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Construction and Practical Research of a Case Library on Cutting-Edge Technologies in Mechanical Engineering

Wei Zhao[1,2,a], Hui Zhang[1,2,b,*], Yuexia Lv[1,2,c], Guangchun Xiao[1,2,d], Jinpeng Bi[1,2,e]

[1]School of Mechanical Engineering, Shandong Key Laboratory of CNC Machine Tool Functional Components, Qilu University of Technology (Shandong Academy of Sciences), Jinan, 250353, China
[2]Shandong Institute of Mechanical Design and Research, Jinan, 250031, China
[a]zwapple@yeah.net, zhaowei@qlu.edu.cn, [b]zhanghui198787@163.com, [c]yuexialv@faomail.com, [d]xgc@qlu.edu.cn, [e] jinpengtqm@126.com
**Corresponding author*

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Abstract: Deepening the reform of the training model for professional degree graduate students is a crucial task in China's current higher engineering education. Case-based teaching, serving as a key bridge connecting theory and practice, relies heavily on the construction of high-quality case libraries. Based on the characteristics and needs of cultivating professional degree graduate students in Mechanical Engineering, this paper elaborates on the necessity of constructing a "Case Library on Cutting-Edge Technologies in Mechanical Engineering." By systematically analyzing the current status and development trends of case library construction domestically and internationally, and integrating the research and teaching experience of the project team in fields like intelligent manufacturing and advanced material processing, the project plans the construction content for a case library covering five cutting-edge thematic areas: High-Quality and High-Efficiency Advanced Processing, High-End Equipment Manufacturing, Industry 5.0 and Intelligent Manufacturing, AI-Driven Mechanical Design and Control, and Green Transformation Targeting Dual Carbon Goals. This includes a total of 20 typical cases. The paper details the overall framework of the case library, the design approach for representative cases, and explores the teaching practice method of "Task-Driven + Case Discussion." Practice has shown that the construction of this case library helps stimulate graduate students' learning interest and cultivate their engineering practice ability and innovative thinking, holding positive significance for promoting the connotative development of professional degree graduate education in Mechanical Engineering.

1. Introduction

In recent years, with the successive issuance of policies such as the "Opinions of the Ministry of Education, National Development and Reform Commission, and Ministry of Finance on Accelerating the Reform and Development of Graduate Education in the New Era" and the

"Opinions of the Ministry of Education on Deepening the Classified Development of Academic and Professional Degree Graduate Education," the importance of professional degree graduate education has been elevated to an unprecedented strategic height [1]. Its core objective is to cultivate high-level application-oriented specialists with solid theoretical foundations, outstanding practical abilities, and prominent innovative qualities, precisely aligning with national strategic layouts and industrial transformation and upgrading needs. In this context, case-based teaching, capable of introducing real engineering scenarios, complex technical challenges, and cutting-edge application scenarios into the classroom, effectively bridging the gap between theoretical teaching and engineering practice, is widely regarded as a key lever for deepening the reform of the training model for professional degree graduate students [2]. Mechanical Engineering, as a cornerstone discipline supporting the national economy and defense construction, is undergoing profound changes represented by intelligent manufacturing, digitalization, and greening. New technologies, processes, and business models are emerging constantly, placing higher demands on the knowledge structure, ability, quality, and innovative spirit of mechanical engineering talents [3]. However, traditional teaching in professional degree graduate courses still has certain drawbacks, such as an overemphasis on theoretical transmission, disconnection between teaching content and cutting-edge technologies, and low student participation in practice, making it difficult to meet the needs of cultivating high-quality application-oriented talents [4]. Therefore, constructing a high-quality, forward-looking case library on cutting-edge technologies in mechanical engineering that keeps pace with industrial development has become an urgent and important task for teaching reform. Based on the teaching and research foundation of the Mechanical Engineering Department at Qilu University of Technology, and drawing on domestic advanced experience, this paper systematically discusses the significance, planned content, practical methods, and expected outcomes of constructing the "Case Library on Cutting-Edge Technologies in Mechanical Engineering," aiming to provide a reference for teaching reform in professional degree graduate courses at similar institutions.

2. Significance of Case Library Construction

Constructing a case library on cutting-edge technologies in mechanical engineering not only enriches teaching resources but also has multiple profound impacts on improving the quality of professional degree graduate student training. Firstly, it is an inevitable requirement for responding to national policy guidance and implementing the concept of classified training. The case library transforms real technical challenges, typical engineering cases, and the latest application scenarios from the industry into structured teaching resources, enabling students to systematically master the comprehensive application of cutting-edge technologies in a near-practical learning environment, significantly enhancing their ability to solve complex engineering problems, engineering thinking, and innovation awareness [5]. Secondly, the case teaching method is essentially a "student-centered" teaching revolution. It guides students from passive acceptance to active inquiry and collaborative thinking through interactive forms such as group discussions, project simulations, and role-playing [6]. This not only optimizes classroom atmosphere and teaching effectiveness but also forces teachers to continuously update knowledge and improve teaching methods, achieving mutual growth in teaching and learning. Furthermore, case library construction is an effective link for promoting the deep integration of industry, academia, and research. Mechanical engineering is a highly practical discipline. By collaborating with leading industry enterprises and research institutes to develop cases, universities can introduce the freshest engineering practices into the classroom, ensuring the advancement and practicality of teaching content [7]. Simultaneously, enterprises can gain channels for technical exchange and talent reserve through participating in case library

construction, creating a win-win situation. Finally, a dynamically updated, open, and shared case library platform helps promote the flow and radiation of high-quality teaching resources among universities, avoiding redundant construction, improving the overall utilization efficiency of educational resources, and forming a sustainably optimized teaching resource ecosystem [8].

3. Overview and Development Trends of Case Library Construction Domestically and Internationally

3.1 Overview of Domestic and International Case Library Construction

In recent years, China has highly prioritized the improvement of professional degree graduate education quality, issuing a series of important policy documents at the national level, providing clear policy direction and institutional guarantees for case teaching reform. In May 2015, the Ministry of Education issued the "Opinions on Strengthening Case Teaching and Joint Training Base Construction for Professional Degree Graduate Students," a guiding document that systematically addressed case teaching for professional degrees at the national level for the first time[9]. In 2017, the Ministry of Education launched the "New Engineering" construction plan, injecting new momentum into case teaching reform. This major initiative prompted universities nationwide to carry out graduate education teaching reforms, with case library construction gaining widespread attention as a key breakthrough[10]. In the engineering field, various universities have also actively explored. For example, Sun Jianchun et al. from Chongqing University of Science and Technology [3] constructed a teaching case library for materials engineering master's degrees based on industry background, emphasizing the practical and comprehensive nature of cases. Pan Yaokun et al. from Shandong University of Technology [5] explored teaching methods integrating "Task-Driven + Case Library." However, shortcomings still exist in domestic mechanical engineering case library construction: systematic, high-quality case resources are relatively scarce; case content is not closely integrated with rapidly iterating cutting-edge technologies; and cross-institutional, cross-regional case sharing mechanisms are still underdeveloped [11].

3.2 Development Trends

In the future, the construction of teaching case libraries for professional degrees will exhibit the following trends:

(1) Diversification: Case content will cover more specialized fields and interdisciplinary subjects, reflecting practical complexity.

(2) Digitalization and Intelligence: Utilizing AI and big data technologies to achieve intelligent case management, personalized recommendation, and virtual simulation, enhancing the learning experience.

(3) Internationalization and Openness: Strengthening the introduction and localization of international case resources while promoting the open sharing of domestic high-quality cases, building a collaborative development ecosystem.

4. Preliminary Work Conducted

The project team has laid a solid foundation for case library construction:

(1) Strong Research Support: The project leader and members have undertaken numerous national and provincial-level research projects (e.g., National Natural Science Foundation of China, Shandong Provincial Key R&D Program) in cutting-edge areas of mechanical engineering such as high-quality and high-efficiency advanced processing, intelligent manufacturing, and green

manufacturing, achieving abundant research results. This provides a rich source of material for transforming research outcomes into teaching cases (research feeding back into teaching). For instance, research results in laser additive manufacturing, intelligent detection, and ultra-precision machining can directly serve as case content.

(2) Preliminary Teaching Practice: Team members have already attempted to introduce cutting-edge technology cases into graduate courses like "Frontier Topics in Mechanical Engineering," such as teaching the application of additive manufacturing technology in the aerospace field, guiding students to discuss material selection and process optimization, receiving positive student feedback, and accumulating initial case teaching experience.

(3) Extensive Resource Investigation: Leveraging the platform of the Shandong Mechanical Design & Research Institute, the project team conducted broad investigations into high-end technological needs in fields like aerospace, marine equipment, and transportation, collecting a large amount of national policy, industrial report, and engineering example data, ensuring the practicality and cutting-edge nature of the case library.

5. Case Library Construction Content and Framework Design

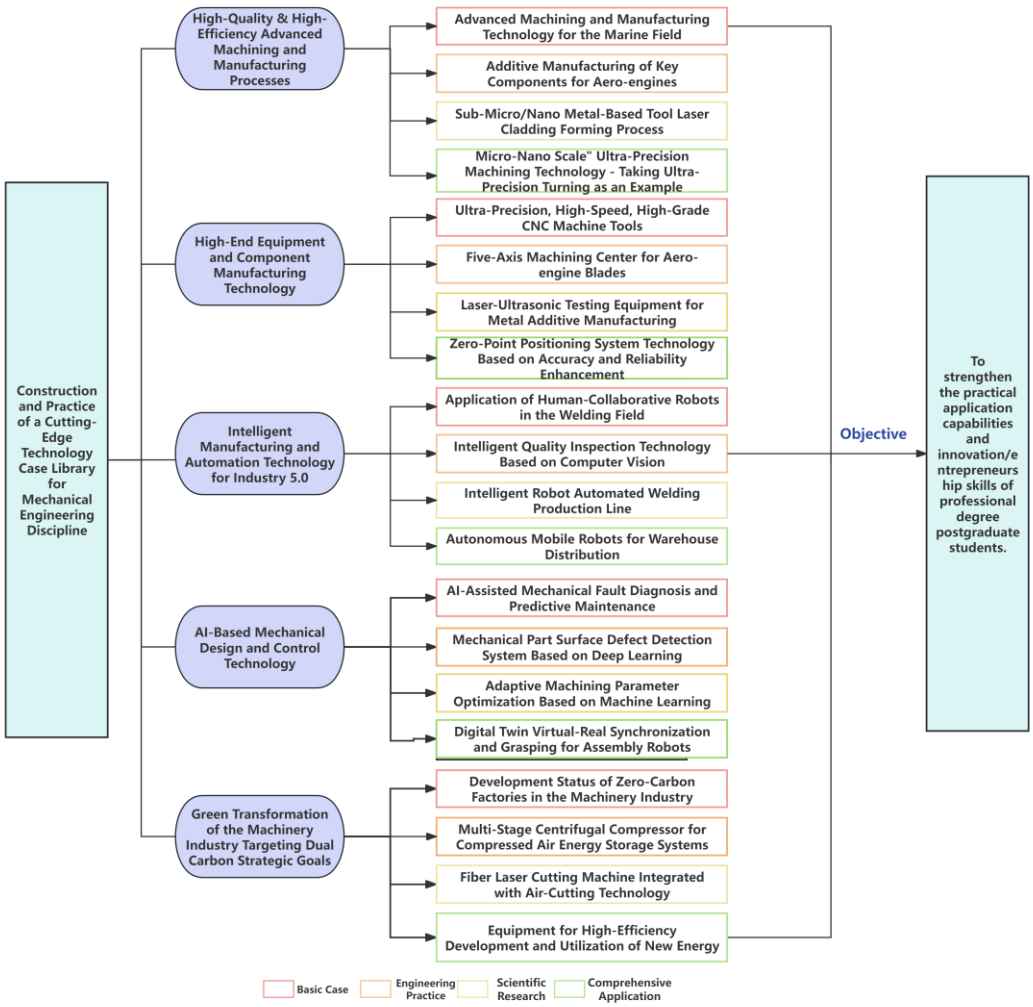

Figure 1 Overall Framework of the Cutting-Edge Technology Case Library for Mechanical Engineering.

This project, based on the training objectives and curriculum system (e.g., "Frontier Topics in Mechanical Engineering," "Advanced Manufacturing Theory and Technology") for professional degree graduate students in Mechanical Engineering, designed a systematic case library construction framework.

As shown in Figure 1, the case library revolves around five cutting-edge technology themes. Each theme includes four types of cases: Basic Theory, Engineering Practice, Scientific Research, and Comprehensive Application, progressing from shallow to deep, totaling 20 typical cases. This aims to promote a comprehensive understanding and integrated application ability of cutting-edge technologies among graduate students. Selected representative cases are described below.

5.1 Module 1: High-Quality and High-Efficiency Advanced Processing and Manufacturing Processes

Case: Application of Additive Manufacturing Technology for Critical Components in Marine Equipment

This case takes critical components with complex flow channel structures in marine exploration equipment as the object, guiding students to learn the principles and advantages of Additive Manufacturing (3D Printing) technology. By comparing the differences between traditional manufacturing processes and additive manufacturing in terms of forming efficiency, structural optimization, and material utilization, students will gain an in-depth understanding of how additive manufacturing breaks through geometric constraints to achieve lightweight and functionally integrated design, meeting high-performance requirements in harsh marine environments.

Case: Preparation Process of Submicron-Nano Metal-Based Cutting Tools via Laser Cladding Forming (Research-Feeding-Teaching Case)

This case is based on a Shandong Provincial Higher Education Institutions Outstanding Youth Innovation Team Project undertaken by the project team. Metal-based cutting tools offer better toughness compared to ceramic tools. Laser cladding technology for tool preparation boasts advantages like high precision and controllable performance. The case will guide students to explore how to achieve submicron/nanoscale microstructure of tool materials through the regulation of laser cladding process parameters, significantly enhancing their hardness, wear resistance, and thermal stability, and understanding the intrinsic relationship between "Process-Structure-Property."

5.2 Module 2: High-End Equipment and Component Manufacturing Technology

Case: Application of High-Grade CNC Machine Tools in Modern Manufacturing Industry

By introducing the high precision, high stability, and other characteristics of high-grade CNC machine tools and their applications in fields like aerospace and precision instruments, this case guides students to analyze the specific performance requirements of different machining tasks on machine tools, understanding the supporting role of high-grade CNC machine tools as "mother machines of industry" for modern manufacturing.

Case: Laser Ultrasonic Online Detection Equipment for Metal Additive Manufacturing (Research-Feeding-Teaching Case)

Based on a Shandong Provincial Key R&D Program Project, this case focuses on the challenge of non-destructive testing of internal defects in metal additive manufactured parts. It guides students to learn the principles of laser ultrasonic testing, analyze how to achieve online, rapid, and accurate identification of defects during the additive manufacturing process, discuss key technical points in the design of the detection system, and cultivate their quality control and equipment development capabilities.

5.3 Module 3: Intelligent Manufacturing and Automation Technology for Industry 5.0

Case: Intelligent Quality Inspection Technology Based on Computer Vision

Using surface defect detection of electronic components or food packaging as the background, this case guides students to learn the entire process of a computer vision system, including image acquisition, preprocessing, feature extraction, and defect recognition. Through practicing the application of deep learning models (e.g., CNN), students will master how to build an efficient and accurate automated quality inspection system.

Case: Intelligent Robotic Automated Welding Production Line for Large Complex Steel Structures (Research-Feeding-Teaching Case)

Based on a Shandong Provincial Key R&D Program (Shandong-Chongqing Science and Technology Collaboration) Project, this case systematically introduces the composition of an intelligent welding production line, involving key technologies such as robot path planning, visual perception, multi-robot collaboration, and real-time monitoring. It guides students to analyze how to achieve automation, informatization, and intelligence in welding large complex components, cultivating their system integration and optimization capabilities.

5.4 Module 4: AI-Based Mechanical Design and Control Technology

Case: Surface Defect Detection System for Mechanical Parts Based on Deep Learning

This case aims to let students understand the basic concepts of surface defect detection and its importance in manufacturing, and understand the specific implementation of deep learning models (e.g., Convolutional Neural Networks) in defect detection. It guides students to discuss the impact of different network structures on detection accuracy and speed, conduct model training, optimization, and performance evaluation, cultivating their ability to use AI technology to solve practical engineering problems.

Case: Design and Optimization of an Intelligent Manufacturing Unit Based on Digital Twin

Digital Twin is a core technology for achieving intelligent manufacturing. This case guides students to learn how to build a digital twin model of a physical entity (e.g., a machining center), use this model for process simulation, predictive maintenance, and production optimization, and understand the concept and application of Cyber-Physical Systems (CPS).

5.5 Module 5: Green Transformation of the Mechanical Industry Targeting the Dual Carbon Strategy

Case: Pathway Planning for Zero-Carbon Factory Construction in Mechanical Manufacturing Enterprises

Centering on the "Dual Carbon" strategy, this case guides students to analyze the energy consumption structure and carbon emission sources of mechanical manufacturing enterprises, explore the realization pathway of a zero-carbon factory through means such as energy management platforms, photovoltaic power generation, process energy-saving transformation, and green supply chain management, cultivating their green engineering awareness and system planning capabilities.

Case: Innovative Design of Equipment for Efficient Development and Utilization of New Energy

Taking new energy equipment like ground source heat pumps as the object, this case guides students through innovative design. The case covers the entire process of resource assessment, equipment principles, structural design, intelligent control, and energy efficiency analysis, cultivating their interdisciplinary knowledge integration and innovation capability oriented towards the new energy industry.

6. Teaching Practice Effectiveness and Feedback of the Case Library

The ultimate goal of building the case library is to serve teaching practice. Based on prior research accumulation and teaching experience, the project team has already applied some cases in actual teaching and achieved significant results. Through the blended teaching method of "Task-Driven + Case Discussion," we have not only achieved deep integration of theory and practice but also stimulated students' innovative thinking and engineering practical abilities.

Furthermore, systematic collection of teaching feedback reveals that case-based teaching is widely praised and welcomed by students. Firstly, students' ability to analyze practical engineering problems has significantly improved, enabling them to independently design processing plans and optimize parameter settings. Secondly, the model of "research feeding back into teaching" has effectively stimulated learning interest; cases developed based on teachers' research projects allow students to more intuitively understand cutting-edge technological trends. Finally, cases developed through university-industry collaboration have broadened students' engineering perspectives, laying a solid foundation for their subsequent degree thesis research and career development.

7. Conclusion and Outlook

Constructing the "Case Library on Cutting-Edge Technologies in Mechanical Engineering" is an important measure to meet the requirements of New Engineering construction and promote the reform of the training model for professional degree graduate students. This paper systematically planned the construction framework and content of the case library, emphasizing its significant value in enhancing students' engineering practice ability, stimulating innovative thinking, and promoting industry-academia-research integration. By transforming real research projects and practical experience into teaching cases, it can effectively achieve research feeding back into teaching, forming a virtuous cycle of mutual promotion between teaching and research. In the future, the project team will proceed according to plan with the writing, teaching trial, and continuous optimization of the case content. Simultaneously, we will actively explore the sharing mechanism of the case library, leveraging information technology platforms to strive for the opening and sharing of high-quality teaching resources within a broader scope, contributing to the improvement of the quality of professional degree graduate student training in Mechanical Engineering in China. The construction of the case library is a dynamic and long-term process that requires continuous updating and iteration with technological development and industrial needs. Its effectiveness also needs further testing and refinement in long-term teaching practice.

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