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Construction of a Case-Based Teaching Model for Science-Education Integration in the Context of "New Engineering": A Case Study of Course "Mechanical Design"

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Abstract: Against the backdrop of New Engineering development, where fostering high-quality engineering and technical talents has become a focus, the teaching quality of "Mechanical Design"—a core technical foundation course for mechanical majors—directly impacts the cultivation of students' engineering design capabilities. To address the prominent issues in current teaching practices, such as the disconnect between theory and practice, insufficient training in innovative thinking, and inefficient feedback on learning outcomes, this paper proposes a targeted teaching reform plan. Guided by the concept of science-education integration and leveraging high-quality scientific research achievements, the plan aims to construct a systematic case-based teaching system. Centering on the synergy of "research, teaching, and learning," this reform takes the innovative design cases of small-scale vegetable transplanters as the core driver. It adapts scientific research outcomes to teaching scenarios, optimizes the content and logical structure of teaching, and innovates learning modes. Practice has demonstrated that this teaching approach can significantly enhance students' learning enthusiasm, engineering practice abilities, and innovation awareness, thereby providing a practical pathway for the reform of core courses in mechanical engineering in the context of New Engineering.

1. Introduction

The construction of New Engineering emphasizes industry demand-oriented talent cultivation, focusing on fostering high-level engineering and technical talents with innovative capabilities, practical skills, and cross-disciplinary integration competence. As a core bridging course between basic courses and professional courses for mechanical majors, "Mechanical Design" undertakes the crucial mission of cultivating students' mechanical system design thinking and engineering practice abilities. Domestic universities have carried out a series of teaching reforms and practices for talent cultivation in the context of New Engineering [1-3]. These initiatives either emphasize the role of "engineering experience" in guiding students' innovative thinking [4] or incorporate cases to enrich practical content in teaching [5]. While such reforms have contributed to improving students' practical abilities, several issues remain unresolved: outdated cases disconnected from industrial practices, scattered cases lacking systematicity, and insufficient innovation guidance during practical training. Aimed at enhancing students' practical and innovative abilities, this study adopts practical cases derived from scientific research achievements as the carrier, guiding students to conduct exploratory learning around these cases. This approach fills the gap in traditional teaching practice carriers for "Mechanical Design", integrates cutting-edge technologies and engineering problems into classroom teaching, synchronously cultivates students' innovative thinking and engineering capabilities, and thus meets the contemporary demand for cultivating high-level mechanical talents.

2. Main Existing Problems in Traditional Teaching

Based on a summary of design teaching practices in recent years, the author argues that there remains a gap between the current curriculum teaching model and the requirements for cultivating high-quality engineering and technical talents in the context of New Engineering. Urgent improvements are needed in the following aspects:

(1) Rigid teaching models: The traditional teaching approach, which takes "textbooks as the outline and lectures as the primary method," still dominates. The update pace of course content lags behind the rapid iteration of knowledge in the mechanical engineering field. Meanwhile, the conflict between the rapid expansion of the mechanical professional knowledge system and the gradual reduction of course hours has intensified. Students are required to master complex and abstract theoretical knowledge within a limited time, which easily triggers learning anxiety and disinterest, making it difficult to stimulate their learning initiative.

(2) Weak practical teaching: Course teaching lacks concrete practical support. Students mostly rely on textbook illustrations, theoretical deductions, and formula calculations to understand mechanical component selection and system design logic, which makes it hard for them to form intuitive cognition and sensory experience of actual mechanical systems. Existing teaching cases are mostly classic and outdated, severely disconnected from current engineering practice scenarios, resulting in a disconnect between theoretical knowledge and engineering applications.

(3) Insufficient integration of innovative training and new technologies: The course design process mainly focuses on single-component design or classic mechanism replication, lacking systematic guidance and training on students' innovative thinking. Meanwhile, modern design technologies such as optimization design and finite element analysis have not been timely integrated into the teaching content. This makes it difficult to align with the core training requirements of New Engineering for talents' innovation and technical application capabilities, which is not conducive to the improvement of students' engineering literacy.

(4) Inadequate consolidation of learning outcomes: In traditional teaching, knowledge consolidation relies on homework or exercise assignments. Tedious knowledge concepts and complex design calculations easily induce students' fear of difficulty. In addition, various standard answers are readily available online, leading to frequent "answer copying" behaviors. This creates a learning illusion where "all assignments are completed correctly, yet students struggle in exams," making it difficult to effectively assess real learning outcomes.

3. Necessity of the Science-Education Integrated Case-Based Teaching Model in the Context of New Engineering

The rigid traditional teaching mode, which prioritizes theoretical indoctrination over practical empowerment and knowledge review over innovative cultivation, coupled with the prominent issue of neglecting the transformation of learning into practice in post-class consolidation, has significant gaps with the requirements for cultivating innovative talents in the context of New Engineering.

Therefore, the case-based teaching mode—integrating cutting-edge scientific research achievements and real engineering scenarios into the teaching process—is an inevitable choice to realize the transformation from "knowledge imparting" to "ability cultivation."

(1) Case studies can stimulate learning interest and enhance students' motivation. Cases transform abstract design theories into clear objectives of "solving specific component design problems," enabling students to clearly perceive the practical value of their learning. On this basis, by focusing on the introduction, interpretation, and application of component design knowledge through case studies, students can enter a learning state driven by critical thinking and the desire to explore practical problems. This completely reverses passive learning, effectively stimulates learning interest, and boosts learning initiative and enthusiasm.

(2) Case studies enhance practicality and enable effective assessment of learning outcomes. Derived from real cutting-edge engineering scenarios, these cases can effectively address the obsolescence of traditional cases and help students perceive the engineering value of knowledge. Through the closed-loop design of "completing component design tasks in cases via post-learning assignments," students can transform component design theories and calculation methods into concrete design practice during the assignment completion process. This not only directly links theoretical learning with practical operation but also mitigates plagiarism.

(3) Cases incorporate cutting-edge technologies and facilitate innovative training. Each case features inherent scenario requirements and strong driving force for scientific research innovation. While guiding students to master basic theories, it can naturally integrate modern technologies such as optimization design and finite element analysis. When completing case-based component design assignments, students can attempt to apply these new technologies and methods to optimize design schemes according to their personal interests and abilities. This breaks through the limitations of single-component design or classic mechanism replication, thereby strengthening the cultivation of innovative thinking and practical capabilities.

4. Construction of the Science-Education Integrated Case-Based Teaching Model in the Context of New Engineering

Guided by the concept of integrating science and education, the case-based teaching method for design courses is rooted in teachers' scientific research activities. Through rigorous screening and adaptation, dynamically developed mechanical products or core components generated during the research process are introduced into classroom teaching as tangible practical carriers. This provides students with intuitive cognitive objects and practical scenarios, effectively addressing the prominent issues of outdated cases and insufficient practical carriers in traditional teaching.

In the process of case selection and adaptation, four core principles must be adhered to. First is the principle of alignment: Case adaptation should accurately align with the core knowledge points and engineering competency training objectives of the course, ensuring high compatibility between teaching content and educational requirements while avoiding disconnection between cases and teaching objectives. Second is the principle of progression: It is essential to fully consider students' knowledge reserves and cognitive rules, designing gradient cases that range from basic to complex and from single-module to comprehensive. This facilitates the gradual and orderly development of students' engineering abilities. Third is the principle of engineering practice orientation: Cases should focus on real-world engineering scenarios, clearly presenting actual engineering problems, key design constraints, and core technical solutions to strengthen the in-depth connection between theory and practice. Fourth is the principle of integrating innovation and interest stimulation: Modern design concepts and technologies such as digital design and intelligent optimization should be incorporated into cases. This not only broadens students' academic horizons but also effectively stimulates their enthusiasm for active exploration and willingness to engage in innovative practices, laying a solid foundation for the effective implementation of teaching reforms.

In the teaching implementation phase, full-process design and control are required. Firstly, establish a corresponding system between teaching content and practical tasks, clarifying the inherent relationships among each teaching module, research case, and engineering design practice task. It is important to follow the logical consistency of "knowledge cognition → whole-machine design", take real engineering scenarios as the context, connect scattered knowledge points into a complete system, and construct a knowledge framework that integrates logic and practicality. Secondly, scientifically optimize the allocation of course hours by adopting a "one-third" ratio model: one-third of the hours are dedicated to case background analysis and engineering problem decomposition; one-third to the correlation analysis of core knowledge points and in-depth theoretical interpretation; and one-third reserved for group collaborative discussions and guidance on key and difficult points. Finally, establish a diversified knowledge consolidation and effectiveness evaluation mechanism: Basic knowledge is assessed through in-class tests and instant Q&A sessions; knowledge application abilities are focused on through practical training such as engineering design practice and scheme optimization; and process evaluation is combined with summative assessment to comprehensively and truthfully evaluate students' mastery of theoretical knowledge and engineering practice abilities.

In the design practice phase, a combination of "teacher-assigned tasks + student-independent topic selection" is adopted. On one hand, relying on their own research accumulation, teachers select research cases with typical engineering representativeness and adapt them into application training tasks. These tasks focus on the core knowledge points and key design skills of the course, ensuring that students firmly grasp the core methods and standardized processes of engineering design through basic training. On the other hand, students are encouraged to independently develop design topics based on their personal interests, extracurricular subject competition themes, or future research plans. Students propose topic ideas, which are then subject to strict review and scientific guidance by teachers in terms of feasibility, knowledge alignment, and practical operability before finalizing personalized practical topics. This two-way selection model breaks the traditional "one-size-fits-all" task allocation method: it stimulates students' internal learning motivation through independent topic selection, while ensuring that practical training does not deviate from the main teaching line through teachers' professional guidance. Thus, it achieves the organic unity of "core competency standards" and "personalized development".

5. Teaching Practice Application in the Course "Mechanical Design"

As a core course in mechanical engineering, Mechanical Design integrates the rigor of theoretical systems with the practicality of engineering applications. Its teaching focus lies in guiding students to realize the transformation of theoretical knowledge into engineering design capabilities. The accurate transformation of scientific research achievements into teaching cases constitutes a key prerequisite for implementing the science-education integration model in this course. In the transformation process, the core principle of "knowledge disassembly and adaptation, and comprehensive consideration of characteristics" should be adhered to. On the one hand, it is essential to deeply explore the core content of scientific research scenarios, such as institutional innovation, strength optimization, and reliability design, and systematically decompose these elements into core knowledge points of the course—including shafting design, gear transmission, connector selection, and bearing combination design—so as to ensure a high degree of compatibility between scientific research cases and the course teaching content. On the other hand, it is necessary to balance the industry-specific features of specialized cases with the universality of knowledge transfer. While retaining the engineering authenticity of the cases, efforts should be made to ensure that students can master transferable general design methods through case studies.

5.1 Selection of Research Cases

In this teaching practice, the small vegetable transplanter independently developed by the authors' team is selected as the core research case. This equipment focuses on the lightweight and reliability design requirements of agricultural machinery, mainly covering core components such as power units, transmission components, seedling feeding mechanisms, transplanting modules, and the chassis. Characterized by a simple overall structure and clear, easy-to-understand working principles, it allows quick engagement without the need for complex professional backgrounds. More importantly, its structural design can fully cover the core modules of the "Mechanical Design" course, establishing an accurate correspondence between "components and knowledge points": transmission components can be linked to core contents such as belt drive, chain drive, and gear transmission; seedling feeding mechanisms can be associated with knowledge points including screw drive, friction and wear mechanisms, and the selection of key connectors; the structural layout and strength verification of the transmission shafting can reinforce core design points such as bearing combination design, shaft structure optimization, and the selection of couplings and clutches. In addition, the detailed design and performance parameter verification of the equipment's key components can be directly transformed into the core carrier of after-class practical assignments. This effectively builds a bridge between theoretical learning and engineering practice, laying a solid foundation for the smooth implementation of subsequent teaching activities.

5.2 Specific Teaching Practice

Course Introduction. The course begins with a video demonstration of the small vegetable transplanter in operation, focusing on the power transmission process between the gasoline engine and the gearbox. Two core questions are then posed: "Why is belt drive adopted in this system? How should the belt drive be designed to meet the workload and stability requirements?" Combined with the practical application background of the case, it is explained that the transplanter needs to switch between multiple operating modes (e.g., idling and transplanting) during field work, and the gasoline engine operates at unstable speeds. The inherent advantages of belt drive—including shock absorption, overload protection, and ease of center distance adjustment—make it highly suitable for such working conditions. By integrating real-world engineering scenarios into the course opening, this approach aims to stimulate students' learning interest and clarify the core objective of the chapter: solving the practical design problems of belt drive systems.

Theoretical Explanation. Guided by the actual design requirements of the transplanter, the core knowledge of belt drive is decomposed into three key modules for in-depth elaboration. First, in terms of type selection, considering the dusty and variable-load working environment of the transplanter, the advantages and disadvantages of flat belts, V-belts, and synchronous belts are systematically compared. Through interactive discussion and analysis, students are guided to conclude that ordinary V-belts are the optimal choice for this scenario. Second, regarding parameter calculation, based on the given operating parameters (e.g., power of 4.1 kW, rotational speeds of 3600 r/min and 1800 r/min), the calculation methods for V-belt model selection, reference diameter, center distance, number of belts, and tension are explained in detail, with full consideration of practical constraints such as limited installation space. Third, for structural design, combined with the vibration characteristics of the transplanter during operation, different tensioning methods (e.g., fixed-center distance tensioning and movable pulley tensioning) are compared, and students are guided to design a tensioning mechanism that matches the equipment's working conditions.

Design Practice. The assignment task is designed as follows: Based on the given design parameters (center distance: 165–175 mm, service life: ⩾ 2000 h, load type: slight impact load), students are required to independently complete the entire design process of the belt drive system, including type selection, parameter calculation, structural drawing, and instruction manual compilation. The task focuses on guiding students to solve three core design issues: rational selection of V-belt model and quantity, matching of center distance and reference diameter, and design of an effective tensioning device. This practice aims to standardize students' engineering design processes and enhance their ability to apply theoretical knowledge to practical problems.

Guidance and Evaluation. A teaching mode combining "centralized guidance and personalized Q&A" is adopted. For common problems encountered by students (e.g., determination of reference diameter and design of tensioning structure), centralized explanations are provided to clarify key concepts and methods. For individual doubts, one-on-one Q&A sessions are conducted to ensure targeted guidance. To assess students' mastery of basic knowledge, in-class tests are carried out. Meanwhile, teaching feedback is collected through questionnaires to identify existing problems (e.g., insufficient proficiency in pulley structure design). Targeted supplementary teaching is then provided in subsequent sessions to achieve dynamic optimization of the teaching process.

6. Conclusion

Centered on the science-education integration in case-based teaching, this study clarifies both the adaptability principle between scientific research achievements and course content and the corresponding implementation pathways. A full-process case-based teaching system has been constructed, encompassing four core links: "clarifying case-driven requirements, exploring core theoretical knowledge, conducting design practice solutions, and implementing feedback-based optimization." This system realizes a closed teaching loop featuring "integrating learning with application and fostering innovation through practice." Verification through teaching practice indicates that this teaching reform model has significantly stimulated students' learning interest, mobilized their learning initiative, and effectively enhanced their engineering practice capabilities and innovation awareness. It fully demonstrates the practical value of the science-education integration model in engineering curriculum teaching.

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