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Teaching Innovation and Practice of Mechanical Engineering Courses from the Perspective of Emerging Engineering Education

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Abstract: Under Emerging Engineering Education, the Thermodynamics and Fluid Mechanics course in Mechanical Engineering faces key challenges. In response, the teaching team at Qilu University of Technology has proposed an innovative pedagogical model titled “Strengthening Foundations and Expanding Horizons, Cultivating Competence and Shaping Spirit.” First, the course content is systematically reconstructed by reinforcing fundamental theories, broadening interdisciplinary frontier knowledge, and integrating ideological and political education. Next, a multimodal resource system is built that integrates dynamic and static materials, virtual and physical learning environments, and professional and ideological elements. Finally, a digitally empowered, multi-stakeholder collaborative teaching model, supported by a developmental evaluation mechanism, is established. Implementation results show significant improvements in course objective attainment, students’ higher-order thinking and innovation abilities, and the teaching and faculty’s research capacities. This practice provides a replicable and scalable paradigm for the innovative transformation of core mechanical engineering courses under the Emerging Engineering Education initiative.

1. Introduction

The construction of Emerging Engineering Education represents a strategic initiative within China’s higher engineering education system to proactively respond to the Fourth Industrial Revolution and the accelerating development of new-quality productive forces. Its overarching goal is to cultivate outstanding engineering talents equipped with forward-looking vision, cross-disciplinary integration capabilities, systems thinking, and a strong awareness of sustainable development. As a foundational component of traditional engineering disciplines, mechanical engineering directly supports national strategic emerging industries, such as intelligent manufacturing, green and low-carbon development, and high-end equipment manufacturing. Mechanical engineering is currently undergoing profound transformations driven by rapid knowledge iteration, increasing complexity of engineering problems, and a growing demand for versatile and practice-oriented talent.

However, conventional mechanical engineering courses often exhibit shortcomings, including outdated content, monotonous learning resources, lecture-dominated instructional approaches, weak integration of practical components with industrial needs, and insufficient value-oriented guidance. These issues hinder the development of students' abilities to address complicated engineering challenges and to foster innovation. In particular, under China's Carbon Peaking and Carbon Neutrality goals, the reform of core mechanical courses has become urgent, necessitating a shift from a "knowledge-centered" paradigm to one that is both "competency-centered" and "value-centered."

In recent years, extensive research has been conducted on innovative teaching practices in mechanical engineering education. Sun et al. [1] proposed a reform model for Fundamentals of Machine Design, integrating ideological and political elements, real engineering cases or projects, and an online-offline blended flipped classroom supported by the Greater Bay Area Online Open Course Alliance. Zhao [2] developed a dual-driven reform framework incorporating disciplinary competitions and engineering projects across four dimensions: curriculum content, instructional system, teaching methods and tools, and ideological-political education. Li et al. [3] explored the deep integration of artificial intelligence into the specialized course Fluid Mechanics, while encouraging students to engage with enterprises, understand industry needs, and form teams to tackle authentic technical problems. Chen et al. [4] designed a "multi-dimensional and three-dimensional" pedagogical model for mechanical engineering courses. Sun et al. [5] proposed a project-based workshop approach, focusing on course resource development, instructional transformation, and diversified assessment.

Qilu University of Technology, a key provincial application-oriented research university, is committed to cultivating versatile talents with strong innovative, practical, and engineering application capabilities to support regional economic development and industrial upgrading. Thermodynamics and Fluid Mechanics is a core compulsory course within the national first-class undergraduate program in Mechanical Engineering at the university. The course systematically addresses fundamental theories of thermodynamics and fluid mechanics, characterized by high conceptual abstraction, extensive engineering applications, and rapidly evolving frontiers. In response, the teaching team has developed an innovative pedagogical model titled "Strengthening Foundations and Expanding Horizons, Cultivating Competence and Shaping Spirit." This model has significantly improved course quality and enhanced students' innovative outputs, while generating replicable and scalable reform practices that support the systematic transformation of core mechanical courses.

2. Issues in Current Course Teaching

2.1. Student Learning Profile Analysis

Drawing on prerequisite knowledge assessments, online questionnaires, classroom performance feedback, and learning outcomes from previous cohorts, a comprehensive student learning profile was constructed. In terms of foundational knowledge and skills, students possess basic prior knowledge relevant to the course. However, their knowledge structure is characterized by obsolescence and fragmentation. With respect to practical application abilities, students demonstrate competence in memorizing formulas and performing basic calculations, yet they lack the capacity for engineering application and complex problem-solving, making them unable to effectively address intricate real-world engineering challenges. From the perspective of cognitive development, students tend to adopt passive learning approaches and exhibit limited motivation for active inquiry. Their systematic engineering thinking, innovative awareness, and sustainable design mindset remain underdeveloped. Although students of this age group are typically adept at using modern information technologies and digital tools, they show insufficient awareness of national strategic demands and evolving industry development trends.

2.2. Teaching Challenges

Based on the student learning profile and considering the characteristics of the course together with actual teaching conditions, the teaching team identified three major instructional pain points.

First, the Thermodynamics and Fluid Mechanics course emphasizes classical theories related to energy transfer and fluid flow, but does not sufficiently incorporate cutting-edge technologies or interdisciplinary knowledge aligned with the green and low-carbon transformation of the mechanical engineering industry. This results in a misalignment between the curriculum content and the needs arising from intelligent industrial upgrading and green transformation under national strategies, such as building a manufacturing powerhouse and achieving the "carbon peaking and carbon neutrality" goals. Consequently, students lack green design thinking and sustainable development awareness, limiting their potential to grow into high-quality engineering talents capable of adapting to industrial transformation.

Second, the course involves complicated thermal-fluid theories and engineering applications that require dynamic interaction and real-world scenarios to facilitate deep understanding. However, current teaching resources encounter a dilemma: excessive static presentations and insufficient dynamic interactions; an abundance of verification-based experiments but a lack of authentic engineering cases; and plentiful traditional paper-based textbooks but limited high-quality digital resources. As a result, students rely heavily on formula memorization and simple verification experiments, lacking an immersive engineering cognitive chain. This hinders the internalization, transfer, and application of thermal-fluid knowledge in complex engineering contexts.

Third, the course requires full-process training to cultivate students' systems thinking and innovative abilities. Yet the traditional lecture-centered model is constrained by limited teaching time and space, insufficient teacher-student interaction, and monotonous knowledge delivery. These issues dampen students' learning initiative and lead to a lack of systematic training from theory to application, resulting in weak systems engineering thinking and inadequate innovation capacity when confronted with real engineering problems. Furthermore, assessment relies predominantly on final examinations, neglecting process evaluation and assessment of practical competencies. This contributes to the phenomenon of students who can pass exams but cannot apply knowledge, ultimately falling short of the core competencies expected of mechanical engineering graduates.

3. Innovative Strategy and Reform Measures

Building on the student learning profile, the intrinsic characteristics of the course, and the identified instructional challenges, the teaching team develops an innovative pedagogical model entitled "Strengthening Foundations and Expanding Horizons, Cultivating Competence and Shaping Spirit".

3.1. Systematic Reconstruction of Course Content

Following the developmental trajectory of engineering competence, the team departs from the traditional chapter-based structure and reorganizes the curriculum into seven coherent teaching modules centered on the discipline's primary knowledge thread. Through targeted pruning and integration, the theoretical foundation of the discipline is reinforced. Through expansion and extension, cutting-edge and interdisciplinary content is incorporated. Concurrently, a clear ideological-political education thread is distilled and embedded. This restructuring achieves an organic integration of strengthening fundamental knowledge, broadening academic horizons, cultivating professional competence, and shaping value-oriented mindset.

3.1.1. Consolidation of Fundamental Theoretical Knowledge

Taking energy transformation and fluid flow in mechanical devices as the central knowledge thread, the teaching team removed redundant content, outdated thermal-fluid technologies, and low-level verification experiments, while streamlining excessive derivations. The content is reorganized around core theories into seven major teaching modules to help students construct a clear, systematic, and logically coherent professional knowledge framework. By linking fundamental theories with real-life scenarios, industrial engineering cases, and current thermal–fluid research hotspots, abstract mathematical expressions are transformed into concrete engineering contexts. This establishes a closed-loop learning structure of principle explanation → model derivation → case validation, thereby cultivating students' solid disciplinary foundation and enhancing their theoretical literacy.

3.1.2. Expansion of Cutting-Edge and Interdisciplinary Knowledge

Aligned with the goals of Emerging Engineering Education and the practical needs of industrial transformation, the team systematically introduces frontier topics such as new-energy power devices and embedded data-sensing systems-guided by national strategic demands, driven by disciplinary advancements and interdisciplinary convergence, and framed with an international perspective. In-depth expansions are conducted on emerging interdisciplinary areas, including machine-learning-based thermodynamic cycles. The teaching team's latest research outcomes and international academic progress were actively integrated into the curriculum. The purpose is to cultivate students' innovative awareness and cross-disciplinary thinking, and enhance their core competitiveness and professional capacity to meet the evolving demands of the mechanical engineering industry.

3.1.3. Integration of Ideological-Political Education Knowledge

The teaching team deeply explores course-specific ideological-political elements from three dimensions: outstanding historical and cultural heritage, landmark national projects and master craftsmen, and systems thinking and engineering philosophy. By implicitly integrating these elements into teaching, the curriculum cultivates students' patriotic sentiment and strengthens their sense of mission to contribute to national development through science and technology. Simultaneously, it nurtures a scientific spirit characterized by bold exploration and perseverance in addressing challenging problems, and promotes a craftsman spirit of pursuing excellence and continuous improvement. Ultimately, the course guides students toward becoming mechanical engineering professionals equipped with sustainable design awareness and systems engineering thinking.

3.2. Construction of a Multimodal Teaching Resource System

The teaching team integrates dynamic and static resources, virtual simulation and real-world experimentation, as well as professional and ideological-political content to establish a comprehensive, multimodal, and three-dimensional teaching resource system. This system encompasses textbooks, videos, laboratory experiments, practical projects, virtual simulations, and a case library. By creating a flexible, inquiry-oriented learning ecosystem, the resource system addresses the diverse learning needs of students in the era of digital intelligence and significantly enhances their ability to internalize knowledge, transfer learning, and apply concepts in engineering contexts.

3.2.1. Development of Integrated Dynamic-Static Resources

Building on classic Chinese textbooks and authoritative English-language originals, the team develops a bilingual Chinese-English textbook aligned with the restructured course content, serving as the primary static teaching medium. Through precise terminology alignment, immersion in international case studies, and cross-linguistic logical training, the textbook enriches students' knowledge structures, broadens their global vision, and supports continuous advancement of engineering education.

In addition, a diversified video resource library is established as the dynamic instructional medium:

- A 460-minute MOOC on the Chaoxing platform provides focused lectures on key topics, supporting targeted and modular learning;
- Forty recorded classroom videos on an intelligent teaching platform facilitate review, reinforcement, and personalized remediation;
- Selected videos from nationally recognized first-class courses provide authoritative, systematic, and high-quality learning materials;
- Thirty-two three-dimensional animated videos developed using VR/AR technologies transform traditional two-dimensional representations of device principles and system processes into stereoscopic dynamic visualizations, enabling deeper visual understanding of abstract theories.

3.2.2. Development of Virtual-Real Integrated Resources

The team establishes a virtual-real integrated experimental and practical resource system that incorporates hands-on offline experiments, online observational experiments, virtual simulation experiments, and on-site industrial visits. Students conduct data measurement and analysis using three sets of physical laboratory equipment, and deepen their theoretical understanding through 20 online micro-experimental videos. In addition, they are engaged in five virtual simulation experiments within a virtual laboratory platform, to obtain immersive and interactive experiences of high-temperature/high-pressure thermodynamic cycles and pipeline flow operations. Additionally, one enterprise site visit per semester connected theoretical knowledge with authentic engineering environments.

3.2.3. Construction of a Professional-Ideological Integrated Case Library

Faculty and students jointly develop a professional-ideological integrated case library comprising engineering cases, research materials, innovative student works, and ideological-political materials. This initiative promotes deep student engagement in teaching, facilitates mutual enhancement of teaching and learning, and enables dynamic resource updating. Leveraging collaboration with more than 20 enterprises in the mechanical engineering industry-education alliance and current social hotspots, 36 engineering cases are developed; 25 research-oriented materials are converted from the team's latest scientific research and academic frontiers; 12 sets of outstanding student coursework and 10 award-winning competition works from the college are selected as innovation cases to exert peer demonstration effects and cultivate an innovative learning atmosphere; and four ideological-political thematic modules along with numerous mini-class materials are established. Students are encouraged to use AI tools to supplement and update content. Thus, students are transformed from passive recipients of ideological-political education into active participants and contributors.

3.3. Innovation in Multi-Interactive Teaching Mode

Leveraging modern information technologies, the teaching team advances a blended teaching reform and establishes a comprehensive pedagogical model. It is characterized by digitally supported deep integration of online and offline learning, multi-stakeholder synergy among industry, teaching, research, competitions, and innovation, and an organic unification of diversified developmental assessment and evaluation.

3.3.1. Digital-Intelligent Technology Empowering Blended Teaching

The team employs digital-intelligent tools to deeply integrate online and offline learning, seamlessly linking in-class and out-of-class activities and using data-driven feedback to support continuous instructional optimization.

- Pre-class preparatory learning: Tasks and resources are released through intelligent platforms; students engage in self-directed study and self-assessment; instructors use the feedback to provide targeted online Q&A and refine instructional design.
- In-class inquiry-based learning: Seminar-style and other active-learning strategies are employed to address key and difficult concepts, while real-time teacher-student-machine interaction supports clarification and problem-solving.
- Post-class extended learning: Assignments reinforce knowledge consolidation, and engineering cases or scientific-technological projects are introduced to promote personalized development and enhance students' innovation capabilities.

3.3.2. Multi-Stakeholder Collaboration

The team constructs an "industry-teaching-research-competition-innovation" collaborative teaching model. Industry partners provide case-based instruction grounded in authentic engineering scenarios, helping students form a complete cognitive chain from theoretical understanding to practical application. The teaching team reinforces the disciplinary foundation with core theories and cutting-edge interdisciplinary topics, while integrating their own research projects into course submodules to cultivate students' initiative and critical thinking. Innovation-oriented activities include special lectures on scientific and technological innovation, refinement of excellent coursework, and peer-supported participation in disciplinary competitions guided by senior student mentors. Transformation of student outcomes is encouraged, with the team supervising the development of high-quality student projects into prototypes and supporting patent applications. This approach forms a closed-loop talent cultivation system, achieving deep integration of engineering practice, innovative literacy, and ideological-political education.

3.3.3. Comprehensive Course Evaluation System

A developmental evaluation framework is adopted that integrates process-oriented and summative assessments as well as quantitative and qualitative methods, covering the full spectrum of online-offline and in-class/out-of-class learning. Students' attainment of competency goals is implicitly evaluated through their contributions to the co-constructed case library, their completion of experimental and practical tasks in process assessment, and their performance on open-ended, higher-order thinking questions in summative examinations. Moreover, students may earn bonus points by creating digital-avatar mini-lectures, developing chapter-based mind maps, or submitting original scientific and technological innovation works. This mechanism effectively stimulates learning initiative, fosters creativity, and promotes deep learning.

4. Outcomes of Teaching Innovation

4.1. Significant Attainment of Course Objectives

Through the implementation of the aforementioned innovative strategies, the teaching team has effectively achieved the course's knowledge, competency, and value-oriented objectives. Students' ability to internalize and transfer knowledge has improved substantially, and the degree of outcome attainment has increased year by year. Despite a gradual rise in examination difficulty, overall course grades and the proportion of excellent performance have steadily improved. Student satisfaction with the innovative pedagogical model consistently exceeds 92% across multiple dimensions, including content breadth and depth, resource richness, and opportunities for practical innovation.

4.2. Substantial Enhancement of Higher-Order Thinking and Innovation Ability

Students' international perspectives and exposure to cutting-edge interdisciplinary knowledge have been significantly expanded, resulting in notable improvements in higher-order thinking, scientific and technological innovation, and related competencies. Through course-based group projects, students have developed innovative works such as a new-energy self-compressing waste robot. Upon refinement, these works have won over 20 national-level awards and more than 40 provincial-level awards, with a student participation rate of 60%. Two awards were obtained in international competition tracks in collaboration with overseas universities. Projects such as elastic heat exchangers have led to six national invention patents, while initiatives such as photovoltaic water-lifting irrigation systems have resulted in seven published research papers. Additionally, 12 national and provincial Undergraduate Innovation and Entrepreneurship Training Programs have been approved.

4.3. Marked Improvement in Faculty Teaching-Research Capability

The teaching team has overseen one provincial-level and five other teaching-research projects, earned three national-level and two provincial-level teaching competition awards, and served as chief editor of one textbook and co-editor of two others. The course has earned two provincial-level recognitions, including the Outstanding National Security Education Course Case, and has been designated as a university-level ideological-political demonstration course. These outcomes have been effectively integrated into teaching practice, forming a continuous feedback-driven improvement cycle.

4.4. Consistent Recognition from Supervisory Experts and Peers

The innovative pedagogical model has received unanimous praise from university supervisory experts and peer faculty. The lead instructor has ranked within the top 5% of university-wide teaching evaluations for three consecutive years. The teaching model has been selected by the university as a typical case and promoted to related programs in more than 10 peer institutions. The teaching team has presented outstanding student projects at high school science and technology festivals, and original cases shared on the course's WeChat public account have been widely distributed and viewed by peers and the public, further amplifying the demonstrative impact of the teaching model.

5. Conclusions

The teaching reform of Thermodynamics and Fluid Mechanics guided by Emerging Engineering Education fully embodies the talent cultivation concept of "strengthening foundations while expanding horizons, cultivating competence while shaping spirit." Through systematic reconstruction of course content, construction of multimodal teaching resources, and innovation in digitally empowered multi-interactive pedagogy, the reform effectively resolves challenge existing in traditional course teaching. Practice demonstrates that, the reform has not only significantly raised course quality and student satisfaction, but has also markedly enhanced students' engineering application ability, systems thinking, innovative literacy, and sense of mission to serve the nation. The teaching reform has yielded a series of high-level innovative outcomes with demonstrable impact. This pedagogical model possesses strong replicability and scalability, offering valuable reference and inspiration for the comprehensive, deep-level transformation of core courses in mechanical engineering and related disciplines under the new era of Emerging Engineering Education.

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References

[1] Sun J.F., Hu G.H., Su F.H., Zhang G.H. (2025) Innovative teaching reform practice of Fundamentals of Mechanical Design for cultivating excellent engineers. Mechanical Design and Manufacturing Engineering, 54(06), 127-131.

[2] Zhao P.F. (2025) Teaching reform and innovative practice of mechanical design courses driven by both discipline competitions and engineering projects. Paper-making Equipment & Materials, 54(04), 174-176.

[3] Li J., Ji Y.T., Wang D. (2024) Innovative exploration of the Fluid Mechanics course in undergraduate mechanical engineering programs. Education and Teaching Forum, (52), 105-108.

[4] Chen Y.L., Li J.W., Zhu Y.F., Gao B. Wang J. (2023) Exploration and practice of teaching innovation in mechanical engineering courses. Education Review, 12(31), 103-107.

[5] Sun M.X., Zheng L.K., Feng Y., Chen H.B. (2022) Teaching innovation and practice of mechanical engineering courses under the background of emerging engineering education. Journal of Nanjing Institute of Technology (Social Sciences Edition), 22(04), 74-78.