Article

Research on Teaching Innovation Practice of Fundamentals of Materials Engineering

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Abstract: As a required course for materials-related majors, the Fundamentals of Materials Engineering is offered in many universities. However, traditional teaching of Fundamentals of Materials Engineering faces issues such as the disconnection between theoretical knowledge and practical engineering problems, limited focus on students' skill development and personal growth, and inadequate support for cultivating higher-order thinking and entrepreneurial abilities. Thus, it leads to students lacking the ability to innovate and solve practical engineering problems. In response to the needs of new engineering disciplines construction and the development of new quality productive forces, teaching reform is imperative. Therefore, this research adopts a student-centered educational approach that emphasizes character development, aligns with modern pedagogical frameworks, and incorporates advanced teaching standards aimed at fostering innovation, complexity, and high-level thinking. With the main focus on incorporating high-level thinking and innovation education and cultivating a sense of patriotism and the ability to solve complex engineering problems, the teaching content has been restructured, engineering cases have been developed, and value-oriented case studies have been designed, and multi-dimensional assessment and evaluation have been formed. The outcomes of the teaching reform practices demonstrated significant improvements in student engagement and learning effectiveness.

Keywords: fundamentals of materials engineering; teaching innovation practice; teaching content restructuring; engineering and ideological-political cases development; multi-dimensional assessment

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1. Introduction

As the core course of materials major, the significance of enhancing the teaching quality of Fundamentals of Materials Engineering is self-evident. With the rapid development of industry, there has been an increasing demand for talents capable of driving new productive forces, which has placed higher requirements on the knowledge, skills, and overall competence of workers [1]. The cultivation of new-type talents cannot be achieved without the high-quality development of education, and it also requires the construction of new-type courses as a guarantee [2]. The traditional teaching methods are unable to meet the requirements for talent cultivation imposed by the current social development environment [3]. Therefore, teaching innovation is imperative.

At present, the main approaches to teaching innovation include changes in teaching concepts, innovations in teaching models, improvements in teaching evaluation models, application of information technology, and application of engineering cases and ideological and political cases, etc. [4-17]. However, these innovative methods are still based on the teachers' own understanding of the curriculum and involve no student participation in the teaching innovation practices [18]. There are even fewer cases of jointly building teaching resource libraries by multiple parties.

Therefore, based on the need for talents resulting from the development of new quality productive forces, this study takes the material engineering foundation course as an example of a material-related degree course, and conducts practical innovations in course teaching. It is expected to provide theoretical support for the implementation path of curriculum teaching innovation.

2. Teaching Problems Analyzing and Solution Elaborating

Fundamentals of Materials Engineering is a core course for the cultivation of professionals in the materials discipline. In the context of higher education supporting the development of advanced technologies and emerging engineering disciplines, it plays a key role in addressing complex engineering problems related to the research, design, and practical application of new materials. However, before the curriculum reform, through on-site investigations and questionnaire surveys, it was found that there were the following three major problems in classroom teaching. First of all, students generally expressed that theoretical knowledge was abstract and difficult to understand. Secondly, when the graduated students apply the knowledge related to this course in their work, they generally express that the content taught in class is disconnected from the actual engineering problems. Finally, the employers pointed out that students showed a lack of advanced thinking in material design and development, weak ability to solve complex engineering problems and insufficient creativity in their work.

Based on the field research results, the three major challenges in the teaching design and process were identified as follows: insufficient integration of digital technology and engineering cases, a teacher-centered instructional approach, and inadequate emphasis on developing students' innovation and entrepreneurship capabilities. In response to these problems, the teaching team took teaching classes of material majors as pilots and carried out teaching innovations and practical activities for Fundamentals of Materials Engineering.

Figure 1 showed the teaching innovations paths. As shown in Figure 1, the teaching innovation paths of Fundamentals of Materials Engineering primarily include the innovation of teaching philosophy, reconstruction of teaching content, improvement of learning outcome evaluations, joint development of engineering and socio-technical case studies, and integration of research and competition results into teaching.

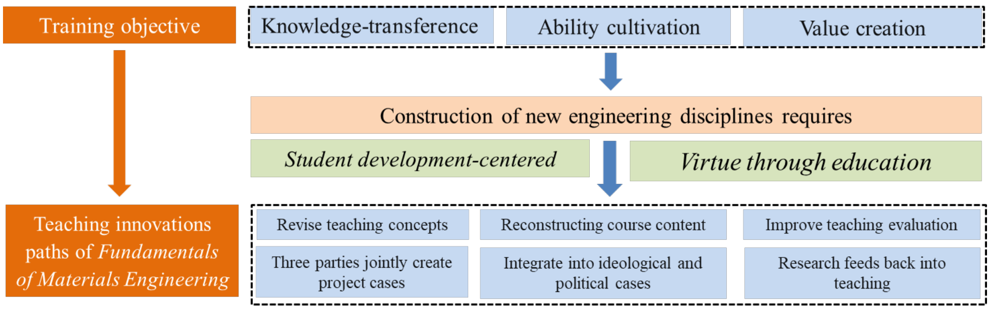

Figure 1. Teaching Innovations Paths of Fundamentals of Materials Engineering.

3. Implementation Plan of Teaching Innovation

3.1. Jointly Created Engineering Case Database by Enterprises, Teachers and Students

In this research, the actual engineering case database was jointly created by employers, teachers and students through breaking down complex engineering problems and integrating them with relevant knowledge points. Table 1 presents nine engineering cases developed as part of the project, which are based on processes involving material and process design, development, and application. These engineering cases cover all course chapters and address the learning needs of students at all levels (including beginner, intermediate, and advanced). The case also incorporated the research achievements of the team and the winning results of the students' science and technology competitions.

Table 1. Engineering Cases Created by Employers, Teachers and Students.

Knowledge point	Case Summary
Fluid statics	Teachers and students jointly conducted the Pascal barrel experiment in accordance with the pressure resistance requirements of deep-sea submersibles. Explore the static pressure control mechanism and establish a relationship model between diving depth and the required material compressive strength.
Fluid dynamics	A collaborative project between the university and the enterprise was initiated to develop key technologies for regulating the wind pressure of engineering ducts, resulting from the difficulty in accurately assessing the wind pressure of the cement plant.
Flow resistance	Simulate the tail flow patterns of fluids passing through bends and components in the pipe using information technology, the methods for reducing fluid resistance can be verified.
Fluid energy loss	Explore the kinetic energy loss characteristics model of fluids with different viscosities in pipes with different roughness utilizing information technology.
high-rise building fire	In response to the social challenge of high-rise building fires, fire prevention and rescue measures were developed by applying the Bernoulli equation and conducting on-site experiments.
Conduction of heat	Given the challenges in enhancing thermal performance of inorganic insulation materials for building walls, educators and students jointly conducted an experiment to enhance the thermal conductivity of the materials, analyzed and discussed the influencing factors of material heat conduction and transmission, and formed an example of applying Fourier's law.
complex heat transfer	Enterprises, teachers, and students jointly conducted a comprehensive heat transfer experiment on refractory bricks to address rational material selection for industrial kilns.
Fuel and combustion	Through teacher-student collaboration grounded in fuel combustion theory, innovative methodologies were developed to optimize combustion efficiency and address industrial challenges associated with low-quality fuel utilization.
Mass transfer principle	Enterprises, teachers and students collaborated to conduct solid-phase reaction experiments, proposed a titanium recovery plan from titanium slag, and solved the problem of difficult titanium resource recovery for the enterprise.

3.2. Integrating Civic and Ethical Education into the Curriculum

The concept of holistic education emphasizes not only the transmission of knowledge and the development of technical skills, but also the cultivation of personal values and character. In this course, the teaching team has explored the civic and ethical dimensions of engineering education and embedded three core themes — civic responsibility, mental well-being, and humanistic literacy — in an integrated and reflective manner. Values education is thoughtfully integrated into the curriculum to foster students' sense of social responsibility, ethical awareness, scientific spirit, and their motivation to apply their knowledge for societal advancement. This study explores the intrinsic link between engineering education and value cultivation, transforming it into concrete instructional elements, as summarized in Table 2.

Table 2. Ideological and Political Cases.

Theme	Knowledge point	Ideological and Political Elements	Cases
Socialism core values	history of fluid mechanics	Mission and Responsibility	Dujiangyan Irrigation Project, the Contributions of Qian Xuesen
	Static pressure	craftsmanship spirit	The breakthrough in the sealing technology of China's "Jiaolong" deep-sea submersible.
	conduction heat transfer	Contributive spirit	The contribution of Chinese high-carbon steel in international infrastructure projects.
	Fuel and combustion	Mission and Responsibility	The energy structure, carbon emissions, and national-level carbon reduction strategies.
Psychological health	Application of Bernoulli Equation	anti-pressure ability	The immense dedication of the Bernoulli family to the cause of education, without seeking fame or fortune.
	Gas fuel combustion	survival skill	List the casualties and economic losses caused by the gas explosion accidents in Shenyang and Yinchuan.
	fluid dynamics	self-motivation (quantitative and qualitative change)	The transformation between laminar flow, supercritical flow and turbulent flow.
	heat conduction	career planning	Presenting Fourier's life story can inspire students to make good career plans.
Humanistic quality	complex heat transfer	dialectical thinking (view things from a dialectical perspective)	Discussing about the changes in heat transfer conditions and characteristics.
	System and control body		Discussing the idea of unity in opposition.
	boundary layer effect		Explore the changes of the internal flow state within the boundary layer through discussions.
	Karman Vortex Street		Discussing the advantages and disadvantages of the Karman vortex street and its applications.
	similarity theorem	engineering ethics	How Chinese scholars overcoming the bottleneck technologies in catalysts.

3.3. Research Feeds Back into Teaching

To promote problem-oriented and project-driven teaching, we incorporate scientific research achievements, innovation cases, and practical applications, encouraging students to apply their knowledge in real-world scenarios. Through problem-oriented and project-driven teaching, we incorporate scientific research achievements, innovative cases, and innovative applications, encouraging students to apply what they have learned (Table 3).

Table 3. Connection between Scientific Research Achievements and Teaching Knowledge Points.

Research contents	Knowledge points	Cases of research contributing to teaching
Development and application promotion of low-carbon and ul-	Basic properties of fluids Fluid dynamics	Develop low-carbon ultra-high-performance concrete (UHPC) with self-compacting properties, long-term durability, and high utilization rate of solid waste residues based on rheological property principles. The fluid performance of the concrete

tra-high-performance concrete (UHPC)		material reciprocally validates its rheological characteristics, and this innovation will be promoted through student academic competitions.
Development and application of cementitious materials for carbon removal in kiln tail gas	Fluid dynamics, mass transfer principles	Study on the flow, adsorption and physical-chemical reactions of the exhaust gas at the kiln tail, develop an aqueous-gas co-hardening cementitious composite for CO_2 removal and integration into cement production processes.
Development of efficient and energy-saving materials	Heat conduction, comprehensive heat transfer	Based on Fourier's law and the influence of material thermal conductivity on heat transfer, continuously refining the pore structure of materials can effectively reduce thermal conductivity, ultimately achieving adiabatic conditions. This approach enables the design and development of high-performance thermal insulation materials.
Development of effective adsorption materials for harmful ions	Mass transfer principle	Based on Fick's law, the teaching teams develop inorganic porous stepped-type adsorption materials.
Research on Energy Saving, Carbon Reduction and Efficiency Enhancement Measures for Cement Kiln System	Fuel combustion, comprehensive heat transfer, fluid mechanics	Based on the perspectives of improving fuel combustion efficiency, increasing effective heat exchange, and reducing resistance, propose comprehensive measures to enhance energy conservation, carbon reduction, and operational efficiency in cement kiln systems.

4. Multidimensional Assessment and Evaluation of Learning Situations

The curriculum emphasizes student-centered development throughout the teaching process. Students are required to study foundational theoretical knowledge independently through online platforms before class. In the class, instructors focus on cultivating students' higher-order thinking skills, their ability to solve complex engineering problems, and ethical development through problem-based learning, project-based teaching, hands-on experiments, or engineering-oriented approaches. Therefore, in terms of the assessment of learning outcomes, a multi-dimensional approach combining both online and offline methods is primarily adopted.

The assessment of knowledge objectives is conducted through an online platform, which evaluates students' study duration, participation level, and completion of online assignments, etc. The assessment of students' learning outcomes by teachers focuses on evaluating their higher-order abilities and the shaping of their values, which could be carried out through challenging assignments, group discussions, and innovative practical activities, etc. See Figure 2 for details.

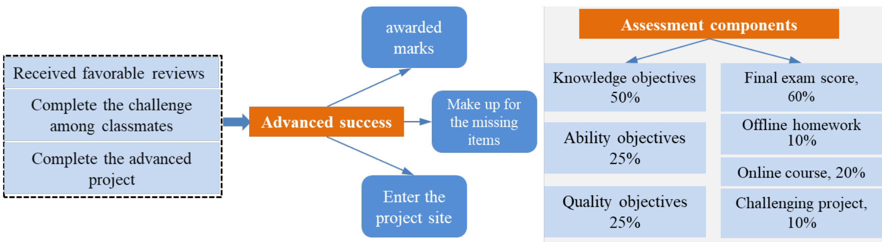

Figure 2. Multidimensional Assessment and Evaluation of Learning Outcomes.

Before class, students completed self-study of basic knowledge, previewed core content and achieved pre-class tests through online platforms. Students could post their questions on the platform, allowing teachers and peers to participate in the ensuing discussions. During the process of asking questions and answering them, as well as asking questions again and answering them, students not only enhanced their learning interest but also mastered the learning content. In the class, firstly, teachers analyzed the learning data on online platform to gain pre-class study situation of students, and then adjusted the class content accordingly. Secondly, the flipped classroom teaching method was adopted. More class time is given to students for face-to-face discussions and debates, thereby enhancing their participation. Finally, employer, teachers and students jointly set up different levels of project tasks, and then student groups choose projects based on their interests and skill levels, and propose solutions to these projects through theoretical verification or experimental validation methods. After class, after class, student groups further verified the solutions proposed in class through literature reviews, theoretical derivations, or experimental research through methods such as literature review, theoretical derivation and experimental research. Meanwhile, teachers provided ways for students to conduct further learning based on the knowledge points.

The assessment system comprises two dimensions: learning objective orientation and performance components. In terms of learning objectives, assessments are categorized into knowledge (50%), ability (25%), and quality (25%) dimensions. The final exam accounts for 60%, while process assessment makes up the remaining 40%. The process score is equally divided between online and offline components, each contributing 20%. The assessment items for online learning include self-study duration, participation in online discussions, and online assignments. The assessment item for offline learning was including offline assignments, laboratory assessments, and the completion of comprehensive projects.

5. The Achievements of Teaching Innovation

Since the implementation of the teaching reform, a new model jointly formed by enterprises, schools and students has gradually emerged. Through mutual learning and teaching, both teachers and students have achieved remarkable results.

5.1. The Achievements of Students

Since the implementation of the teaching innovation for the fundamentals of materials engineering, the abilities to propose solutions, design solutions, material properties improvement, and solve complex engineering problems of students had been significantly enhanced. Students, leveraging the knowledge and professional skills acquired in this course, combined with the research directions of their instructors, participated in numerous competitions in the industry. Since the teaching innovation in 2021, students had won numerous national and provincial awards in various technological competitions, with the number of award-winning students reaching several dozen. From 2022 to 2024, the teaching team selected a sample of about 50 students per class each year, and through the network platform, analyzed the learning situation of the students after teaching innovation implementation. The results of the data analysis are shown in Figure 3 and Figure 4.

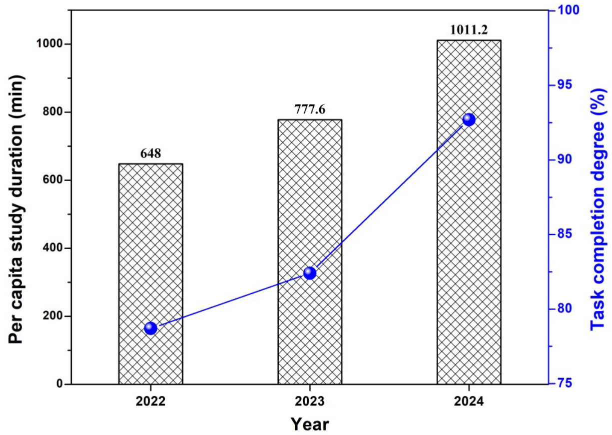

Figure 3. Average Online Study Duration and Participation Rate of Students from 2022 to 2024.

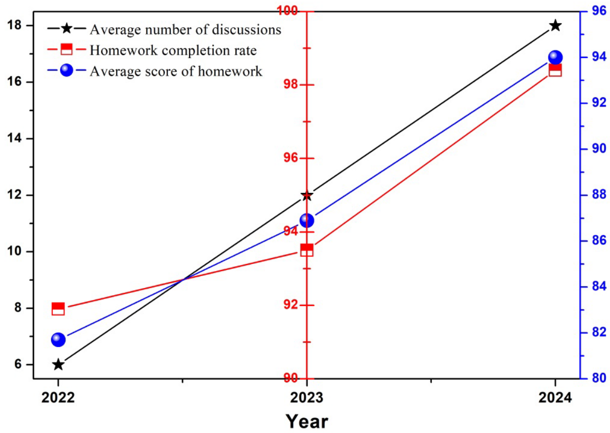

Figure 4. Discussion Degree, Homework Completion and Homework Score of Students from 2022 to 2024.

Figure 3 presents the average online study duration and participation rate of students from 2022 to 2024, both of which show a continuous upward trend. Figure 4 showed the discussion degree, homework completion and homework score of students from 2022 to 2024. Similarly, the average number of online discussions, homework completion rates, and homework scores all increased steadily from 2022 to 2024. Especially, the average number of discussion was grew approximate linear. Analysis of pre-class comprehensive scores revealed that students with moderate overall performance tended to engage more actively in online discussions than those with either high or low scores. However, the completion statuses of the challenging projects of students were strictly positively correlated with their pre-class comprehensive scores.

As could be seen from the above, the grades of students were composed of the results of the final exam, offline assignments, online learning and the completion of challenging projects. Figure 5 showed the difficulty index of improvement of scores which expressed using the number of stars. More stars indicate a higher difficulty level in score improvement for that category. Among them, the improvement of the completion rate of challenging projects poses the greatest difficulty. The final exam and offline assignments had similar difficulty levels for score improvement, while the online course score was the most difficult to improve. While online assessments focus primarily on participation and carry a lower weight in outcome evaluation, the other three components are all based on measurable learning outcomes. Moreover, challenging projects were highly comprehensive, which not only tested the basic knowledge and their ability to analyze and solve problems of students, but also assess their teamwork skills. Therefore, challenging projects had the highest difficulty index in score improvement.

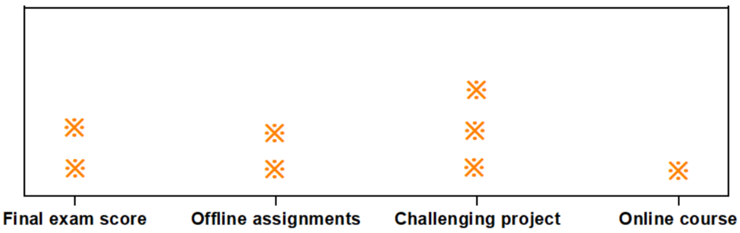

Figure 5. The Difficulty Level of Score Improvement.

5.2. The Achievements of Teachers, School and Employer

Since the teaching innovation in 2021, the team members had been selected as members of the academic committee of the Concrete and Cement Products Branch of the Chinese Ceramics Society, and had been appointed as technical experts of the National Enterprise Technology Center of Jiahua Special Cement Co., Ltd. They have received a total of four awards or honors and have participated in two course-related research projects, as shown in Table 4.

Table 4 listed the achievement of teachers during the teaching innovation process.

Table 4. The Achievements of Teachers after Teaching Innovation.

Teaching Competition	Awards, in China	Level	Year
Glass Production Equipment, fluid mechanics	The Third Young Teachers' Lecture Competition in Inorganic Non-metallic Materials-Winner Prize	National Association	2021
Fundamentals of Materials Engineering Conduction heat transfer	The Second Prize of the Fourth National Young Teachers Teaching Competition	school	2023
Fundamentals of Materials Engineering Comprehensive Experimental	The Fourth Teacher Practical Teaching Competition-Merit Award	school	2022
Fundamentals of Materials Engineering Comprehensive Experimental	The Fifth Teacher Practical Teaching Competition-Merit Award	school	2024
Research project	Project source	Level	Year
Research on the Construction of Fundamentals of Materials Engineering in the Context of New Quality Productivity Development	Sichuan Provincial Higher Education Society-Higher Education Research Project	provincial	2024
Solid-phase reaction	First-class Undergraduate Virtual Simulation Experiment Teaching Course in Sichuan Province	school	2022

Students and teachers participating in competitions and academic exchanges have played a positive role in promoting the school. Employers are involved in the entire student training process and have the right to revise the training plan, achieving early-stage talent development and implementing customized training strategies. The establishment of long-term cooperative relationships among employers, schools, and teachers has not only built a solid bridge between theory and practice for students, provided a platform for teachers to conduct research and technology transfer, and offered a talent pre-training and innovation platform for employers, but also enhanced the school's visibility. The Data show that since the implementation of the teaching innovation, the research funding obtained by teachers from employers has increased by approximately 20%.

6. Conclusions

During the teaching innovation process, various approaches such as problem-oriented instruction, project-based learning, enriched teaching environments, and multi-dimensional assessments were employed to encourage students to create value with their knowledge and cultivate a spirit of precision and high-level engineering professionalism. After the teaching innovation, the enthusiasm for learning, the interest in practice, and the participation in research projects of students had improved. The teaching abilities and peer recognition of teachers had improved, resulting in more teaching and research achievements.

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