

Research on the Teaching Design of Mechanical Energy Conservation Based on PBL Teaching Mode

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Abstract: This study aims to explore the design of high school mechanical energy conservation teaching based on the PBL (Problem-Based Learning) teaching model, in order to enhance students' interest in learning, autonomous learning ability, and problem-solving ability. Through the analysis of the teaching content, teaching objectives, and learning characteristics of high school students regarding the law of conservation of mechanical energy, combined with the theoretical basis and implementation process of the PBL teaching model, a complete set of teaching designs has been developed the plan. This plan stimulates learning motivation, cultivates critical thinking, team collaboration skills, and innovative spirit by guiding students to solve real-world problems related to the conservation of mechanical energy. During the teaching implementation process, students deeply understand the principles and applications of the law of conservation of mechanical energy through various methods such as group cooperation, data consultation, and experimental exploration. Finally, they formulate solutions, present them, and discuss them, thus forming an effective closed loop in knowledge construction and ability development.

Keywords: PBL Teaching Model; Conservation of Mechanical Energy; Instructional Design; Autonomous Learning; Problem-Solving Ability

1. Introduction

The "General High School Physics Curriculum Standards (2017 Edition)" explicitly states that physics teaching should prioritize cultivating students' physical concepts, scientific thinking, scientific inquiry, and scientific attitudes and responsibilities as core curriculum objectives [1]. The law of conservation of mechanical energy, as the core principle permeating the energy

concept system, is a crucial avenue for achieving these objectives. However, traditional teaching often adopts a "teach formulas-practice exercises" model, leading students to rely on rote memorization and mechanical application. This approach results in a superficial understanding of the physical essence, conditions of validity, and universality of the law. When confronted with real and complex situations, students often exhibit common issues such as diminished interest in learning, weak self-inquiry awareness, and insufficient comprehensive application abilities.

The PBL teaching model, with its core concept of "starting with problems, centering on students, and focusing on collaborative inquiry," is considered an ideal way to overcome the aforementioned difficulties [2]. It drives students to autonomously integrate knowledge, develop higher-order thinking, and enhance collaborative abilities through the process of attempting to solve ill-structured real-world problems. However, current PBL practices in middle school physics classrooms often become a mere formality due to vague problem design, a lack of structured support during the inquiry process, and a disconnect between evaluation and objectives, failing to form an effective closed loop that promotes deep learning among students. Therefore, this study aims to go beyond the general exploration of PBL concepts and focus on the specific content of high school physics, constructing a PBL teaching design system with clear theoretical understanding, closed-loop processes, and strong operability. We chose the "law of conservation of mechanical energy" as the content carrier, and explored the case through "verification through free fall motion" as the core throughout, constructing a four stage teaching closed-loop model (as shown in Figure 1). This study will elaborate on how to integrate the case into a complete teaching loop and provide a comprehensive plan from learning situation analysis, goal setting to process

implementation (see Table 1 in Chapter 3 for specific teaching implementation plans), and evaluation feedback (see Table 2 in Chapter 4 for evaluation systems). Strive to provide a practical blueprint for frontline teaching that can be directly referenced, replicated, and implemented, effectively promoting the effective transformation of PBL mode from concept to classroom practice.

2. Theoretical Basis and Design Framework

2.1 Theoretical Basis

The theoretical foundation of this instructional design integrates constructivist learning theory and relevant principles of cognitive psychology, with the core competency framework of physics as the guiding target. Constructivism posits that learning is a process in which learners actively construct meaning through socio cultural interaction, which establishes the basic principles of creating authentic situations, promoting social negotiation, and supporting meaning construction for this design [3]. The theory of conceptual change in cognitive psychology points out that scientific learning requires cognitive conflict, concept deconstruction, and reconstruction, which directly guides this case to drive students to revise their preconceptions by designing conflict points where predictions do not match actual measurements [4]; the mental model theory suggests that effective problem solving relies on individuals' inherent mental models, and the core goal of this instruction is to guide students to revise their naive mental models about energy conversion systems into scientific structured models through inquiry [5]; cognitive load theory suggests that instructional design needs to optimize information presentation to reduce external cognitive load, and the structured inquiry plan and data processing template provided in this case are scaffolding built to reduce students' irrelevant cognitive burden and focus on core thinking [6]. The entire PBL inquiry process, guided by the core competency framework of physics, becomes a unified development of physical concepts, scientific thinking, scientific inquiry, and scientific attitudes, enabling the organic integration of theory, methods, and teaching objectives [7].

2.2 Design Framework: PBL Closed-Loop Model for Capability Development

Based on the aforementioned theories and tailored to the learning characteristics of senior one students, we have constructed a PBL four-stage teaching closed-loop model centered on ability development (Figure 1). This model emphasizes that learning is a complete cycle with problem-solving as the main thread and iterative improvement, aiming to achieve simultaneous enhancement of interest, knowledge, and ability [8-10].

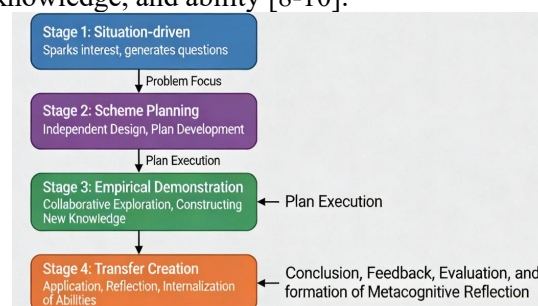


Figure 1. PBL Four-Stage Teaching Closed-Loop Model

Model Explanation: Learning begins with a real-life driving situation that triggers strong curiosity and cognitive conflict (Phase I). Faced with unstructured challenges, students need to independently analyze the essence of the problem and collaboratively design a feasible exploration plan. This process focuses on cultivating their abilities in analysis, planning, and autonomous learning (Phase II). By implementing the plan, collecting evidence, and participating in evidence-based debates, students collaboratively construct new knowledge and deeply understand its conditions for establishment (Phase III). Finally, students apply the new knowledge to new situations or engage in creative design, completing the transfer and transformation of achievements and achieving a sublimation of problem-solving abilities (Phase IV). Formative evaluation and reflection run through each phase, providing immediate feedback and basis for adjustment for learning, making the entire teaching process a self-optimizing and continuously developing closed loop, ultimately outputting solid physical concepts, strong subject interest, and transferable autonomous problem-solving abilities.

3. Teaching Plan Design and Implementation

To transform the four-stage teaching closed-loop model (as shown in Figure 1) constructed in Chapter 2 into practical classroom teaching, we designed a detailed PBL teaching implementation plan using "the law of

conservation of mechanical energy" as the instructional content and "verifying the conservation of mechanical energy through free-fall motion" as the core inquiry activity. This plan strictly follows the four-stage logical sequence of "situation-driven → plan formulation → inquiry verification → transfer and creation," systematically presenting the teaching objectives, teacher activities, student activities, and design intentions for each stage. It

serves as an operational blueprint for translating the theoretical framework into classroom practice. Through this plan, students will experience a complete scientific inquiry process in real-world problem contexts, achieving the organic integration of knowledge construction and ability development. The specific teaching phase divisions, teacher-student activity arrangements, and design intentions are detailed in Table 1.

Table 1. PBL Teaching Implementation Plan for "Verifying the Law of Conservation of Mechanical Energy through Free-Fall Motion"

Topic: 8.4 Verification of the Law of Conservation of Mechanical Energy		Grade: Senior 1	Class hours: 2 class hours
Mark Teaching objectives	physical concept	Through exploration, understand the content and expression of the law of conservation of mechanical energy, and initially Establish the physical concept of "energy conservation in total amount under specific conditions".	
	scientific thinking	1. Be able to accurately state the applicable conditions of laws and make judgments and inferences in specific physical situations (such as simple pendulum, inclined plane). 2. Go through the process of "simplifying complex problems establishing ideal models" to develop models Constructive ability.	
	scientific inquiry	1. Go through the entire inquiry process of "posing questions, designing experiments, obtaining evidence, explaining, and communicating". 2. Learn to design experimental schemes for verifying the conservation of mechanical energy, and be able to analyze experiments The physical essence of error.	
	Scientific attitude Responsibility	In collaboration, we should cultivate a scientific attitude of seeking truth from facts, being rigorous and conscientious, and daring to question Doubt and debate.	
Teaching preparation	Equipment: Iron stand, heavy hammer, electric spark timing device (or photoelectric gate sensor), paper tape, scale, student power supply. Materials: "Free-Fall Inquiry Planning Book" and "Classroom Reflection Journal" template.		
teaching process			
Teaching and Learning Environment section	teacher activities	student activities	Design intent
Situation driven and problem generating	Create a conflict situation: Play a video comparing the motion of a roller coaster loop with the free fall of an apple. Ask: "How do designers ensure the safe operation of a roller coaster? Can its energy secret be revealed through a simpler motion?" 2. Guide the transformation of the problem: Organize a discussion: "To study the ideal situation of 'only gravity doing work', which kind of motion is the purest and most convenient for laboratory research?" Guide students to reach a consensus and choose free-fall motion as the research model. 3. Generate core questions: Write them on the blackboard and clarify the driving task for this class: "Design and conduct an experiment to verify whether the mechanical energy of an object is conserved during free-fall motion."	1. Observation and Association: Watch videos and experience the manifestation of physical laws in different scenarios. 2. Discussion and decision-making: Group discussion, acknowledging the scientific validity and necessity of simplifying and modeling complex problems as free-fall studies. 3. Task confirmation: Clearly understand the research problem that needs to be solved ultimately	Starting from real and interesting scenarios, we can stimulate students' inherent interest. Guiding students through the scientific abstraction process from complexity to simplicity, and from reality to models, is the crucial first step in problem solving.
	Scheme planning and design	Provide thinking scaffolding: Use questions to guide deep thinking: "What do we need to measure? (v, h) Why?" "How to measure v? (Review of the principle of the ticker-timer/photoelectric gate) How to minimize the influence of air resistance?" Distribute the "Free Fall Inquiry Plan": Guide student teams to systematically design the experiment from aspects such as experimental purpose, principle,	1. Collaborative design: Work in groups to complete a detailed experimental design plan based on discussions and the framework of the "Planning Document". 2. Presentation and defense: The presenting team elaborates on their design approach and addresses queries from other

	<p>equipment, steps, data recording sheet, and possible errors.</p> <p>3. Organize a "scheme feasibility hearing": Invite two groups to present their preliminary schemes, and guide the entire class to focus on discussing key points: How can the installation of the paper tape reduce friction? Which two points should be selected for energy comparison? Where should the height h be measured from</p>	<p>teams regarding operational details and error control.</p> <p>3. Optimization plan: Based on the feedback from the hearing, revise and improve the plan for this group.</p>	<p>is the core of autonomous learning and engineering thinking.</p>
Experimental exploration and collaborative argumentation	<p>Inspection and process guidance: Emphasize and inspect key operational norms (such as positioning the timing device vertically, applying power before releasing, and straightening the paper tape).</p> <p>Hosting the "Data Demonstration Meeting":</p> <p>a. Evidence Presentation: Each group will project and present the processed data (such as a comparison table or coordinate graph of $v^2/2$ and $g \cdot h$).</p> <p>b. Guide in-depth debate: Key questions: "Does all the data perfectly support $v^2/2 = g \cdot h$? Is the main deviation too large or too small? What physical problem does this indicate? (Air resistance does negative work, consuming mechanical energy.) Is this force a 'non-conservative force'?"</p> <p>c. Promote scientific consensus: Summarize the debate and lead students to jointly draw the core conclusion: within the allowable range of error, when only gravity does work, mechanical energy is conserved. Write down the complete law expression and conditions on the blackboard.</p>	<p>Conduct experiment: Operate according to the optimized plan, obtain the paper tape, and measure accurately.</p> <p>Process and analyze data: Calculate the changes in kinetic and potential energy at each point to verify the hypothesis.</p> <p>Participate in collective argumentation: Present evidence and conclusions as the "advocate"; question the rationality of data from other groups as the "reviewer". Through confrontation, deeply understand the physical essence of "error" as "work done by non-conservative forces", thereby internalizing the conditionality and approximation of conservation laws.</p>	<p>Let the authority of scientific conclusions stem from evidence and logic. Through critical analysis of errors, we can transform teaching difficulties into points of thinking enhancement, enabling students to truly understand the physical connotations of laws.</p>
Summary of transfer and reflection	<p>1. Guide to structured laws: Help students summarize laws in concise language, emphasizing their "condition-conclusion" structure.</p> <p>2. Design a migration ladder:</p> <p>a. Basic application: Calculate the velocity of an object with a mass of 2kg falling freely from a height of 5m to the ground.</p> <p>b. Condition judgment: Analyze whether the mechanical energy is conserved in the case of "an object falling freely in vacuum" and "falling freely in air".</p> <p>c. Situational regression: "Now, how can we use more scientific language to explain the operation of the roller coaster on an 'ideally smooth' track?"</p> <p>3. Assign reflective homework: Write a reflective journal titled 'My Journey of Inquiry', reflecting on the entire process from confusion, design, setbacks to clarity</p>	<p>1. Summarize and generalize: Participate in completing the normative expression of the law.</p> <p>Complete the migration: solve problems and consolidate conditional judgment ability in application.</p> <p>3. Establishing connections: Transfer the conclusions of free fall back to the initial situation and appreciate the value of the model.</p> <p>4. Conduct metacognitive reflection: Analyze the thought process through journals, solidify inquiry methods and scientific attitudes.</p>	<p>The depth of understanding is tested through "application", and sub-problems are explored and integrated into the original complex problem through "regression", forming a cognitive loop. Reflective journals promote metacognitive development, transforming learning experiences into learning abilities</p>

4. Teaching Evaluation Design

Teaching evaluation is a critical component of the PBL four-stage closed-loop teaching model (see Figure 1). It not only serves to assess students' learning outcomes but also plays a feedback-regulating role in promoting the achievement of teaching objectives and optimizing the teaching process. To effectively evaluate the extent to which this PBL program

achieves its core goals—such as "stimulating learning interest, enhancing self-directed learning abilities, and developing problem-solving skills"—we developed a diversified evaluation system deeply integrated with the teaching process. This system spans the entire PBL inquiry process, covering dimensions such as problem design, student engagement, collaborative skills, knowledge mastery, solution application, and ability improvement,

transitioning from single-knowledge testing to assessment methods, and weight allocations are formative and developmental evaluation. The detailed in Table 2 [11].
specific evaluation dimensions, indicator settings,

Table 2. PBL Learning Process and Ability Development Evaluation System

Evaluation dimension	evaluation metric	Evaluation Type	Evaluation method	weight
question design	The question is open-ended and enlightening, closely related to the topic of conservation of mechanical energy, and can stimulate students' interest	Formative evaluation , Summative evaluation	Observe students' reactions to problems and analyze their proposed solutions to problems	0.15
	The difficulty levels of questions are clearly structured, catering to the challenge needs of students at different learning levels	Formative evaluation, Summative evaluation	Check the participation and problem-solving abilities of different students within the group	0.1
Student engagement	Each student actively spoke up during group discussions ,participating in problem analysis and the formulation of solutions	formative evaluation	Classroom observation, group discussion records	0.1
	Students actively participate in activities related to experimental design, data collection, and analysis (specifically for the mechanical energy conservation experiment)	formative evaluation	Experimental report, on-site observation of the experiment	0.1
collaboration skills	Members within the group have a reasonable division of labor, collaborate with each other, and jointly advance the process of problem solving	formative evaluation	Group division of labor plan, observation of group cooperation situation	0.1
	The team can communicate effectively in the process of problem-solving , respects different opinions , and has a good team atmosphere	formative evaluation	Audio recording or observation record of group discussion	0.1
Knowledge management	Students can correctly understand the concept and conditions of the law of conservation of mechanical energy	Formative evaluation , summative evaluation	Classroom questioning, homework, and quizzes	0.1
Solution And application	Students can apply the law of conservation of mechanical energy to solve physical problems in different scenarios (Such as problems involving simple pendulum, inclined plane slider, etc.)	Formative evaluation , summative evaluation	Homework, quizzes, exams,and project results presentation	0.1
capability enhancement	Students' expression abilities have been enhanced, encompassing both oral expression (group presentations) and written expression (report writing)	Formative evaluation , summative evaluation	Group presentation performance, report quality	0.1
	Students ' critical thinking skills have developed , enabling them to offer their own insights on problem - solving strategies and theories related to the conservation of mechanical energy	Formative evaluation , summative evaluation	Viewpoint elaboration in classroom discussion records, student assignments, and project reports	0.05

5. Conclusions

This study systematically constructs a PBL teaching design scheme for high school mechanical energy conservation, with the core objectives of enhancing students' learning interest, autonomous learning ability, and problem-solving ability. This scheme is not simply a pile of activities, but a clearly structured, closed-loop, and highly operable teaching system, based on learning theories such as constructivism, conceptual change, and cognitive load, and tailored to the specific learning situation of senior one students. Its core innovation lies in proposing a four-stage teaching closed-loop model with the logical

sequence of "situation drive - scheme planning - exploration and argumentation - transfer and creation", organically integrating the knowledge learning of the law of conservation of mechanical energy into the entire process of solving a real and complex problem, namely "cracking the energy code of roller coasters".

This design exhibits distinct practical orientation characteristics. It transforms theoretical models into executable classroom steps through detailed implementation tables, and ensures the observability and evaluability of ability cultivation objectives through an embedded and multidimensional evaluation system. The entire design forms a complete teaching loop from "interest stimulation" to "ability internalization",

theoretically providing a clear and feasible path for overcoming the drawbacks of traditional physics law teaching and effectively implementing the cultivation of core competencies in physics. Although this study focuses on theoretical design and scheme construction, its rigorous theoretical basis, detailed analysis of student learning situations, and complete operational framework lay a solid foundation for its implementation and verification in real teaching environments, possessing significant reference value and promotion potential. Future research can use this scheme as a blueprint to conduct in depth empirical teaching research, further optimizing the design of each link by collecting and analyzing teaching practice data, thereby continuously enriching and developing the application paradigm of PBL mode in middle school physics teaching.

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