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Innovation and Practice of College Physics Teaching from the Perspective of Multi-Physics Coupling

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Abstract: Traditional college physics teaching mostly deals with single physical fields, which is convenient for basic knowledge instruction but tends to fragment the inherent connections among physical phenomena, making it inconsistent with the real physical picture of complex systems in modern engineering practice. Multi-physics coupling studied in this paper focuses on the mutual influence and synergistic interaction of multiple physical fields—including thermal, stress, electromagnetic, and fluid fields—in space and time, representing a frontier and focus of current and future scientific research and engineering design. From the perspective of multi-physics coupling, this paper combines the current situation of college physics teaching and proposes innovative teaching strategies. It aims to effectively break disciplinary barriers, cultivate students' systematic physical thinking, and genuinely integrate the concept of multi-physics coupling into all links of college physics teaching through comprehensive reform and practice. These efforts will greatly enhance students' ability to analyze and solve complex practical problems, and ultimately cultivate more engineering and technological talents with interdisciplinary literacy and innovative competence.

Keywords: Multi-physics coupling; College physics; Teaching innovation

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1. Introduction

In real-world engineering and scientific problems, physical phenomena do not exist independently but arise from the mutual influence and interaction of multiple physical fields. For instance, the thermal protection of hypersonic vehicles involves strong coupling between aerodynamic heating and structural deformation; the performance of electronic devices is jointly determined by electric, thermal, and stress fields. Such multi-physics coupling effects directly reflect the authenticity and complexity of the physical world. However, studies show that the traditional college physics teaching system is usually taught in separate modules: mechanics, thermology, electromagnetism, etc. Although such "decoupled" instruction helps beginners grasp basic physical concepts, it inadvertently creates disciplinary barriers and weakens students' understanding of the integrity and connectivity of physical phenomena. Facing increasingly complex demands of modern science and technology, it is urgent and important to cultivate innovative talents with cross-field analysis and synthetic thinking ability. Integrating the scientific idea of multi-physics coupling into college physics teaching is not only an enrichment and deepening of teaching content but also an important reform of teaching philosophy. On this basis, guided by the perspective of multi-physics coupling, this paper aims to restructure teaching content and innovate teaching methods, shifting college physics teaching from single-point knowledge explanation to complex problem-solving ability cultivation, so as to provide theoretical support and practical guidance for deepening college physics teaching reform.

2. Significance of college physics teaching innovation from the perspective of multi-physics coupling

2.1. Solving knowledge fragmentation and helping students establish a complete physical picture

Traditional college physics teaching is usually organized chapter by chapter: mechanics, thermology, electromagnetism, optics, etc., with isolated knowledge points. Students often memorize physical laws as isolated formulas and fail to understand the inherent connections between fields. The core idea of multi-physics coupling is to reintegrate originally scattered concepts based on real physical processes [1]. For example, the piezoelectric effect involves mechanical deformation, electric field variation, and energy conversion. Electro-thermal coupling emphasizes the close links among electric current, resistance, Joule heat, temperature field, and thermal expansion [2]. College physics teaching from the multi-physics coupling perspective guides students to understand that the physical world is not governed by single fields but by mutual influence and restriction of multiple fields. With deeper learning, students can better grasp the main ideas of conservation laws, boundary conditions, and field quantity transfer, gradually shifting from memorizing formulas and doing exercises to understanding physical mechanisms and building an overall picture. They can construct a structured knowledge system, laying a solid physical foundation for future professional study.

2.2. Approaching engineering practice and improving students' physical modeling and application ability

Beyond theory, the core value of college physics lies in solving real problems. Modern engineering problems are almost always characterized by multi-field coupling: electromagnetic-thermal-mechanical coupling in motor operation, mechano-electric coupling in MEMS, electrochemistry-thermal-fluid coupling in battery operation, etc. Traditional teaching focuses on single-field solutions and is disconnected from engineering practice, leaving students knowing what but not why. In contrast, multi-physics coupling teaching takes small engineering problems as carriers, focusing on guiding students to extract key physical quantities from phenomena, determine coupling relationships, build simplified models, and then analyze and solve them. This process helps improve students' modeling ability, dimensional analysis ability, approximation ability, and numerical calculation awareness. Students will no longer regard physics as an abstract theory but as a key tool for engineering analysis. Multi-physics coupling teaching can fully stimulate students' learning motivation, cultivate their application awareness, and ultimately guide them to shift from "exam-oriented learning" to "problem-solving learning" [3].

2.3. Promoting the transformation of teaching methods and shifting classrooms from lecturing to inquiry

Most multi-physics coupling problems cannot be fully described by analytical formulas. Therefore, teachers must adopt innovative classroom models such as simulation, experiment, and project-based learning. Specifically, teachers can combine real coupling cases to guide students in thinking, letting them observe corresponding phenomena by changing parameters, compare results, and explain rules, thus promoting deep integration of learning, application, and exploration. In addition, multi-physics coupling teaching requires teachers to continuously enrich teaching resources, optimize experimental projects, and design progressive cases to achieve synchronous updating of content and methods. For most students, coupling problems are more challenging and comprehensive, which is significant for stimulating critical thinking, cultivating cooperative inquiry awareness, and improving innovative literacy. Especially with the in-depth advancement of curriculum ideology and politics and new engineering construction, taking multi-physics coupling as a grip to continuously promote teaching reform can greatly improve classroom efficiency, guide students to transition from shallow to deep learning, lay a solid physical foundation for professional study, and boost the high-quality development of basic course teaching [4,5].

3. Effective strategies for innovation and practice of college physics teaching from the perspective of multi-physics coupling

3.1. Restructuring teaching content: Taking typical coupling phenomena as clues to integrate fragmented knowledge points

Traditional college physics teaching is carried out by disciplines and branches with weak connections among knowledge points, making it difficult for students to clearly understand the inherent links between fields. From the multi-physics coupling perspective, teachers need to reorganize teaching content at the fundamental level. The key is to take small, concrete, and understandable coupling phenomena as the main line to genuinely connect mechanics, thermology, electromagnetism, optics, etc., into a structured knowledge system. In actual teaching, instead of organizing content by chapters, teachers divide units around four basic coupling problems: mechano-electric, electro-thermal, magneto-thermal, and opto-electric coupling [6]. For example, in “electrostatic field” teaching, teachers can introduce small cases of piezoelectric ceramics generating electricity under force and deforming when energized, organically integrating Hooke’s law, stress and strain, electric field intensity, potential difference, and energy conservation. When teaching “circuits and Joule’s law,” teachers can visually present temperature changes of thermistors and thermal expansion of conductors, and coherently explain electric current work, heat transfer, temperature field distribution, and thermal expansion laws [7,8]. Notably, content selection should follow the principles of low threshold and strong relevance, avoiding complex mathematical derivation and focusing on physical mechanisms and coupling relationships. Teachers should also actively build a hierarchical coupling case base, developing demonstration-level, inquiry-level, and expansion-level cases to continuously improve comprehensiveness.

3.2. Integrating lightweight simulation tools: Visualizing coupling processes and reducing abstract understanding difficulty

Multi-physics coupling processes are usually invisible, intangible, and not directly measurable. Over-reliance on schematic diagrams and textual descriptions may increase students’ understanding burden. Therefore, teachers should actively introduce lightweight, easy-to-operate, low-threshold multi-field coupling simulation tools to visualize invisible coupling processes. With the help of observable, operable, and verifiable visual dynamic models, students can understand more easily. In practice, teachers do not need to use large professional software; instead, they can select appropriate simple simulation platforms according to classroom needs, control parameters, and present images in real time [9]. For example, in "electromagnetic-thermal coupling" teaching, teachers can guide students to change current magnitude and material thermal conductivity via the simulation platform to clearly show the time evolution of temperature field distribution. In "mechano-electric coupling" teaching, students can drag deformation sliders to observe output voltage changes in real time. In class, teachers should adopt the model of "teacher demonstration → student observation → conjecture rules → parameter modification → conclusion verification," converting abstract coupling relationships into intuitive images to help students thoroughly understand abstract physical knowledge [10,11]. Studies show that visual teaching helps students form coupled physical images in the shortest time, reduces cognitive load, and motivates them to participate in class more enthusiastically.

3.3. Designing miniature inquiry experiments: Improving hands-on and analytical ability through small-scale coupling experiments

Multi-physics coupling teaching cannot stay at the theoretical and simulation levels; it must be implemented in experiments. Traditional physics experiments are mostly single-field verification experiments, which cannot fully reflect coupling mechanisms. Teaching innovation requires teachers (or teachers and students together) to design low-cost, easy-to-operate, and safe miniature coupling inquiry experiments, allowing students to explore coupling laws through hands-on operation and improve their abilities in data measurement, phenomenon analysis, and error handling in practice. Miniature inquiry experiments should follow the principles of small devices, simple principles, and clear goals, avoiding complex instruments or dangerous operations [12]. For example, in the experimental design of "relationship between force applied to piezoelectric materials and voltage output," teachers can use simple pressure devices, voltmeters, and piezoelectric plates to guide students in exploring the quantitative law between pressure magnitude and output electrical signals, helping them understand mechano-electric coupling. In designing "temperature and resistance variation of energized conductors," low-voltage power supplies, thermistors, and thermometers can be used to guide students in exploring the coupling relationship among current, resistance, and temperature [13,14]. As shown in the above designs, the core of experimental tasks is inquiry rather than simple imitation. During experiments, teachers should guide students to think actively: Do single-field laws still hold? What new phenomena arise from coupling? What factors affect coupling strength? Supported by miniature coupling experiments, students can not only master basic physical knowledge firmly but also cultivate scientific awareness and improve inquiry ability. More importantly, they shift from passively watching experiments to actively doing experiments and analyzing laws, eventually forming a "theory-simulation-experiment" trinity teaching system.

3.4. Optimizing classroom mode and evaluation method: Promoting learning-centered teaching and strengthening comprehensive literacy assessment

Multi-physics coupling teaching requires changing the traditional lecturing classroom, building a problem-driven, group-cooperative, task-led classroom mode, and establishing a matching process evaluation system—an important measure to ensure the sustainable effectiveness of teaching reform. In class, teachers can drive learning with small questions: combining daily phenomena, asking specific questions such as “Why do energized motors generate heat?” and “Why can pressure produce electrical signals?”, guiding students to decompose physical processes and identify coupling relationships [15]. Classroom organization should adopt “short lectures, quick inquiries, small presentations,” with each unit centered on a miniature coupling task. Teachers should encourage students to express ideas, question each other, and improve together. The evaluation method should no longer take the final written test as the only standard; instead, a diversified evaluation system should be built, including classroom participation, simulation operation reports, miniature experiment records, coupling phenomenon analysis assignments, and group inquiry achievements. The focus of evaluation should shift from formula memorization and problem-solving skills to physical picture construction, coupling mechanism understanding, modeling ability, and inquiry spirit. For example, in actual assessment, teachers can create simple coupling scenarios and ask students to identify involved physical fields, write coupling relationships, and qualitatively explain phenomena rather than perform complex calculations. This respects students’ dominant position in class and ensures the comprehensiveness and objectivity of assessment.

4. Conclusion

As shown by the above research and analysis, restructuring teaching content with typical coupling phenomena, visualizing processes with lightweight simulation tools, elaborately designing miniature inquiry experiments to improve students’ practical ability, and optimizing classroom modes and building diversified evaluation systems can help students clearly sort out inherent connections among physical knowledge points, improve their physical modeling ability, and cultivate good comprehensive thinking. Notably, multi-physics coupling teaching is not a simple superposition of teaching content; instead, it helps students construct a systematic knowledge system in a way closer to the real physical world and guides them to shift from passive acceptance to active inquiry. Only in this way can college physics truly become the cornerstone for the growth of science and engineering talents and boost college physics teaching to a higher level.

Disclosure statement

The author declares no conflict of interest.

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