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Reform and Innovation of Fundamentals of Materials Science Course Under the Background of Emerging Engineering Education

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Abstract

Under the background of Emerging Engineering Education (3E), which aims to cultivate interdisciplinary, innovative, and practice-oriented engineering talents, the Fundamentals of Materials Science course faces prominent challenges such as outdated teaching content, disjointing theory and practice, monotonous practice form and single-mode teaching and assessment. To address these issues, this study explores a systematic reform and innovation path covering three core dimensions: optimization of the teaching contents, reconstruction of the teaching models, and improvement of the assessment system. Through integrating cutting-edge interdisciplinary achievements, adopting student-centered teaching methods and establishing a multi-dimensional assessment mechanism, the reform enhances students' initiative in learning, strengthens their abilities to apply theoretical knowledge to solve engineering problems, and effectively aligns the course with the talent training goals of 3E. Practice results show that the reformed course significantly improves students' comprehensive quality and meets the demand for high-quality materials-related talents in the new engineering context.

Keywords

Course Reform and Innovation, Fundamentals of Materials Science, Teaching Content and Models, Assessment System.

1. Introduction

Fundamentals of Materials Science serves as a cornerstone course for undergraduate majors such as Materials Science and Engineering, Mechanical Engineering, and Civil Engineering [1]. It systematically expounds the intrinsic relationships between material composition, structure, performance, and preparation processes, building a critical theoretical and practical foundation for students' subsequent professional learning and engineering practice. However, with the rapid development of emerging engineering fields in new energy materials, biomedical materials or intelligent composite materials) and the increasingly urgent demand for compound engineering talents, the traditional Fundamentals of Materials Science course exhibits obvious inadequacies that restrict its ability to adapt to the 3E background [2, 3]. On the one hand, the teaching content is outdated and disconnected from cutting-edge developments. The traditional curriculum focuses excessively on basic theories of conventional materials, such as traditional metals and ceramics of structural material, while neglecting the integration of emerging materials and interdisciplinary knowledge. At present, new energy materials of perovskite solar cell materials, graphene-based composites and the combination of materials science with artificial intelligence for material design have been research hotspot as important parts of the pillar of the new materials industry. However, students can hardly acquire this kind of knowledge from the traditional teaching, leading to their lack awareness of the latest industry trends and interdisciplinary thinking. On the other hand, traditional teaching models are teacher-centered and lack interactivity and practicality. Most classes adopt the "lecture-based" teaching method, where teachers unilaterally impart knowledge and students passively receive it. There is insufficient integration of practical links such as experiments, engineering cases, and project-based learning, resulting in students' weak ability to translate theoretical knowledge into engineering problem-solving skills, which is a key deficiency compared with the 3E requirement of "strengthening practical innovation" [4, 5]. Additionally, the current assessment systems are too single to reflect the comprehensive abilities of the students. Traditional assessment relies heavily on final written examinations, which focus on testing students' memory of theoretical concepts rather than their practical operation, innovative thinking, and teamwork abilities [6]. This misaligns with the 3E goal of evaluating students' comprehensive quality from multiple dimensions. In response to these challenges, this study proposes targeted reform and innovation strategies for the Fundamentals of Materials Science course by teaching content optimization, teaching model reconstruction, and assessment system improvement, and further discusses the application and effectiveness of relevant teaching methods, aiming to build a course system that is compatible with the new engineering background and promotes the all-round development of students' professional literacy.

2. Strategies for Course Reform and Innovation

To meet the talent training requirements of 3E, the reform of Fundamentals of Materials Science focuses on three key aspects: optimizing teaching content, reconstructing teaching models, and improving assessment systems, forming a coordinated and systematic reform framework.

2.1. Optimization of Teaching Content: Adding Cutting-Edge and Interdisciplinary Knowledge

The core of content optimization is to "connect basics with frontiers" and "integrate disciplines", making the curriculum content more in line with the development of the materials industry and interdisciplinary trends.

(1) Strengthen the relevance of content and construct a systematic knowledge framework. It is necessary to break through the traditional chapter boundaries and restructure the content based on the logical main line of "components - structure - performance - application". When explaining crystal structure, the teachers can simultaneously associate the microscopic causes of differences in material mechanical properties. In the class, we can take the extreme difference in hardness and conductivity between diamond and graphite as example. They are both composed of carbon atoms, but their crystal structures are completely different. In diamond, each carbon atom forms a covalent bond with four adjacent carbon atoms, creating a tetrahedral structure. The interatomic bonding force is extremely strong and there are no free electrons, thus making it extremely hard (with a Mohs hardness of 10) and non-conductive. However, the carbon atoms in graphite are arranged in a hexagonal layered structure. The atoms within each layer are bonded by strong covalent bonds, while the layers are only connected by weak intermolecular forces. Under external force, the layers can slide easily, thus graphite has low hardness and can be used as a lubricant), at the same time, there are free electrons within the layers, so it has good electrical conductivity. This detailed case explanation

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can guide students to establish the core cognition that "microscopic structure determines macroscopic performance", and avoid knowledge fragmentation.

(2) Supplement emerging materials and frontier technologies. The course syllabus should be revised by increasing modules on emerging materials such as new energy storage materials (lithium-sulfur batteries, solid-state batteries), biomedical materials (hydrogel scaffolds, degradable metal implants), and intelligent materials (shape memory alloys, self-healing composites). Additionally, each module is taught with a combination of theoretical principles, industrial application cases, and latest research progress. When explaining the content of “material deformation”, the concept of shape memory alloys can also be introduced simultaneously. Shape memory alloys refer to materials that undergo deformation under external force, and then return to their original shape after being heated to a certain temperature. The hinges used in China's domestically developed spacecraft are made of this material, enabling the solar panels to be unfolded controllably.

(3) Strengthening the connection between theory and engineering practice. Add a “Engineering Case Analysis” section in each chapter. For example, when teaching “material strengthening mechanisms”, take the “lightweight design of high-speed rail car body materials” as a case to analyze how to select and optimize aluminum alloy materials by combining solid solution strengthening and precipitation strengthening. When explaining “phase transformation”, using the “heat treatment process optimization of automotive engine valves” to help students understand the practical application of phase transformation theory in industrial production.

(4) Simplifying redundant classic content and highlight core competencies. It is important and necessary to streamline repetitive content on conventional material properties and focus on explaining universal principles. Taking the “relationship between structure and performance” as an example, the content can be transferred to emerging materials, such as the materials for Li-ion batteries, which can stimulate students' thinking on the solution to solve the performance degradation of the batteries by modulating the phase structures. This not only reduces the burden of knowledge for students but also guides them to master “transferable skills” for adapting to future material innovation.

2.2. Reconstruction of Teaching Models: Applying Student-Centered and Diversified Methods

Usually, the traditional teaching model is centered around the teacher, ignoring the participation of students. Here, different ways are raised to break away from the traditional “teacher-centered” model, and construct a diversified teaching system that emphasizes student participation, interaction, and practice, to cultivate students’ autonomous learning and innovative thinking.

(1) Combining online and offline blended teaching. By combining various resource of MOOCs, virtual simulation experiments and academic paper databases, an online course resource platform can be built to realize “pre-class preview + in-class interaction + after-class review” teaching closed-loop. For example, students learn the basic principles of “material preparation processes” through online MOOCs before class. In class, teachers organize discussions on difficult points and guide students to simulate the “powder metallurgy process of titanium alloys” using virtual simulation software, which solves the problems of high cost and long cycle of traditional experiments. After class, students can complete online exercises and discuss with teachers and classmates through the platform.

(2) Introducing project-based learning and team cooperation. Based on the course contents of different disciplines, teachers can set up interdisciplinary project tasks, such as “Design of high-strength alloy materials” “Development of energy storage materials”, and divide students into teams of 4-5 people. Each team need to complete the whole process from project proposal, literature review, scheme design, to result presentation. In this process, students not only apply

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the knowledge of materials science but also exercise abilities in teamwork, communication, and innovation. Teachers play the role of guides, providing suggestions on project progress and technical difficulties.

(3) Inviting industry experts and front-line engineers for joint teaching. Connecting the theoretical knowledge in textbooks with practical applications is a necessary skill for engineering students. In order to achieve this goal, it is necessary to regularly invite engineers from leading enterprises of traditional or new material companies and researchers from research institutes to give lectures, such as “Latest technical challenges in the field of solid-state hydrogen storage materials” “Industrial application of Ti-based materials”, which can enable students to realize the problems of materials in actual production and application, understand the actual needs of the industry, narrow the gap between campus learning and enterprise practice, and establish a “engineering-oriented” learning concept.

2.3. Improvement of Assessment System: Establishing Multi-Dimensional Assessment

To comprehensively evaluate students’ learning effects and meet the 3E requirement of “assessing both knowledge and ability”, the course reform constructs a multi-dimensional assessment system that combines process assessment (accounting for 60% of the total score) and final assessment (accounting for 40% of the total score) with equal emphasis on theory and practice.

(1) Diverse integration and covering the entire process. Different from the traditional final evaluation system, in this reform, the process assessment plays the predominant rile, covering multiple links to reflect students’ learning process comprehensively, including pre-class preview, in-class performance, after-class assignments and peer evaluation. Pre-class preview (accounting for 10% of the total score) aims to evaluate the completion of online preview tasks and preview notes. At the same time, in-class performance and after-class assignments account for 20% and 15% of the total score, respectively. During the class, participation in discussions, performance in virtual simulation experiments and team cooperation in personal projects are assessed. While after the class, the quality of case analysis reports, project progress reports and literature reviews are evaluated. In team projects, team members are asked to score each other’s contribution, responsibility and communication ability to complate the peer evaluation. In the section of final assessment, reform is applied to change the traditional written examination and focus on testing students’ comprehensive application ability. The examination questions are added by scenario-based questions and open-ended questions, such as “Based on the service environment of aerospace area, design a high-strength and lightweight alloy materials and explain the principle” “Discuss the application prospects and challenges of carbon nanotubes in flexible electronics”. These measures can reduce the proportion of memory-based questions and increasing the proportion of application and innovation-based questions.

(2) From "Knowledge memory" to "Comprehensive ability". In order to break the evaluation orientation centered on theoretical memory, this reform adds the weight of the ability dimension. The proportions of knowledge-based and ability-based assessments are approximately 60% and 40%, respectively. In the case of dimension of knowledge mastery, the examinations focus on the understanding and application of core concepts rather than mechanical memorization, such as crystal defect, alloy phase structure and phase diagram. In the section of dimensions of comprehensive ability, scientific thinking and practical application should be investigated. For example, assessing the ability to analyze the logical connection among "material structure - performance - preparation" by analyzing “the strengthening mechanism of Al-Cu alloy”.

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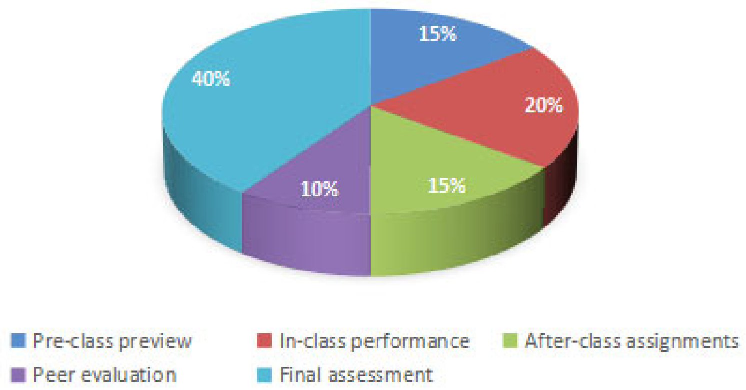

Figure 1. The schematic diagram of the multi-dimensional assessment system

3. Practice Effects and Analysis

The reform and innovation strategies of Fundamentals of Materials Science have been implemented in three consecutive grades (2021-2023) of materials science and engineering majors in a certain university, with a total of 182 students participating. Through questionnaire surveys, score analysis, and enterprise feedback, the practice effects are summarized as follows.

(1) Improvement in learning initiative and interest. The questionnaire shows that 87% of students believe that the added emerging material modules and engineering cases "greatly stimulate learning interest", and the participation rate of online preview and in-class discussion reaches more than 90%, which is 45% higher than that before the reform.

(2) Improved innovative thinking and scientific research ability. In the "Innovation and Entrepreneurship Competition", the number of teams participating in materials-related projects increased by 62% after the reform, 15 projects won provincial awards and 2 projects won national awards. Additionally, more and more students participate in their mentors' research projects, and contribute to the publication of high-quality academic papers or invention patents. This reflects that the reform has effectively cultivated students' innovative consciousness and interdisciplinary thinking.

(3) Enhanced ability to apply knowledge to solve the practical application problems. The average score of students in the practical operation assessment of virtual simulation experiments and project design are increased by over 20% compared with that before the reform. In the enterprise internship, more than 60% of the students were rated as "excellent" by the internship units, mainly due to their ability to "quickly connect theoretical knowledge with practical problems".

4. Conclusion

The reform and innovation of Fundamentals of Materials Science under the background of Emerging Engineering Education addresses the key problems of the traditional course, such as outdated content, single teaching mode, and incomplete assessment system, through three core strategies of optimizing teaching content, reconstructing teaching models, and improving assessment systems. The core of content optimization is to "connect basics with frontiers" and "integrate disciplines". Reconstructing teaching models is achieved by breaking away from the traditional "teacher-centered" model and constructing a diversified teaching system. Moreover, the course reform constructs a multi-dimensional assessment system that combines process assessment (including pre-class preview, in-class performance, after-class assignments and peer evaluation) and final assessment with equal emphasis on theory and practice. Practice shows that the reform not only enhances students' mastery of basic knowledge but also significantly improves their practical application ability, innovative thinking, and interdisciplinary literacy, effectively aligning the course with the talent training goals of 3E. However, the reform still has room for improvement. In the teaching of emerging materials, the updating speed of teaching resources needs to keep pace with the rapid development of the industry, and the integration of digital teaching tools is still in the preliminary stage. In the future, it is necessary to establish a dynamic update mechanism for teaching content, deepen the integration of digital technology and course teaching, and further strengthen cooperation with industries and research institutes, to continuously improve the quality of the course and provide more powerful support for cultivating high-quality materials-related engineering talents in the new era.

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