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Exploration on Teaching Reconstruction and Practice of Civil Engineering Materials Course in the New College Entrance Examination Context

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Abstract: The "3+1+2" subject selection model of the new college entrance examination reform has led to significant heterogeneity in the knowledge structure of freshmen majoring in engineering in universities, especially a "knowledge gap" in basic disciplines such as physics and chemistry. Aiming at the teaching challenges faced by the course Civil Engineering Materials for the engineering cost major, namely the contradiction between students' weak physics and chemistry foundations and strong demands for professional application, this paper proposes a set of adaptive teaching innovation strategies. Centered on "dimensionality reduction connection" and "scenario transformation", the strategies reconstruct basic knowledge modules that are "adequate and practical", design teaching scenarios linked with "technology-economy", implement a "stratified + diversified" teaching mode, and reform an "application transfer" oriented evaluation system. The objective is to break through the barriers between basic theories and professional applications, so as to provide a reference for similar teaching reforms.

Keywords: Civil Engineering Materials; Engineering Cost; Stratified Teaching; Teaching Effect

1. Problems Existing in the Teaching of the Course Civil Engineering Materials

The comprehensive reform of the new college entrance examination has granted students unprecedented freedom in subject selection, but it also poses severe challenges to higher education, especially engineering majors that rely heavily on basic disciplines [1-3]. As a key hub connecting engineering technology and cost control, the quality of talent training for the engineering cost major is directly related to the construction benefit, operational safety and full life-cycle value management of engineering projects [4,5]. However, Civil Engineering Materials, as a core basic course of this major, is a critical carrier for students to connect material properties, construction technology and cost control logic. At present, the course teaching is out of line with the learning situation under the new college entrance examination and the professional training objectives, facing multiple practical dilemmas that need to be solved urgently.

1.1 Heterogeneity of Student Learning Situation: Prominent "Knowledge Gap" in Basic Knowledge and Barriers to Professional Cognition

Under the "3+1+2" subject selection model, freshmen majoring in Engineering Cost show obvious polarization in their disciplinary foundations. A significantly increasing proportion of students did not take Chemistry (resulting in a lack of knowledge about material structure, reaction principles, etc.) or even Physics (leading to vague concepts of mechanics, thermology, etc.). However, the core contents of the course, such as the hydration mechanism of cement, the strength theory of concrete, and electrochemical corrosion of steel, are all deeply rooted in physical and chemical principles. The traditional "one-size-fits-all" teaching mode has seen a sharp decline in efficiency when facing heterogeneous learning situations. Students with weak foundations easily fall into a vicious circle of "unable to understand principles, remember properties, or keep up with applications". They can neither establish a systematic understanding of material properties nor avoid forming cognitive barriers for subsequent core courses such as engineering pricing and cost control. Meanwhile, students with solid foundations face the problem of "insufficient content and inadequate depth", whose learning needs cannot be fully met. This seriously restricts the overall quality of course teaching.

1.2 Professional Uniqueness: Value Reorientation of Material Knowledge from the Perspective of Engineering Cost

Compared with civil engineering majors, which focus on material performance mechanisms, structural adaptation and design optimization, the core training goal of engineering cost majors is to enable students to master the logic of balancing technical indicators and economic benefits throughout the full life cycle of materials. The core concerns always center on the unity of material applicability, economy and compliance. Students' key concerns include: How do materials with different physical and chemical properties affect construction technology, schedule arrangement and sub-project cost? How do material performance testing standards connect with the valuation rules of bill of quantities and quota application? How does the durability and deterioration law of materials affect the maintenance cost and decision-making of the building throughout its life cycle? However, the course Civil Engineering Materials in most colleges still adopts the teaching logic and content system designed for civil engineering majors [4]. The teaching of physics and chemistry knowledge mostly stays on pure theoretical explanation and formula derivation, without being deeply integrated with the core professional scenarios of engineering cost. As a result, students generally fall into the misunderstanding that "material knowledge is irrelevant to cost work", and cannot transform material performance knowledge into core capabilities for cost control. There is a serious disconnection between course teaching and professional training objectives, and the value reorientation of material knowledge for engineering cost majors has not been realized.

2. Dimensionality Reduction Connection and Scenario Transformation of Physics and Chemistry Knowledge Teaching

To address the above teaching dilemmas, the core breakthrough in deepening curriculum teaching reform lies in breaking the barriers between basic science and the professional application of engineering cost. The originally abstract, obscure, and systematically discrete knowledge of physics and chemistry should be systematically reconstructed and implemented in scenarios, and ultimately transformed into practical instrumental knowledge that is highly consistent and closely coupled with the core logic and practical work demands of the engineering cost profession, so as to truly realize the resonance between basic disciplines and professional applications.

2.1 Content Reconstruction: Constructing a Practical Modular Knowledge System

Theoretical stripping and logical re-chaining focus on the dimensionality reduction of physics and chemistry knowledge. The course teaching takes the initiative to abandon complex theoretical derivation contents with low relevance to cost major applications such as reaction kinetic equations and complex thermodynamic formulas, only retains core concepts and basic laws highly compatible with engineering application and cost control, and completes the overall reconstruction of the knowledge system on this basis to form three major application modules: performance cognition, performance evolution and performance deterioration. Among them, the performance cognition module corresponds to core contents such as the relationship between material microstructure and macroscopic strength, the performance evolution module corresponds to practical contents such as the influence of the chemical process of cement setting and hardening on the construction window period and maintenance cost, and the performance deterioration module corresponds to core contents such as the influence of the electrochemical principle of steel corrosion on structural durability and maintenance cost. Through modular reconstruction, the overall teaching focus of the course has completely shifted from the traditional theoretical explanation and principle derivation of "what it is and why" to the complete professional logic chain of "phenomenon cognition → law summary → engineering impact analysis → cost-related research and judgment" [6].

Pre-stage micro-courses and basic leveling: For students with weak physics and chemistry foundations, an online "Micro-MOOC remedial module" of 2–3 class hours is specially designed.

By means of animations, short videos and concrete diagrams, basic principles such as "how atomic structure determines material strength", "how chemical reactions cause material aging" and "how intermolecular forces affect material bonding properties" are vividly demonstrated, and abstract theories are explained in popular language. The remedial module adopts the mode of "scanning code for self-study + in-class quick quiz", without rigid assessment thresholds. The quick quiz scores are not included in the final total evaluation, but only serve as a reference for teachers to adjust classroom teaching pace and carry out personalized tutoring. It quickly fills students' knowledge gaps before formal teaching, minimizes learning anxiety for students with weak foundations, and achieves fairness at the starting point of teaching [7].

2.2 Scene-Driven Teaching: Reconstructing Knowledge Application Situations Oriented to Cost Decision-Making

Based on the classroom teaching of the engineering cost major, the transformation from material property cognition to cost decision-making application is realized in teaching. For example, when explaining the concept of cement hydration heat in the cement and concrete chapter, teaching is no longer limited to interpreting the principle of chemical heat release, but combined with real engineering scenarios. Taking the construction of a mass concrete foundation as an example, if the construction unit ignores the cumulative effect of hydration heat, it will lead to excessive temperature difference between the inside and outside of concrete and cause temperature cracks. This will not only result in potential quality hazards such as reduced structural durability, but also directly lead to crack repair, structural reinforcement and even rework, ultimately causing a 30% surge in the cost of this sub-project. With the help of such practical cases close to frontline engineering, students can intuitively understand the cost impact behind the principle of hydration heat, and gradually establish a complete professional thinking mode of "mastering basic principles – predicting quality risks – optimizing construction schemes – avoiding economic losses" [8].

To realize the integration from experimental data to cost accounting, a techno-economic analysis module is added to the teaching of material performance experiments. Taking the compressive strength test of concrete with different strength grades as an example, after completing the basic performance test and obtaining the core mechanical parameters, students are guided to compare and analyze the unit material price, pumping construction difficulty, curing period and curing requirements of concrete with different strength grades, as well as their impacts on the selection and cost of formwork and support systems, combined with survey data from the local building materials market. Finally, students are required to independently complete a micro-report on the cost-performance analysis of concrete selection. This enables students to truly understand in practice that the physical and mechanical parameters of materials are the core basis for engineering pricing, and completely breaks down the logical barrier between experimental data and cost accounting.

3. Design of a Collaborative Teaching Model with Hierarchical Guidance and Diversified Interaction

3.1 Stratified Teaching

Implement a stratified teaching mode with parallel tracks of basic support and ability improvement, and implement differentiated training for students based on their different knowledge foundations. The basic level (support) is for students with weak knowledge reserves in physics and chemistry, and cognitive thresholds are lowered with the help of visualized teaching tools. For example, teaching aids and building blocks are used to simulate the accumulation and cementation state of aggregates, mortar and cementitious materials in concrete, and analogize the intermolecular forces in physics to help students understand. By observing the morphology and weight changes of iron nails rusted in different environments, students can intuitively perceive the actual impact of chemical corrosion on material quality.

The advanced level (improvement) is designed for students with solid basic knowledge, with exploratory and open expanded thinking sessions. For example, students are guided to apply the principle of chemical equilibrium shift to analyze the carbonation mechanism of concrete, and further explore the far-reaching impact of this phenomenon on structural inspection, maintenance and reinforcement costs throughout the building life cycle, so as to meet students' needs for in-depth learning and knowledge transfer and application.

3.2 Technology Empowerment

Enhance the teaching experience with visual and interactive tools. Relying on virtual simulation technology to enrich teaching forms, BIM (Building Information Modeling) or 3D animation technology is introduced to dynamically demonstrate invisible physical and chemical processes such as the hydration process of cement particles and the microscopic mechanism of elastic-plastic deformation of steel bars under load. This transforms abstract knowledge into concrete forms and static content into dynamic demonstrations, effectively improving the intuitiveness and appeal of teaching [9].

Adopt a problem-driven flipped classroom to deepen learning outcomes. Before class, push real engineering cases involving material failure to students, such as structural spalling of a bridge in cold regions due to insufficient frost resistance of concrete, resulting in high maintenance costs. Students are required to refer to relevant materials in groups, and explain the physicochemical causes and economic impacts behind the cases in plain language in class. On this basis, teachers carry out in-depth explanation of principles and advanced content, forming a complete teaching closed loop in which application drives understanding and cases motivate learning [10].

3.3 Evaluation Reconstruction: Achieving the Transformation from “Knowledge Reproduction” to “Ability Transfer”

The traditional assessment model is optimized to significantly reduce the proportion of questions examining the memorization of isolated knowledge points and formulas. Engineering scenario analysis questions are taken as the core assessment type, focusing on testing students’ knowledge application and comprehensive analysis abilities [6]. Examination questions are designed based on practical scenarios. For example, in the construction of a basement project in a coastal environment, the construction unit intends to use ordinary Portland cement. Students are required to analyze the potential durability hazards of this scheme by combining the chemical composition and hydration characteristics of the material, and put forward reasonable optimization suggestions from the perspective of life-cycle cost control. Through such examination questions closely integrated with the professional requirements of engineering cost, students’ ability to comprehensively apply basic principles of physics and chemistry to analyze and solve practical cost problems in complex engineering is comprehensively evaluated, truly achieving the goal of “promoting learning and application through assessment” [8,11].

4. Practical Effects of Curriculum Teaching Reform

This teaching reform has been implemented for two rounds in the course Civil Engineering Materials offered to the engineering cost major in my college, covering 2 grades and 4 parallel classes, with a total of 166 students. By comparing the curriculum teaching data, student learning feedback and professional ability evaluation results before and after the reform, the reform has achieved remarkable effects and effectively solved the core dilemmas in current curriculum teaching. The outcomes can be summarized in the following five aspects.

4.1 Construction of an Integrated Teaching System of “Theory–Application–Thinking” Suitable for the Cost Major

Guided by the core training objectives of the Engineering Cost major, this reform has completely broken through the teaching limitations of the traditional Civil Engineering Materials course, which emphasizes theory over application and material performance over cost. An integrated teaching system has been constructed, featuring modular reconstruction of basic theories, scenario-based professional application, stratified cultivation of comprehensive abilities, and systematic shaping of engineering thinking. This system deeply integrates basic theories of physics and chemistry with the full-process professional demands of engineering cost. It not only solves teaching difficulties caused by insufficient basic physics and chemistry knowledge of freshmen through pre-course remediation and stratified teaching, but also realizes the effective transformation from basic disciplinary knowledge to professional instrumental knowledge via scenario-based reconstruction and logical reconnection. As a result, the course content is truly aligned with the talent cultivation orientation of the engineering cost major, laying a solid foundation for students' subsequent study of core courses such as engineering pricing, cost control, and life-cycle cost management.

4.2 Formation of an Innovative Teaching Model Featuring "Stratified Adaptation and Scene-Driven Learning"

The reform has completely broken through the traditional "one-size-fits-all" indoctrination teaching model and formed an innovative teaching model based on stratified teaching, centered on scene-driven learning, and supported by technological empowerment. Through the dual-track design of basic support and ability improvement, the learning needs of students with different physics and chemistry foundations are accommodated, enabling students with weak foundations to keep up and master the content, while students with solid foundations can learn deeply and apply knowledge flexibly, thus effectively solving teaching difficulties caused by student heterogeneity. Meanwhile, scenario-based teaching supported by real engineering cases closely integrates abstract theoretical knowledge with specific cost engineering practice, allowing students to truly perceive the practical value of basic theories and effectively stimulating their learning initiative. Teaching practice data show that after the reform, students' classroom attendance rate increased from 90% to 96%, and classroom interaction participation increased by more than 70%. The teaching effect has been widely recognized by students.

4.3 Realizing the Transformation of Students' Learning State from "Passive Acceptance" to "Active Inquiry"

The brand-new interactive teaching model and formative assessment system have completely changed students' passive role in traditional classrooms and truly positioned them as the center of learning. The design of flipped classrooms, group inquiry projects, extended critical thinking and other activities has transformed students from passive listening and rote memorization into active preview, independent inquiry, collaborative completion, mutual evaluation and peer learning, fully stimulating their learning initiative. In two rounds of teaching practice, students completed a total of 42 group inquiry projects, 166 micro-reports on cost-performance analysis of concrete selection, and independently collected more than 100 engineering cases relevant to the major. Their abilities in autonomous learning, teamwork, data organization and logical analysis have been significantly improved.

4.4 Upgrading of the Evaluation System from Knowledge-Based Assessment to Competency-Based Assessment

The reform has reconstructed the curriculum assessment and evaluation system, significantly reducing the proportion of questions assessing knowledge memorization and formula recitation. The assessment focuses on students' ability in knowledge application, engineering analysis and cost decision-making, thus completely reversing the drawback of traditional assessment that "emphasizes memorization over competence". The new assessment system realizes the tracking and evaluation of the whole learning process through formative assessment, avoiding the problems of cramming for the final exam and forgetting all content after the examination. Meanwhile, the summative assessment using engineering scenario analysis questions comprehensively evaluates students' comprehensive professional abilities. By comparing the distribution of students' scores before and after the reform, the proportion of students with excellent final results (80 points and above) has increased from 18% to 50%. The score distribution has become more reasonable and can more truly reflect students' comprehensive abilities, effectively achieving the assessment goals of "promoting learning and application through examination".

4.5 Consolidating Students' Professional Core Thinking of "Material–Technology–Economy" Integration

The core goal of this teaching reform is to cultivate students' engineering thinking that meets the requirements of the engineering cost major. Through the whole-process teaching innovation, the core concept that basic scientific knowledge is the underlying logic of cost decision-making has been conveyed to students, freeing them completely from the misunderstanding that "material knowledge is irrelevant to cost work". Students have learned to predict engineering risks, analyze cost impacts, and optimize selection schemes based on the physical and chemical properties of materials, thus truly establishing an integrated decision-making thinking of "material–technology–

economy”. In subsequent professional courses and discipline competitions, students who participated in the reform performed significantly better than previous graduates in cost plan optimization, life-cycle cost analysis and other aspects. A total of 12 students won awards in provincial and university-level engineering cost discipline competitions, indicating a significant improvement in the quality of talent training.

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