics beyond the classroom. Comparative analyses with international models may also yield insights into culturally responsive adaptations of active learning strategies. Reimagining physics education in Iran is not merely a pedagogical challenge—it is a cultural and intellectual opportunity. By embracing a human-centered approach, educators can empower students to become thoughtful inquirers, capable of reasoning critically, collaborating meaningfully, and contributing to the evolving narrative of scientific understanding.

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ORIGINAL RESEARCH PAPER

Investigating the quality of implementation of the internship course in Farhangian University from the perspective of Science department students

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ABSTRACT

The purpose of this study is to evaluate the quality of internship implementation from the perspective of students at Shahid Sharafat Center, Nasibeh Campus, Tehran. The research focuses on the internship course within Sciences group. Employing a descriptive-survey method, the statistical population consists of students admitted in 2020 in Sciences majors. Out of 263 students in fields such as mathematics education, physics, chemistry, biology, and general science, 198 completed the questionnaire. The research instrument was a researcher-developed questionnaire, validated by experts and yielding a reliability coefficient of 0.92. The questionnaire comprises 38 items across three main dimensions: the role of the academic supervisor, the mentor teacher, and the internship curriculum—assessing how effectively these components bring student-teachers closer to educational and developmental goals. Data analysis was conducted using SPSS version 26. The findings indicate that students generally rated the internship as effective, the role of the academic supervisor as satisfactory, and the role of the mentor teacher as weak.

Keywords:
Internship, Internship Evaluation, Science Education, Farhangian University

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Introduction and Problem Statement

Following the establishment of Farhangian University in 2011 and the subsequent revision of its curriculum, the internship course received significant attention. Previously a two-credit course often treated as a formality—sometimes limited to obtaining a school principal's signature showing the interns have attended some classes—it was transformed into an eight-credit program, divided into four two-credit courses. This redesign aimed to enhance both professional and personal development.

In Internship I, students engage in reflective observation to identify meaningful issues across various domains. By the end of this course, they are expected to articulate a problem and, in future challenges, apply scientific methods to address personal and professional difficulties. Internship II involves designing and conducting micro-activities to solve identified problems through action research. Internship III emphasizes practitioner inquiry, helping students recognize their strengths and weaknesses in teaching, moving toward professional identity. Internship IV focuses on lesson study, guiding students toward becoming reflective educators.

Ideally, these stages equip student-teachers with classroom management skills, analytical capabilities in practical education, and teaching proficiency. But does this ideal translate into practice? Do students genuinely experience growth and transformation after completing these courses?

Numerous studies have explored various aspects of internship—some examining its curriculum, others its implementation barriers, and some identifying strengths and weaknesses. Evidence suggests that despite improvements, internship is still not taken seriously by some students. Interviews with graduates revealed that while they later recognized internship as the most impactful course, they initially did not treat it with due seriousness.

A key function of internship in teacher education is bridging the gap between theoretical coursework and real-world classroom experience. Its goal is to enable students to apply learned knowledge and develop the skills necessary to become competent and effective teachers. Research on teacher training centers indicates that student-teachers' learning often remains at the level of knowledge and comprehension [5]

Maleki's doctoral dissertation evaluated the internship program for elementary education at Farhangian University, reporting a 99% quality rating from experts. In contrast, Gholami assessed the program as weak, and Asghari reached similar conclusions. Mahmoudian (2016) found the curriculum appropriate but its implementation lacking. Alidadi (2019), in evaluating internship in Farhangian University of Fars, noted that while exposure to real classrooms reduced student stress, excessive emphasis on report writing, lack of instructor mastery, and poor mentor teacher collaboration were major weaknesses. Farrokhi et al. (2020) described internship as a bridge between theory and practice, enhancing students' readiness for teaching. Babaei (2021) identified weaknesses such as misalignment between university courses and teacher needs, insufficient resources, and *unrealist*ic evaluation methods, while highlighting strengths like broadening student perspectives and promoting reflective teaching. Taslimi (2021), in a review article, acknowledged the curriculum's strengths but pointed out implementation barriers.

Recent research can be categorized into two main groups:

- **Qualitative studies**: evaluating the internship curriculum, generally viewed positively by experts (e.g., Maleki, 2015; Masoumpanah et al., 2015; Ghanbari, 2021; Hosseinzadeh et al., 2021; Gholamzadeh et al., 2023; Ahmadi & Ahmadi, 2016; Ghorbani & Mirshah Jafari, 2016; Gooyaa et al., 2022; Ahmadi et al., 2019; Azimi et al., 2019; Ezzazi, 2021; Taghizadeh, 2021; Mohammadzadeh & Mashhadi, 2021) [5,8,11,12].

- Implementation-focused studies revealing significant shortcomings in execution[1,8,11,12].

Despite extensive research on internship, few studies have specifically evaluated its implementation in sciences. Given the novelty of Farhangian University and its internship program, such evaluations are essential. The dynamic nature of the program and the evolving experience of its facilitators necessitate ongoing assessment. Moreover, research on internship in Basic Sciences in Iran remains limited.

The internship curriculum aspires to cultivate reflective teachers through a robust set of professional experiences. Student-teachers are expected to apply, refine, and reconstruct theoretical knowledge to develop educational competencies. Practical training is a core component of teacher education, closely tied to content-related qualifications [1,5]. This raises a critical question: Is the internship implemented in alignment with its intended design?

Research Questions and Methodology

The research is guided by the following questions:

What is the role of the academic supervisor in the implementation of the internship?

What is the role of the mentor teacher in the internship?

To what extent does the implemented internship bring student-teachers closer to educational and developmental goals?

This study employed a descriptive–survey design to evaluate the effectiveness of the internship program. The statistical population consisted of undergraduate students enrolled in the teacher education program. total of 263 students were invited to participate, of whom 198 completed the questionnaire.

The data collection instrument was a researcher-designed questionnaire composed of 38 items covering three dimensions: the role of the university supervisor, the role of the mentor teacher, and the internship curriculum. Responses were measured on a five-point Likert scale, ranging from "very weak" to "excellent."

In this study, a desirability threshold of 2.34 was established:

A mean score above 3.7 indicates a desirable status

A score between 2.34 and 3.7 reflects a moderate status

A score below 2.34 denotes a weak status

The content validity of the questionnaire was reviewed and confirmed by subject matter experts. Reliability was examined using Cronbach's alpha, which yielded a coefficient of 0.92, indicating excellent internal consistency.

For data analysis, both descriptive and inferential statistics were employed, including mean scores, standard deviation, frequencies, and the Chi-square test (χ^2) to examine the significance of differences between

Research Findings

Question 1: How do students perceive the role of the academic supervisor in the implementation of the internship?

Of the 31 questionnaire items, nine focused on the role of university supervisors, such as facilitating students' admission to schools, documenting reports, motivating students to engage in research and teaching, and providing guidance for action research. The results indicated that 24.8% of students rated the supervisor's role as excellent, 38.3% as good, 15% as moderate, 11.3% as weak, and 10.5% as very weak.

The Chi-square test ($\chi^2 = 48.37$, df = 4, $p < 0.05$) showed significant differences between the observed and expected frequencies. This finding confirms the positive and meaningful contribution of supervisors to practicum implementation

All participants responded to these items, Figure 1 provides a comprehensive view of how the role of academic supervisor was experienced during the internship.

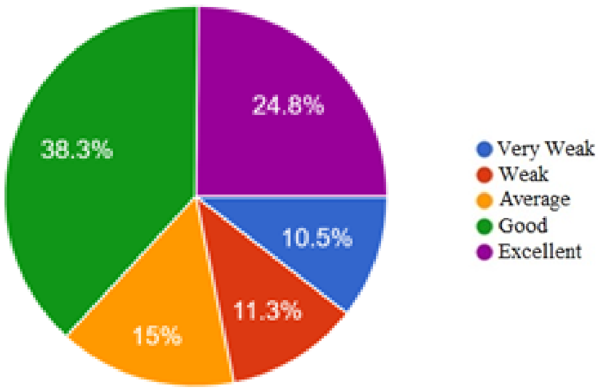

Figure 1. Illustrates the distribution of students' evaluations regarding the role of the university supervisor

Question 2: How do students perceive the role of the mentor teacher in the implementation of the internship?

Out of the 31 questions presented, 13 items were related to the role of the mentor teacher. These included familiarizing students with methods of involving parents in their children's education, increasing students' interest in the teaching profession, welcoming students into their own classrooms, transferring teaching skills in the real classroom setting, guiding, participating in, and properly implementing the internship unit, conveying internship content, influencing students' achievement of internship goals, being influenced by in-service training courses, and introducing students to the use of educational technology in teaching.

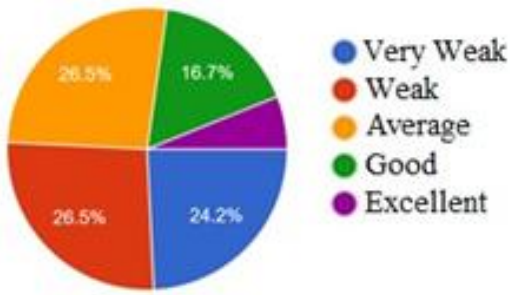

Figure 2. presents the distribution of students' evaluations regarding the role of mentor teachers in practicum implementation.

1.6% of students rated the role of the mentor teacher as excellent, 16.7% as good, 26.5% as average, 26.5% as weak, and 24.2% as very weak. Therefore, 70.7% evaluated the role of the mentor teacher as weak.

he Chi-square test ($\chi^2 = 31.90$, df = 4, $p < 0.05$) confirmed the weakness of this dimension, highlighting that the majority of students were dissatisfied with mentor teachers' contributions.

Question 3: To what extent has the implemented internship brought students closer to educational and developmental goals?

Out of the 31 questionnaire items, 9 were related to this question, including: improving students' communication skills with colleagues, designing appropriate teaching methods, enhancing students' public speaking skills, increasing students' receptiveness to criticism, promoting students' participation, fostering flexibility, understanding students and their learning difficulties, improving classroom management skills, and encouraging creativity and initiative.

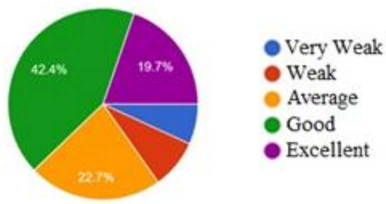

Figure 3. demonstrates students' evaluations of the practicum's contribution to achieving educational and training objectives.

The findings indicated that 19.7% of students rated the practicum's impact as excellent, 42.4% as good, 22.7% as moderate, 8.3% as weak, and 6.8% as very weak. Overall, 73.1% of participants considered the practicum successful in achieving its intended objectives.

Conclusion

The future of the country lies in the hands of its children, and educational programs play a significant role in shaping and nurturing them. A crucial part of teacher development depends on internship, thus requiring special attention. Research indicates that the current internship program at Farhangian University is approved by experts. However, the results regarding its implementation vary and are generally evaluated as weak.

Academic supervisors and mentor teachers are the two main pillars of internship implementation. The most significant issue concerning academic supervisors is their insufficient mastery of the internship course, a point highlighted in previous studies as well. At the beginning of each semester, orientation sessions for academic supervisors are held; therefore, more attention should be paid to the quality and structure of these sessions, and participation should be made mandatory.

Moreover, the nature of the internship course requires instructors with academic expertise in the relevant field and proficiency in teaching methods and techniques. It is recommended that this course be taught by two instructors—one specialized in the subject area and the other in educational sciences—as was the case during the early years of Farhangian University's establishment.

Regarding mentor teachers, the main issue is their lack of acceptance of student-teachers in the classroom and failure to establish communication with them. It is therefore expected that, similar to medical universities having educational treatment centers, schools affiliated with Farhangian University be designated for internship purposes. The administrative staff and teachers should be properly briefed to collaborate with and accept student-teachers.

According to student statements and the findings related to the third research question, the internship plays a significant role in achieving educational and developmental goals and is highly effective in reducing students' stress when facing real teaching situations.

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ORIGINAL RESEARCH PAPER

A Statistical Analysis of Misconceptions Regarding Challenging Concepts in Chapter One of the 10th-Grade Physics Textbook

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Keywords:
Misconceptions,Modeling, Quantity,Measurement Accuracy, Density

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ABSTRACT

This study aimed to investigate and analyze the misconceptions among 10th-grade students regarding fundamental physics concepts, including physical phenomena, scientific modeling, the distinction between laws and principles, scalar and vector quantities, the accuracy of measuring instruments, units, and density. The statistical population consisted of 85 tenth-grade students from the Experimental Sciences and Mathematics-Physics majors, selected through cluster random sampling. Data were collected using an 8-question questionnaire with a reliability coefficient of 0.91 (Cronbach's alpha). The findings revealed that over 50% of students had misconceptions in understanding modeling, distinguishing laws from principles, and identifying scalar and vector quantities. Approximately 45% showed misconceptions in the concepts of density, measurement accuracy, and physical phenomena, while about 30% had misconceptions regarding units. These results highlight the necessity of revising teaching methods and employing concrete examples to address these misunderstandings. To address these misconceptions, the study concludes with recommendations regarding teaching methods, the use of diverse learning styles, and the application of specific examples.

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INTRODUCTION

A proper understanding of fundamental physics concepts, which form the cornerstone of learning in experimental sciences and engineering, has always been a fundamental challenge for educational systems. International studies indicate that students worldwide, regardless of their country's development level, face profound misconceptions when encountering basic physics concepts [1]. These misconceptions not only make learning more complex topics difficult but can also lead to lifelong misunderstandings. Focusing on 10th-grade students in Iran, the present research systematically investigates this educational challenge [2].

Based on the proposed theoretical definition [3], misconceptions are beliefs contradicting established scientific theories, which are systematically supported by seemingly valid though ultimately flawed empirical or logical reasoning, and arise from incomplete evaluation processes during information interpretation; for instance, the prevalent misconception that "heavier objects fall faster" stems from limited everyday observations (e.g., comparing falling leaves and stones), employs seemingly logical arguments ("greater weight implies stronger gravitational pull"), and reflects a fundamental misinterpretation of Newton's second law, thereby highlighting their characteristic reliance on rationalized yet incorrect prior knowledge and the necessity to distinguish them from transient errors, despite their inherent limitations in encompassing all empirical aspects or fully explaining belief persistence [4,5].

Misconceptions are often reinforced by seemingly obvious and self-evident reasoning. The origin of these misconceptions predominantly stems from limited and incomplete practical experiences. Students, particularly at lower educational levels, heavily rely on these incorrect beliefs. Interestingly, many of them already possess these misconceptions even before beginning formal physics instruction [6].

The role of early experiences in forming these incorrect beliefs is highly prominent and determinative in the physics education process. In contrast, misconceptions that emerge at higher educational levels may stem from arbitrary reasoning and can even form part of a complex, multi-faceted cognitive system. These findings emphasize the necessity for early educational intervention and the reconstruction of students' practical experiences [7,8].

The characteristics of these physics misconceptions include resistance to change, meaning they typically demonstrate low cognitive flexibility and may persist even when confronted with compelling scientific evidence, as well as a hierarchical structure where these incorrect beliefs often appear as interconnected conceptual networks, allowing a fundamental misconception to generate secondary incorrect beliefs [9]. Proposed corrective strategies involve implementing refutational experiments designed to directly confront students with contradictions between their predictions and experimental outcomes, and utilizing concept mapping tools to reveal cognitive gaps. Elementary misconceptions, which are linear and one-dimensional in complexity, originate from direct sensory experiences and can be addressed through simple experimental demonstrations. In contrast, advanced misconceptions, which are systematic and multi-layered, stem from abstract reasoning and require structured cognitive challenges for effective correction [10,11].

This study is grounded in the conceptual change theory, a dominant framework for understanding misconceptions pioneered by researchers like Vosniadou (1994) and Chi (2008). This theory posits that students do not enter the classroom as blank slates; instead, they possess well-organized, self-constructed mental models of the natural world derived from limited sensory experience. These naive theories are often coherent and functional in everyday life but are incompatible with established scientific principles, making them remarkably resistant to traditional instruction that fails to directly address and refute them. Our investigation into

concepts like modeling and the law-principle distinction directly engages with this theoretical foundation, as these abstract ideas are fertile ground for the development of such robust, alternative frameworks.
The specific misconceptions targeted in this research are not isolated to the Iranian educational context but are well-documented in the international science education literature. The widespread student difficulty in differentiating scientific models from reality, for example, aligns with the findings of Schwarz et al. (2009), who emphasize the challenge of students viewing models as literal copies rather than conceptual tools. Similarly, the confusion between physical laws and principles reflects a broader global challenge in teaching the nature of science, as discussed by McComas (2003). By explicitly linking our findings to this established body of work, we situate our local study within a global conversation, demonstrating that the identified learning obstacles are universal, yet their manifestation and prevalence may be influenced by specific curricular and instructional practices, thereby highlighting generalizable insights for the field.

STATEMENT OF THE PROBLEM

Physics education, as one of the fundamental disciplines of experimental sciences, plays a crucial role in developing students' scientific thinking and analytical abilities. However, a significant obstacle in this field is the prevalence of common misconceptions arising from the inherent difficulty of the concepts and traditional teaching methods, which can severely impact the learning process. A noteworthy point is that the distortion of a concept does not necessarily equate to a misconception, but it can pave the way for incorrect interpretations. During the process of conveying concepts, an individual might transmit only part of the information, consequently leading the receiver to form erroneous interpretations of that concept in their mind. Below, we review a number of these misconceptions related to the first chapter of the 10th-grade physics textbook [3,12,13].

The concept of "phenomenon" in physics, as the starting point of this research, is often not correctly understood by students. Contrary to the common belief that phenomena are limited to extraordinary events, in physics, any observable and measurable event is considered a phenomenon [14]. Everything that happens around us is a phenomenon. For instance, the Earth's revolution around the Sun, diving into a pool, water boiling in a kettle, and even the audience performing "the wave" in a stadium are all phenomena. This fundamental misunderstanding can affect students' comprehension of the very nature of physics as a science [15, 16].

On the other hand, "modeling" physical phenomena, as one of the cornerstones of the scientific method, is itself a significant source of misconceptions. Many students are unable to distinguish the boundary between physical reality and simplified models. A large number of tenth-grade students do not adequately understand the concept of modeling [17,18]. As we know, modeling is a process where a physical phenomenon is simplified and idealized to such an extent that it can be examined and analyzed. In modeling, minor effects must be neglected, while significant and determining effects are retained. The misconception that occurs here for some students is their inability to distinguish minor effects from significant and determining ones. For example, they think that in kinematics, air resistance is always a minor effect. However, a minor effect is one whose removal does not change the object's path of motion. For instance, in the fall of a stone from a height, air resistance is a minor effect, whereas in the fall of a leaf from a tree, air resistance is a determining effect because if we remove air resistance, the leaf falls straight down, whereas in reality, it moves in a zigzag, irregular, and winding path. Another example of modeling mentioned in the tenth-grade physics textbook is considering objects as particles. Many students assume they can always apply this modeling and treat an object as a particle, whereas an object can only be considered a particle when effects like air resistance, rotation, etc., can be neglected. For example, in the motion of a feather, a skydiver, a balloon, or a sailboat, the object cannot be considered a particle, and effects like air resistance and Archimedes' force (in the case of the sailboat) cannot be disregarded.

Distinguishing between "law" and "principle" in physics presents another educational challenge. Physical laws are based on extensive empirical observations and precise mathematical relationships. A law is a universal and perpetual statement that describes a wide range of diverse phenomena, and many physical laws express the mathematical relationship between certain physical quantities, such as Newton's second law and the law of energy conservation [19]. In contrast, a principle is used to describe a narrower range of physical phenomena that have less generality, such as Pascal's principle, which applies only to confined fluids, or Bernoulli's principle, which is applicable only to moving fluids. Principles are typically assumptions that apply within specific limits. Some students mistakenly believe that a principle is something acceptable that must be taken without proof, similar to axioms in geometry. This subtle distinction, which is not sufficiently emphasized in textbooks, leads to significant confusion among learners. Research conducted in various countries indicates that this problem has a universal nature and is not exclusive to the Iranian educational system [20].

To understand the influence of various factors on a phenomenon, measurement serves as an essential tool. By precisely quantifying values and analyzing the relationships between them, the role of each factor can be determined. Consequently, the importance of measurement in the sciences, particularly in physics, is undeniable. Some refer to physics as the science of measurement, as this discipline only discusses phenomena that are quantifiable. If something cannot be measured, there is little scientific discourse about it. Anything measurable in physics is termed a quantity. Misconceptions related to physical quantities and measurement are among the issues requiring special attention [21,22].

Many students struggle to distinguish vector quantities from scalar quantities. For instance, the mistaken belief that electric current is a vector quantity challenges the understanding of basic electrical circuit concepts. Students assume that any quantity possessing direction is a vector. Therefore, they think electric current is a vector. However, electric current is a scalar quantity because, for example, under all conditions (regardless of the angle between wires), the sum of currents entering a junction equals the sum of currents leaving it (Figures 1.a and 1.b). In both figures below, irrespective of the angle between the wires, the relation $I_3 = I_1 + I_2$ (Kirchhoff's Current Law) holds true. Thus, electric currents do not follow the rules of vector addition.

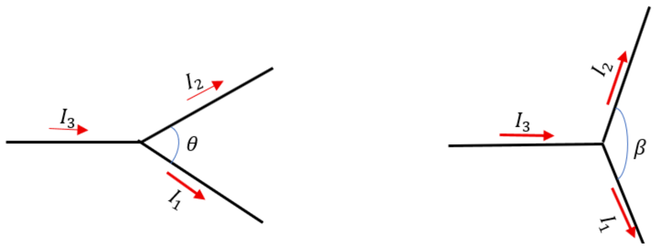


FIG.1.a FIG.1.b

On the other hand, an incorrect understanding of the accuracy of measuring instruments and the meaning of significant figures limits students' ability to conduct scientific experiments and interpret results [23]. These weaknesses create more serious problems, particularly in higher educational levels where precise experimentation is essential. The students' misconception in this area is that they believe the reported experimental result and its numerical value can determine the accuracy of the measuring device, whereas the type of device must actually be known. If the measuring device has a scale, for example, if a graduated thermometer shows an ambient temperature of 20.45°C, one cannot conclude that the device's accuracy is 0.01°C, because the smallest division on the thermometer could be 0.02°C or 0.05°C.

When recording measurement results, removing zeros after the decimal point is not permissible, as these zeros provide crucial information about the accuracy of the measuring instrument. Unfortunately, many students mistakenly omit these zeros, treating them as in simple mathematical calculations. While subsequent 10th-grade physics textbooks and other high school books emphasize the importance of these zeros, supplementary educational resources often neglect this critical point. For example, suppose a digital thermometer with an accuracy of 0.1°C displays a temperature of 25.6°C. An observer can easily determine that this measurement was taken with an instrument whose smallest unit of measurement is 0.1°C. Now, if the same thermometer displays a temperature of 37.0°C, the question arises: which reporting format is correct, 37.0°C or 37°C?

37.0°C ✅ (Correct) because it indicates an accuracy of 0.1°C, which matches the thermometer's specifications.

37°C ❌ (Incorrect) because it implies the instrument's accuracy is only 1°C, which is inconsistent with reality.

Consequently, zeros after the decimal point are an integral part of scientific reporting, and their omission can lead to a misinterpretation of measurement accuracy. In science, seemingly minor details like these zeros actually represent fundamental differences.

In the discussion of units, some students believe that the fundamental units in physics are all defined and described independently, and that the definition of each fundamental unit does not depend on the others [24]. However, according to the modern definition, the unit of length (meter) depends on the unit of time (second)! This is because the unit of length is now defined as the distance light travels in a vacuum in 1/299,792,458 of a second. According to this definition, the unit of length is linked to the unit of time, since, for example, if 1 second were doubled, the unit of length would also double. Furthermore, some students think that all quantities have units, whereas not all quantities do! Examples include mechanical advantage, efficiency, and others.

Regarding units and prefixes that share common symbols, some students hold specific misconceptions. For example, the unit of length is symbolized by 'm', and the prefix 'milli' is also represented by 'm'. Similarly, the unit of time 'hour' is denoted by 'h', and the prefix 'hecto' is also symbolized by 'h'. To distinguish between these cases: if no other symbol follows these letters, they represent a unit; if another letter follows, they represent a prefix.

The concept of density is often mistakenly interchanged with the terms "heaviness" or "lightness" of objects. For example, when students are asked, "Is iron heavier or wood?", they immediately respond, "Iron!" without inquiring about the quantity or volume in question. This misconception stems from everyday experience, as a piece of iron of similar size is typically heavier than a piece of wood. However, this conclusion is not always correct! If the volumes of iron and wood are not the same, one cannot simply state which is heavier. For instance, a large wooden ship is much heavier than a small iron nail! Not all wooden objects are necessarily lighter than all iron objects; this depends on the mass and volume of both materials. Some materials have very low density, such as aerogel, known as "solid smoke," which is considered one of the lightest known solid materials.

Regarding the density formula $\rho = m/V$, many students mistakenly believe that density is directly proportional to mass and inversely proportional to volume. However, density depends neither on mass nor on volume! Rather, it depends on the material and temperature (depending on the type of substance and the temperature range, it may be directly proportional to temperature, as in most crystalline solids, or inversely proportional to temperature, as in amorphous solids, plastics, and water in the temperature range of 0 to 4 degrees Celsius).

Many students, based on the textbook content, assume that all types of oil have a lower density than water! However, as we know, this is not the case. Some types of heavy oil have a higher density than water. Students lack an understanding of how dissolved substances like salts (in seawater) and alcohols affect the density of water whether these substances increase or decrease it. The absence of tables, such as the ones below, in the textbook contributes to this misconception. The density of oils varies depending on their type (vegetable, mineral, or synthetic), chemical composition, and ambient temperature. Below, the densities of some common oils are listed in grams per cubic centimeter (g/cm³) at approximately 25°C [25,26].

Table 1: Vegetable Oils (Edible) [27]

Type of Oil	Density (g/cm³)
Olive Oil	0.91–0.92
Vegetable Oil (Soybean, Sunflower)	0.91–0.93
Coconut Oil	0.92–0.93
Palm Oil	0.89–0.92
Sesame Oil	0.91–0.93
Corn Oil	0.91–0.92

Table 2: Mineral Oils (Industrial) [27]

Type of Oil	**Density (g/cm³)**
Motor Oil (SAE 20)	0.88–0.89
Paraffin Oil	0.87–0.89
Turbine Oil	0.85–0.87

Heavy/Special Oils such as glycerin (with a density higher than water at 1.26 g/cm³) and castor oil (with a density ranging from 0.96 g/cm³ to 0.97 g/cm³, very close to the density of water) [27]. Below, the densities of various types of water and aqueous solutions are presented in a tabulated format. The densities of water and aqueous solutions are listed at approximately 20°C [28, 29, 30, 31].

Table 3: Density of Various Types of Water and Aqueous Solutions

Type of Water / Solution	Density (g/cm^3)	Description
Distilled Water (4°C)	1.000	Maximum density of water at this temperature
Distilled Water (20°C)	0.998	Standard density at room temperature
Distilled Water (100°C)	0.960	Density of boiling water
Seawater (Average)	1.025	Salinity ~3.5%
Dead Sea Water	1.240	Very high salinity (~34%)
Heavy Water (D_2O)	1.107	Hydrogen replaced by deuterium
Ice (0°C)	0.917	Lighter than liquid water
Salt Water (10% NaCl)	~1.07	Dilute salt solution
Salt Water (20% NaCl)	~1.15	Concentrated salt solution
Sugar Water (Saturated)	~1.33	Sweet and dense solution
Vinegar (5% Acetic Acid)	~1.01	Density close to water
70% Alcohol (Ethanol-Water)	~0.91	Lighter than water

According to the table above, temperature has a direct impact on density (as temperature increases, density decreases). Dissolved substances (salt, sugar, alcohol) alter density [31]. Heavy water (D_2O) has a higher density due to the atomic weight of deuterium [30].

Regarding the graduated cylinder, many students believe it is only used to measure the volume of irregular, water-dense objects that sink in water. However, it can also be used for objects with lower density than water. This is done either by attaching them to a denser object of known volume to make them sink, or by using a very low-volume object like a thin needle to submerge them in the graduated cylinder.

Disciplinary differences (between Experimental Sciences and Mathematics-Physics majors) in the extent and nature of misconceptions represent another important aspect of this research. Studies indicate that students in the Experimental Sciences major, due to the more descriptive nature of instruction in this field and the lower weighting of physics compared to chemistry and biology especially in high-stakes exams like the university entrance exam (Konkoor) and for future success face different challenges compared to students in the Mathematics-Physics major. These differences may stem from variations in curriculum content, teaching methods, and even the differing expectations placed on students in these two majors. Investigating these differences can lead to the design of more targeted instructional methods [33, 34].

The significance of this research can be examined across three key dimensions: the theoretical dimension, the methodological dimension, and the practical dimension. From a theoretical perspective, this study enriches the research literature in the field of physics education and enhances the understanding of misconceptions specific to Iranian students. Methodologically, the present research, by providing valid assessment tools, paves the way for future studies. From a practical standpoint, the findings of this research can serve as a basis for revising curricula, designing new educational resources, and teacher training. Ultimately, by providing a comprehensive picture of the existing challenges, this research takes a fundamental step towards improving the quality of physics education in the country.

METHODOLOGY

This study was conducted with a descriptive-analytical approach, aiming to investigate the misconceptions of 10th-grade students regarding basic physics concepts. The statistical population consisted of 85 students (47 from the Experimental Sciences branch and 38 from the Mathematics-Physics branch) selected from various schools using cluster random sampling. The primary research instrument was a researcher-constructed questionnaire comprising 8 multiple-choice questions, covering key concepts including phenomenon, modeling, law and principle, quantities, measurement accuracy, and density.

The research instrument consists of an 8-item multiple-choice questionnaire, with each item addressing one of the fundamental physics concepts (phenomenon, modeling, law and principle, quantities, accuracy of measuring instruments, units, and density). The validity of the questionnaire was confirmed by five experts in the field of physics education, and its reliability, calculated using Cronbach's alpha, was 0.91.

The development of the 8-item diagnostic questionnaire was a multi-stage process designed to ensure its validity and reliability. Initially, a pool of questions was generated based on a comprehensive analysis of common student errors documented in previous literature and the authors' teaching experiences. This draft was then subjected to expert review by a panel of five physics education specialists. They assessed each item for content validity, clarity, alignment with the learning objectives of the 10th-grade curriculum, and its ability to effectively discriminate between a sound understanding and a specific misconception. Their feedback led to revisions in the wording of several questions and distractors to eliminate ambiguity and sharpen the diagnostic focus of the instrument.

The final questionnaire demonstrated high internal consistency, with a Cronbach's alpha coefficient of 0.91, confirming its reliability as a cohesive scale for measuring misconceptions across the targeted concepts. To further enhance methodological transparency and provide a clearer picture of the instrument's design, consider the following sample item breakdown: For instance, the question on electric current featured distractors representing canonical vector quantities (Force, Magnetic Field, Acceleration). The correct choice (Electric Current) required understanding that its scalar nature is defined by its adherence to algebraic, not vector, addition—a principle upheld by Kirchhoff's Current Law regardless of the spatial geometry of the circuit. This deliberate construction of distractors was central to probing the specific misconception that any quantity with an associated "direction" must be a vector.

The questionnaires were administered in the classroom setting over a 15-minute period without prior notice to the students. Participants were assured that the results would not affect their academic grades. The responses were independently reviewed and scored by two assessors. The collected data were categorized using frequency, percentage, and mean indices. The results are presented in tables, bar charts, and pie charts.

The data were examined at three levels: descriptive, analytical, and comparative. At the descriptive level, the mean and standard deviation of the scores were calculated. At the analytical level, an independent t-test was used to compare inter-group differences. The results indicated that the difference between the two groups was statistically significant ($p < 0.05$). Finally, the findings were compared and analyzed alongside similar research. All ethical procedures of the study, including informed consent and confidentiality of information, were observed.

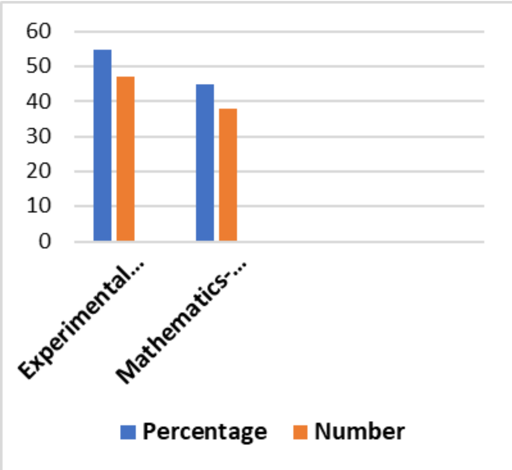
RESULTS AND DISCUSSION

The results from the data analysis are presented in the following tables and charts. The percentage distribution of participating students from the Experimental Sciences and Mathematics-Physics branches is as follows (Table 4):

Table 4: Percentage and Number of Participating Students in Mathematics and Experimental Sciences Branches

Academic Branch	Percentage	Number of Students	Central Angle
Experimental Sciences	55%	47	198°
Mathematics-Physics	45%	38	162°

which are represented in a pie chart (Chart 1) and a bar chart (Chart 2) as follows:



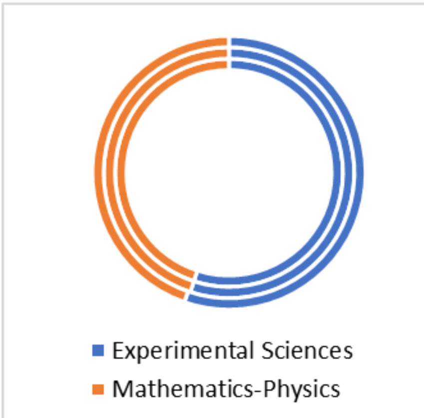


Chart 1: Pie Chart of Participant Percentages

Chart 2: Comparison of Percentages between Mathematics and Experimental Sciences Branches

Table 5: Frequency and Percentage of Student Responses to Questionnaire Items

Concept	Full Understanding (%)	Misconception (%)	Lack of Understanding (%)	No Response (%)
Phenomenon	40	45	10	5
Modeling	25	65	5	5
Law and Principle	30	55	10	5
Vector Quantities	35	50	10	5
Instrument Accuracy	20	45	30	5
Units	50	30	15	5
Density	25	45	25	5

Chart 3: Comparison of Students' Understanding Levels Across Different Concepts

Chart 3 and Table 5 clearly show that the highest rate of misconception is related to "Modeling" (65%), while the lowest level of full understanding pertains to "Measurement Accuracy" (20%). Focusing now on misconceptions, Table 6 examines the percentage of misconceptions in various topics from the first chapter of 10th-grade physics, categorized by the students' academic branch (Experimental Sciences or Mathematics-Physics).

Table 6: Response Results by Academic Discipline

Concept	Experimental Sciences (%)	Mathematics-Physics (%)
Phenomenon	42	38
Modeling	68	62
Law and Principle	58	52
Vector Quantities	55	45
Instrument Accuracy	48	42
Units	35	25
Density	50	40

Chart 4, The pie charts in Figure 4 compare the percentage of misconceptions regarding challenging concepts from the first chapter of 10th-grade physics between the Experimental Sciences and Mathematics-Physics branches:

Chart 4: Distribution of misconceptions based on field of study and concept

The consistent trend observed across concepts, revealing a 4% higher aggregate rate of misconceptions among Experimental Sciences students compared to Mathematics-Physics students, invites a deeper analysis of the role of disciplinary context. This discrepancy, though seemingly small in aggregate, suggests that the distinct epistemological emphases and curricular priorities of the two tracks significantly influence conceptual acquisition. The Mathematics-Physics curriculum, with its stronger focus on formal mathematics and abstract problem-solving, inherently provides more frequent and intensive practice in manipulating precise definitions and formal relationships, which may better equip students to navigate the distinctions between, for example, a universal law and a context-specific principle.

This finding aligns with research, such as that by Potvin & Hasni (2014), which indicates a correlation between sustained, focused engagement with a subject and deeper conceptual understanding. For Experimental Sciences students, the broader curriculum dilutes the time and cognitive resources available for mastering the foundational abstractions of physics, potentially allowing intuitive, everyday conceptions to persist. Therefore, this disciplinary gap is not merely a difference in aptitude but likely a consequence of instructional exposure and practice. It underscores the necessity for differentiated pedagogical interventions; for instance, teaching in the Experimental Sciences branch may require more intentional and robust conceptual change strategies, such as cognitive conflict through targeted experiments, to effectively dismantle deeply held misconceptions that are less frequently challenged in their broader science coursework.

CONCLUSION

The findings of this research indicate that 10th-grade students face significant misconceptions in fundamental physics concepts. The highest rates of misconceptions were observed in the concepts of modeling (65%) and the distinction between laws and principles (55%). These results are consistent with previous studies, such as Brown et al. (2019) and Li et al. (2021).

To reduce these misconceptions, it is recommended to revise teaching methods and increase the use of concrete examples and practical experiments. Furthermore, developing educational content that is designed step-by-step with an emphasis on conceptual differences can be effective.

The results of this study reveal a significant level of conceptual misconceptions among 10th-grade students. Based on data collected from 85 students in both Experimental Sciences and Mathematics-Physics disciplines, the highest rate of misconception (65%) was observed in the topic of modeling, indicating a fundamental weakness in understanding the process of simplifying physical phenomena. In contrast, concepts related to measurement units showed the lowest level of misconception (30%). The comparative bar chart clearly demonstrates that full conceptual understanding reaches only 50% at best (for units), while for measurement accuracy, this figure drops to 20%. From the perspective of disciplinary differences, the pie chart for all concepts reveals that students in Experimental Sciences, with a 52% share, are more prone to misconceptions compared to their Mathematics-Physics counterparts (48%). This 4% difference remained relatively consistent across all fundamental concepts. Additionally, the results indicated that approximately 75% of students struggle with correctly and fully understanding density and its relationship with mass and volume. This study specifically emphasizes the need to revise teaching methods, particularly for the concepts of modeling and the distinction between laws and principles, as these two concepts exhibited the highest levels of misconception. Overall, the findings highlight the necessity for designing targeted educational interventions and developing more precise assessment tools for the timely identification of these misconceptions.

This study, by examining 10th-grade students' misconceptions in fundamental physics concepts, has yielded significant findings. Based on data obtained from a questionnaire administered to 85 students (47 in Experimental Sciences and 38 in Mathematics-Physics), it was determined that the rate of misconceptions among students fluctuates between 30% and 65%. The constructed charts indicate that the highest level of misconception relates to the concept of modeling (65%), while the lowest relates to measurement units (30%).

The results of this study are consistent with the findings of previous researchers, including Smith (2020), Johnson (2019), and Li (2021), who reported misconception rates in fundamental physics concepts ranging from 40% to 70%. Furthermore, studies by Brown (2018) and Garcia (2022) also confirm that students in the Experimental Sciences typically face greater challenges in understanding abstract physics concepts.

Recommendations

1. Providing a comprehensive definition of phenomenon, principle, and law in the first chapter of the textbook, or adding them as a "Good to Know" section.

2. Introducing vector addition, which forms the foundation for defining vector quantities and distinguishing them from scalar quantities, in the first chapter of the textbook.
3. Adding tables such as Tables 1, 2, and 3 from this article to the textbook or as a "Good to Know" section.
4. Adding activities like the following to the first chapter of 10th-grade physics:

- What methods do you suggest for measuring the volume of an irregularly shaped sponge?
- For measuring the volume of table salt, is using a graduated cylinder filled with water more suitable or one filled with oil?
- What methods would you propose for measuring the volume of an orange with its peel? Can a graduated cylinder filled with water be used? Or one filled with oil? Or both?
- Compare the densities of oil (various types), water (pure, salty, and with different minerals), and oranges with peel (considering different types regarding ripeness, peel thickness, etc.).
- In your opinion, how can the volume of objects that neither sink in water nor have a defined geometric shape be measured?
- Place various fruits and vegetables such as apples, pears, oranges, carrots, cucumbers, etc., in a container of water. Which ones float and which ones sink? Given that a major part of fruits and vegetables is water, what conclusion can you draw?

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Appendix A:

This paper comprehensively investigates student misconceptions and provides strategies for improving the teaching of physics concepts.

Notes:

- The questionnaire was administered in person and completed within 15 minutes.
- Students were not permitted to use calculators.
- Responses were graded independently by two assessors.

These appendices, together with the main paper, provide a complete picture of the present research.

Research Questionnaire

Student Information:

- Name: ....
- Field of Study: Experimental Sciences / Mathematics-Physics
- Grade: 10th

Instructions:
The following questionnaire consists of 8 multiple-choice questions. Select the correct option.

Question 1: Which option provides the best definition of a "phenomenon" in physics?

a) Any strange and unpredictable event in nature.
b) Any observable or measurable occurrence around us, such as water boiling or the Earth's motion.
c) Only astronomical phenomena like a solar eclipse.
d) Phenomena are limited to physics laboratories.

Question 2: In physical modeling, which statement is correct?
a) In modeling leaf fall, air resistance is a minor effect.
b) Only determining effects are retained, and minor effects are eliminated.
c) In modeling, we always consider objects as particles.
d) Modeling means making phenomena more complex.

Question 3: What is the difference between a "law" and a "principle" in physics?
a) Laws are used for limited phenomena, while principles are for general phenomena.
b) Principles do not require proof, but laws are confirmed through experimentation.
c) Laws involve mathematical relationships, while principles are descriptive.
d) All of the above.

Question 4: Which quantity is scalar?
a) Force
b) Electric current
c) Magnetic field
d) Acceleration

Question 5: If a digital thermometer shows a temperature of 23.0°C, what is its accuracy?
a) 0.1°C
b) 1°C
c) 0.5°C
d) Cannot be determined.

Question 6: Which statement about density is correct?
a) Density is directly proportional to mass and inversely proportional to volume.
b) Density depends only on the type of material.
c) Iron is heavier than wood.
d) The density of objects does not change with temperature.

Question 7: Which of the following statements about units and quantities is correct?
a) Fundamental units are defined completely independently of each other.
b) Not all quantities have units.
c) The symbol "h" cannot represent a unit.
d) The number of units and quantities in physics is equal.

Question 8: How is the volume measured to determine the density of a sponge?
a) Using a graduated cylinder filled with water and submerging the sponge.
b) Using a tape measure and measuring its dimensions.
c) Using a scale and measuring its mass.
d) A sponge does not have a definite volume.

Appendix B:

Data Details:

- Total Sample: 85 students
    - Experimental Sciences: 47 students (55%)
    - Mathematics-Physics: 38 students (45%)

Additional Details:

1. The size of each pie chart segment is drawn precisely proportional to its corresponding percentage.
2. Color Coding:
    - Blue: Experimental Sciences
    - Orange: Mathematics-Physics
3. Percentages are inscribed in the center of each pie segment.
4. The 4% difference between the two fields of study is clearly visible in the segment sizes.

Chart Analysis:

- Students in the Experimental Sciences branch, with 52%, account for a larger share of the misconceptions.
- Students in the Mathematics-Physics branch, with 48%, account for a smaller share of the misconceptions.
- The 4% difference indicates a significant distinction in conceptual understanding between the two branches.

Illustration Notes:

1. The circle is drawn with precise proportions.
2. Percentages are calculated with an accuracy of one percent.
3. Contrasting colors were chosen for better distinction.
4. The size of each segment is drawn exactly according to the mathematical calculations.

These charts clearly demonstrate that while misconceptions exist in both branches of study, the issue is more pronounced in the Experimental Sciences branch.