

# Research and Practice on the Teaching of Fundamentals of Mechanical Design Course in the Context of Emerging Engineering Education

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**Abstract:** *In the context of Emerging Engineering Education, the teaching reform of Fundamentals of Mechanical Design course aims to address the insufficient integration of theory and application, the cognitive disconnect between abstract concepts and concrete practice, and the lag between fixed instructional hours and dynamic learning status. Guided by a student-centered philosophy, the course has implemented innovative blended teaching practices: constructing a curriculum ideology and politics case library aligned with national strategies, provincial needs, and institutional contexts, to foster students' sense of mission and responsibility toward building an engineering powerhouse; reconstructing the teaching content system by integrating research projects, competition entries, and disciplinary frontiers; developing an online resource ecosystem featuring micro-lectures, mechanical animations, exercise question bank, and knowledge graphs; and leveraging real-time data from the smart teaching platform like ChaoXing and FiF to establish a precision feedback mechanism for learning analytics. The practical results validate the positive impact of these measures and demonstrate the effectiveness of the reform path, providing a valuable reference for teaching reforms in higher education.*

**Keywords:** Fundamentals of Mechanical Design, Emerging Engineering Education, Teaching Reform, Blended Learning, Curriculum Ideology and Politics.

## 1. Introduction

To proactively respond to the new round of technological revolution and industrial transformation, and to serve the national innovation-driven development strategy, the Emerging Engineering Education (3E) has been proposed. It aims to cultivate versatile talents equipped with interdisciplinary thinking and the ability to solve complex engineering problems [1]. As a foundational course for non-mechanical engineering majors, Fundamentals of Mechanical Design course fosters students' engineering logical thinking by introducing common mechanisms and general-purpose components in mechanical systems, serving as a vital bridge between students' specialized knowledge and mechanical engineering practice. Guided by the development of 3E, promoting the reshaping of teaching content and the innovation of instructional models for this course has become a critical task in deepening engineering education reform.

In recent years, scholars have explored multiple dimensions — including teaching philosophies, instructional models, and quality cultivation—to align with the talent cultivation needs of 3E. Regarding teaching philosophy, Song et al. [2] and Liu et al. [3] explored new education mechanisms for this course based on the Outcome-Based Education (OBE) concept and the integration of 3E with engineering education accreditation, respectively. Lu et al. [4] focused on the military field and proposed a curriculum content reconstruction model under the “Teaching as Combat” philosophy. In terms of teaching models and methods, explorations such as AI-driven project-based learning [5], online-offline blended teaching [6], participatory teaching [7], and teaching mode based on speculative and innovative design [8] have significantly enhanced students' learning interest and interactive experiences. Regarding quality cultivation and evaluation, Yun et al. [9] integrated research cases throughout the course; Wang et al. [10] focused on fostering students' innovative

practical abilities; Zhang et al. [11] implemented a reform path featuring “three-way cultivation + three-way integration”; and Gao et al. [12] constructed an effect evaluation system of curriculum ideology and politics (CIP), achieving the organic unity of knowledge transmission, ability cultivation, and value shaping.

Despite the fruitful results of existing research, systematic solutions addressing specific pain points, such as the weak mechanical background and lack of spatial imagination among non-mechanical majors, still require further development. In light of this, within the context of 3E, this paper analyzes the current teaching situation of Fundamentals of Mechanical Design course for Transportation Engineering majors. It proposes systematic reform measures and conducts an empirical analysis of their effectiveness, providing a valuable paradigm and guidance for the teaching reform of this course in higher education.

## 2. Course Teaching Analysis

### (1) Learner Profile

**Knowledge Reserve:** Students have completed courses such as Higher Mathematics and University Physics, possessing certain logical reasoning and theoretical calculation capabilities. However, the vast majority have had no exposure to actual mechanical processing and production, finding mechanical concepts abstract and void. A survey indicated that 85% of students have never seen the internal structure of a reduction gearbox.

**Cognitive Characteristics:** As digital natives, the post-2000s generation is accustomed to an online lifestyle. They are active-minded and quick to accept new things, yet they exhibit short attention spans, a preference for fragmented information over dry text, and a strong inclination toward visual stimuli.

**Emotional Attitudes:** Due to their non-mechanical engineering backgrounds, some students show great enthusiasm as they require mechanical knowledge to support hardware system construction for disciplinary competitions. Conversely, others hold the view that mechanics is irrelevant to me, with their learning motivation stemming primarily from exam requirements rather than an intrinsic drive to explore mechanical mysteries.

### (2) Pain Point Analysis

**Insufficient integration of theory and application:** The course traditionally emphasizes theories, formulas, and design criteria while neglecting the introduction of practical application cases and cutting-edge scientific developments. Students remain unclear about the application scenarios of the theories they learn, leading to confusion regarding learning goals and a lack of interest.

**Need for stronger cognitive bridging between the abstract and the concrete:** Knowledge points are relatively dry, scattered, and abstract. Even with dedicated instruction, students often fall into a passive and superficial learning state, struggling to establish intuitive engineering concepts, which in turn breeds a fear of difficulty.

**Lag between fixed instructional hours and dynamic learning status:** Classroom time is limited, making it difficult for instructors to cater to individual differences. Furthermore, the lack of digital tools for after-class tutoring results in pre-class preparation and post-class review becoming mere formalities. Students lack timely support channels when facing difficulties, and instructors find it challenging to implement precision teaching interventions.

### (3) Course Objectives

**Knowledge Objectives:** To enable students to understand and recognize machinery, comprehend the motion characteristics of common mechanisms, and master the design methods for common mechanisms.

**Ability Objectives:** To enable students to apply acquired knowledge to analyze the motion characteristics and failure modes of common mechanisms, and to optimize mechanical design based on mechanism characteristics.

**Value Objectives:** to enhance students' sense of professional responsibility and patriotism, instill the spirit of craftsmanship, and establish a firm commitment to serving the country through engineering.

## 3. Teaching Reform Measures

Addressing the aforementioned pain points, the course adheres to a student-centered philosophy. By developing high-quality online resources, reshaping teaching content, and innovating instructional models, the course promotes digital resources, blended models, intelligent feedback, cutting-edge content, featured CIP, and science-education integration. These efforts aim to deepen the teaching connotation and enhance the reform effectiveness.

### (1) Teaching Content Reshaping

To address students' weak spatial reasoning, the course has integrated a collection of over 110 mechanism animations and principle analysis videos. Obscure 2D textbook diagrams are transformed into intuitive 3D animations, effectively lowering the cognitive threshold.

Research projects led by the instructors are converted into teaching cases. By analyzing the design challenges and solutions of mechanical structures within these projects, students perceive the engineering application value of theoretical knowledge through vivid research cases.

Implementing the Competition-Teaching Integration model, award-winning works from competitions such as the National Undergraduate Mechanical Innovative Design Competition (UMIC) are introduced into the classroom. Sharing the full life-cycle design process—from initial conceptualization and schematic iteration to physical fabrication—stimulates students' potential for innovative design.

Keeping pace with the latest developments in mechanical engineering, the course selects cutting-edge research from top-tier journals, covering topics such as micro-nano manufacturing, tensegrity mechanisms, and bionic design. This guides students toward future trends and inspires their interest in scientific exploration.

### (2) Online Resource Construction

Based on the reshaped teaching content, high-quality PPT courseware sets have been updated and developed, emphasizing image-text alignment and logical clarity to facilitate post-class review.

Instructional videos recorded in smart classrooms are edited and deconstructed into smaller units. Specifically, long videos are partitioned into 5–10 minute micro-lectures to accommodate students' fragmented cognitive rhythms.

A course knowledge graph has been established to semantically link fragmented micro-lectures, courseware, and knowledge points into a networked system. This establishes a holistic knowledge system, resolving the cognitive pain point of missing the forest for the trees.

An online question bank containing over 520 exercises has been established, complete with detailed solutions. Each item is assigned a specific difficulty level, tags, and associated knowledge points, thereby constructing a tiered question bank system that ranges from basic and intermediate to advanced levels. Upon the completion of each offline chapter, online quizzes covering the corresponding knowledge points are automatically pushed to students.

Q&A and Course Suggestion sections have been established on the ChaoXing platform. Instructors resolve student queries via the cloud and dynamically adjust teaching strategies based on student feedback.

### (3) CIP Construction

The course aligns with the 3E construction and national innovation-driven development strategy, integrating the unique “Ecological Green + Ideological Red” characteristic of Northeast Forestry University (NEFU). It addresses common CIP challenges, such as the rigid stacking of introductory elements, the homogenization and superficiality of CIP cases, and the fragmented, non-systematic nature of ideological components. A cluster of CIP cases has been established to span the entire teaching process. By dissolving the salt of CIP into the water of the curriculum, the course implements a distributed and immersive teaching methodology that unifies knowledge, ability, and values.

By aligning closely with national strategies, the course guides students to understand national blueprints like the “14th Five-Year Plan for Intelligent Manufacturing” and “Made in China 2025”, alongside the strategy for scientific and technological self-reliance. It encourages students to appreciate the significance of major national equipment and experience the inspiring spirit of scientists and master craftsmen, thereby fostering a firm commitment to serving the country through engineering.

The course draws upon provincial realities, connecting directly with “4567” modern industrial framework of Heilongjiang province. It introduces the mechanical structures utilized in the advanced processing of regional forestry specialties, such as birch sap, fungus, and pine nuts, while analyzing gearbox applications in the wind power and new energy vehicle sectors. Simultaneously, it honors the NEFU spiritual genealogy centered on the “Man-Pulled Plow” and “Crane Soul” spirits, fostering a commitment to serving the nation through ecological preservation.

#### (4) Precision Learning Feedback

By leveraging digital and intelligent technologies, the course has opened the feedback black box of teaching and learning, facilitating a transition from empirical judgment to data-driven decision-making.

Utilizing the big data analytics of the ChaoXing platform, instructors capture real-time score distributions and accuracy rates of chapter quizzes. Combined with classroom interactions, this precisely identifies common knowledge gaps and high-frequency errors, allowing for targeted review in subsequent offline sessions.

The FiF platform is used to analyze formative assessment scores. An academic alert list is generated to ensure early detection and intervention for students at risk. address not only academic hurdles but also psychological well-being and confidence building. Instructors engage in one-on-one instant communication and emotional motivation via the ChaoXing platform. This approach goes beyond resolving academic confusion, focusing equally on psychological guidance and the reconstruction of student confidence.

## 4. Outcomes of Teaching Reform

Teaching reform practices demonstrate that student learning outcomes have achieved significant enhancement. Data indicates that following the reform, the average course score

reached 76.6 out of 100, with a 90% pass rate and an excellence rate climbing to 22.5%. The average course goal attainment reached 0.726, demonstrating that students have not only mastered the theoretical knowledge but also developed core competencies in solving complex engineering problems. Furthermore, students actively engaged in competitions such as UMIC and Course Design Competitions, securing four provincial and ministerial-level awards.

Compared to other non-reformed classes in non-mechanical engineering majors, the average score, pass rate, excellence rate, and goal attainment of this course increased by 12.2%, 10.7%, 14.9%, and 16.2%, respectively. This compelling set of incremental data provides robust evidence for the efficacy of the reform pathway.

In the most recent instructional cycle, targeted interventions were implemented for 17 students on the academic warning list. Notably, nine of these students successfully passed the assessment, achieving an effective intervention rate of 53%. This indicates that the early warning mechanism has effectively curbed the phenomenon of students falling behind. High-quality instructional provision has yielded highly positive feedback, with the comprehensive evaluation of teaching quality ranking at the forefront of the college.

## 5. Conclusion

In response to the 3E requirements for interdisciplinary and versatile engineering talent, this paper addresses the instructional pain points in Fundamentals of Mechanical Design course for non-mechanical majors. Upholding a “student-centered” philosophy, a systemic reform framework characterized by “Content Reshaping, Digital Empowerment, Value Cultivation, and Data-Driven Diagnosis” has been constructed and implemented. Teaching practice shows that by building a progressive knowledge system and introducing engineering cases and scientific frontiers, the barriers between theory and application have been effectively bridged. Leveraging digital resources and hybrid instructional models has transcended the spatiotemporal constraints of traditional classrooms, not only resolving the abstract cognitive hurdles of mechanical structures for non-mechanical students but also achieving precision teaching and personalized assistance through full-process data-driven diagnosis. Furthermore, the integration of a CIP case cluster has successfully stimulated students’ internal learning drive and sense of professional mission. Following the reform, students’ engineering practice capabilities, innovative design thinking, and proficiency in solving complex engineering problems have been significantly enhanced, with a marked improvement in course goal attainment. In the future, we will further deepen the application of Artificial Intelligence in instruction, explore adaptive learning paths based on knowledge graphs, and refine sustainable mechanisms for the integration of science, education, and industry.

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