



# A "Virtual-Real Integration" Teaching Model for Core Materials Courses Based on Multi-Course Integration

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**Abstract.** Facing the urgent demand for engineering practice and digital capabilities under the New Engineering initiative, long-standing issues in traditional foundational courses for Materials Science and Engineering-such as fragmented knowledge and disconnection from industrial practice-persist. Guided by the core principles of "virtual-real integration and industry-education collaboration", this study constructs a systematic four-in-one teaching reform framework of "concept reshaping, curriculum restructuring, pedagogical innovation, and evaluation transformation" (CCPE). By deeply integrating three courses-Engineering Drawing, Mechanics of Materials, and Computer Applications in Materials Science-and designing vertically integrated teaching projects centered on typical engineering components, a complete competency-training loop of "design-analysis-simulation-validation" has been established. The reform explores a "virtual-real complementary" learning path in which simulation results and mechanical theory reinforce each other. Teaching practice, evaluated through the Engineering Education Accreditation (EEA) achievement analysis across three consecutive rounds, demonstrates significant improvement in student learning outcomes: students below the 0.7 threshold decreased from over 50% to only seven. The reform substantially enhances students' engineering thinking, knowledge integration capabilities, and industry relevance, providing a viable pathway for foundational course reform in materials-related majors.

**Keywords:** Teaching reform; Multi-course integration; Virtual-real integration; Industry-education collaboration; Engineering competency

## 1 Introduction

With the advancement of the Emerging Engineering Education initiative, higher engineering education is accelerating its transformation toward interdisciplinary integration, and practice-orientation. In 2025, five national departments jointly issued *the Opinions on Strengthening the Construction of Data Element Disciplines and the Development of a Digital Talent Workforce*, emphasizing the use of application scenarios to cultivate interdisciplinary, innovative, and practice-oriented talents. However, the

foundational course system in Materials Science still faces structural challenges. While industry demands graduates’ comprehensive abilities in engineering modeling, structural simulation, and digital analysis, foundational core courses in traditional curricula remain fragmented, with teaching content overly focused on theoretical derivations or isolated operations. This lack of integrated, real-world practices hinders the effective development of students’ engineering competencies<sup>[1-3]</sup>.

To address these issues, this paper proposes an integrated teaching model based on industry-education collaboration, using three interconnected courses—Engineering Drawing, Mechanics of Materials, and Computer Applications in Materials Science—as teaching cases. The proposed CCPE framework guides students through the complete workflow from drawing creation and mechanical modeling to digital simulation validation, leveraging simulation results to reinforce theoretical learning. This approach achieves knowledge integration and capability enhancement, offering a viable solution for the reform of foundational courses in materials science.

## **2 Challenges in the Current Course Teaching**

### **2.1 Fragmented Course System and Disconnected Knowledge Chains**

Core materials courses (Engineering Drawing, Mechanics of Materials, and Computer Applications) are taught in isolation, lacking organic integration. Engineering Drawing focuses on drafting without linking geometry to mechanical analysis. Mechanics of Materials emphasizes formula derivation, yet abstract stress-strain concepts lack visual carriers, hindering connections between theory, graphics, and physical objects. The software course (e.g., SolidWorks) has been reduced to skill training, where students model but fail to apply simulation results practically. This fragmented approach severely impedes systematic engineering thinking.<sup>[4-6]</sup>

### **2.2 Teaching Content Divorced from Industrial Reality and Weakened Engineering Context**

Most current cases are textbook-style idealized exercises (e.g., “simply supported beams”), disconnected from real engineering problems. Students lack exposure to authentic stress scenarios like stress concentration in transmission shafts, leaving their understanding purely theoretical<sup>[7]</sup>. More critically, the absence of real enterprise project data (e.g., equipment drawings, failure reports) prevents students from appreciating engineering complexity, leading to a decline in both learning motivation and practical abilities.

### **2.3 Vague Course Evaluation Objectives and Weak Comprehensive Application Abilities**

Current singular evaluation of courses emphasize knowledge infusion over ability transfer, leading to a situation where students possess knowledge but cannot apply it.

They memorize mechanics formulas but fail to use them in practical stress analysis, and can operate modeling software but struggle to link simulation results with actual material behavior. This results in a perceived "disconnect between learning and application" during internships, reflecting a systemic deficiency in students' comprehensive abilities related to engineering thinking and problem-solving.

### 3 Overall Framework and Implementation Pathways for Teaching Reform

To address the fragmented course system and diminished teaching relevance, this study proposes a four-in-one reform pathway from a top-level design perspective, termed "Conceptual Remodeling, Curriculum Restructuring, Pedagogical Innovation, and Evaluation Transformation" (CCPE). Using the integration of three core courses—Engineering Drawing, Mechanics of Materials, and Computer Applications in Materials Science—as the starting point, the model aims to establish a new teaching paradigm centered on capability integration, supported by digital tools, and oriented toward engineering practice. The schematic framework of the CCPE model is illustrated in Figure 1.

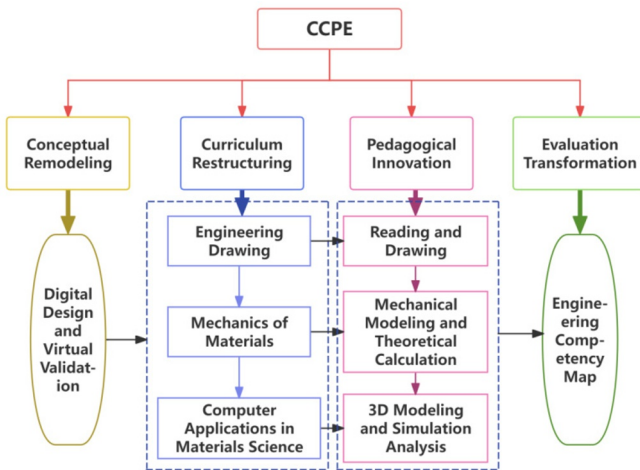


Fig. 1. A detailed diagram of CCPE model

#### 3.1 Remodeling Teaching Philosophy: Establishing an Engineering Competency View Centered on "Digital Design and Virtual Validation"

The primary effort promotes a fundamental shift in teaching philosophy—from imparting fragmented knowledge to cultivating integrated capabilities of "Design-Analysis-Validation". The three courses are repositioned as interlocking links within the digital engineering process: Drawing defines engineering thinking graphically, Mechanics provides quantitative analysis of physical laws, and Simulation serves as a virtual validation tool for design solutions. This philosophy guides students to establish a systematic

problem-solving framework, elevating learning objectives from solving textbook problems to addressing practical engineering challenges.

### 3.2 Restructuring the Curriculum System: Building Industry-Education Collaboration Projects Centered on “Typical Engineering Components”

Vertically integrated teaching projects are designed around typical engineering components (e.g., transmission shafts, load-bearing beams), requiring students to complete the workflow: “Blueprint Reading and Drawing-Mechanical Modeling and Theoretical Calculation-3D Modeling and Simulation Analysis”. The drawing segment emphasizes standardized expression; mechanics involves load analysis based on drawings; software completes virtual simulations cross-validated with theoretical calculations. This “one case, multiple courses” approach integrates discrete knowledge points through industry-aligned tasks, facilitating knowledge transfer from isolated mastery to integrated application. To ensure authentic industry engagement, the reform operates through a structured, semester-long partnership with two local manufacturing enterprises. Formal agreements define their roles across three stages: (1) project design-co-defining project scopes and providing authentic datasets (e.g., equipment drawings, failure reports); (2) teaching delivery-delivering guest lectures and participating in classroom mentoring; (3) student immersion-visiting partner companies for on-site case analysis. This multi-stage engagement embeds industry participation throughout the learning process, keeping teaching cases current and relevant to industrial practice.

### 3.3 Innovating Teaching Methods: Promoting Mutual Enrichment between Virtual and Physical Realms

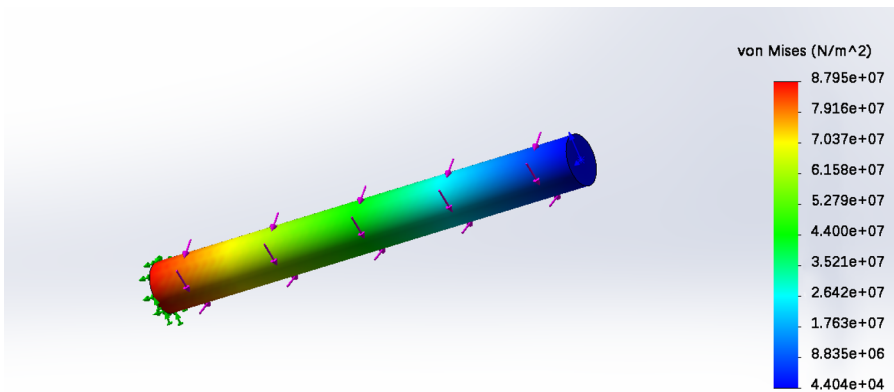


Fig. 2. Stress distribution diagram of a long axis.

Teaching methods shift from unidirectional instruction to project-driven inquiry-based learning, emphasizing “mutual enrichment between virtual and physical realms”. Intuitive results from SolidWorks simulations—stress contour plots and deformation animations—deepen understanding of abstract mechanics concepts. As shown in Figures 2 and

3, students analyze torsional deformation on a long axis and perform stress analysis on a power strip housing<sup>[8, 9]</sup>, transforming abstract theories into concrete visualizations. This approach strengthens the connection between theoretical knowledge and practical application, lowering learning thresholds and enhancing comprehension.

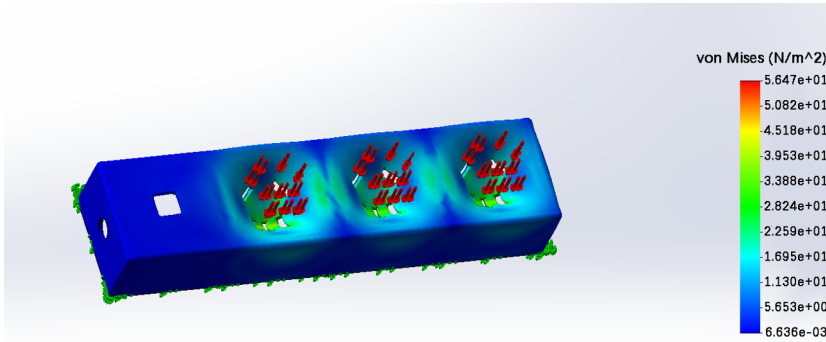


Fig. 3. Stress distribution diagram of a power strip housing.

### 3.4 Reforming the Evaluation System: Constructing a Comprehensive Assessment Scheme Oriented Towards an “Engineering Competency Map”

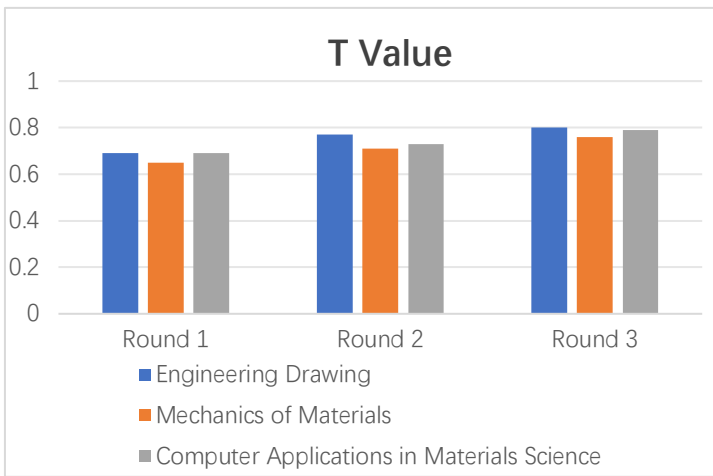
The traditional examination-oriented evaluation is reformed by shifting focus toward students’ problem-solving abilities. Guided by engineering competency mapping, assessment emphasizes knowledge integration, tool proficiency, and logical rigor demonstrated throughout project practices, covering simulation reports, comparative analyses, and optimization suggestions. Enterprise partners actively participate through structured forms rating student projects on design feasibility, compliance with industry standards, and practical implementation potential. This formalized input ensures assessment criteria reflect both academic rigor and industrial expectations. This approach, integrating external perspectives, authentically reflects students’ engineering competency development, guiding them from passively receiving knowledge to actively applying abilities, achieving alignment between teaching evaluation and industrial demands.

## 4 Implementation Outcomes and Preliminary Evaluation of the Teaching Reform

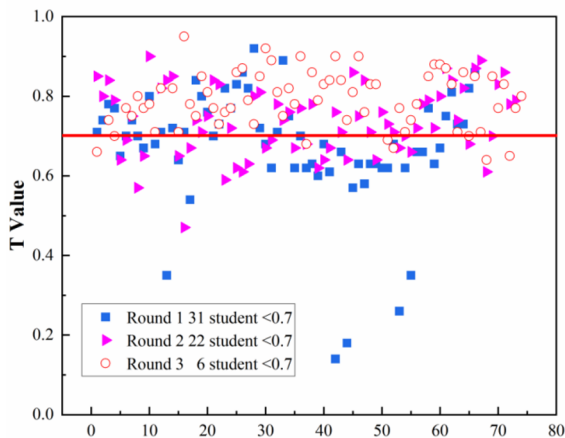
The systematic reform has significantly enhanced students’ abilities and better aligned teaching with industrial demands. To evaluate learning outcomes, student achievement across three consecutive course rounds is analyzed using the Engineering Education Accreditation (EEA) method<sup>[10]</sup>. Round 1 represents baseline data collected prior to CCPE implementation (traditional teaching), while Rounds 2 and 3 correspond to the

first and second iterations after the CCPE model was introduced. Following EEA principles, a threshold value (T) exceeding 0.7 is required to meet accreditation standards.

Figure 4 compares T values across the three rounds. While Round 1 (baseline) shows relatively low overall achievement, Rounds 2 and 3 demonstrate progressively higher T-values as students adapted to the integrated approach. This trend is further illustrated in Figure 5, which presents individual student T value distributions. In the baseline round (Round 1), over half of the students fell below the 0.7 threshold. Following the introduction of the CCPE model, this decreased significantly to approximately 20% in Round 2 and by Round 3, only seven students remained below 0.7. This progressive improvement provides strong evidence for the reform's effectiveness.



**Fig. 4.** Comparison of T-values across three rounds: Round 1 (baseline, traditional teaching) and Rounds 2-3 (post-reform iterations under the CCPE model).



**Fig. 5.** The T-value of individual students across three rounds: Round 1 (baseline, traditional teaching) and Rounds 2-3 (post-reform iterations under the CCPE model).

Project-based learning significantly enhanced students' learning initiative and engineering identity, with over 80% reporting heightened interest in mechanics concepts. Course integration enabled most students to articulate the logical chain from drawing to simulation and explain theory-simulation discrepancies. Abstract concepts like stress concentration were concretized through SolidWorks visualization. Through complete "drawing-calculation-simulation-analysis" cycles, students progressed from mechanical execution to engineering thinking, demonstrating comparative analysis and optimization skills. The process-oriented evaluation system enabled timely weakness identification, improving pass rates and shifting outcomes from memorization to competency application.

## 5 Conclusion and Outlook

In response to the challenges in foundational materials courses-fragmented knowledge, weak practical training, and disconnection from industrial practice-this study established a new teaching paradigm centered on "virtual-real integration and industry-education collaboration". The CCPE model integrates simulation-theory interplay as its core learning logic, guided by an engineering competency map for assessment, with industry partners engaged throughout the semester in project design, mentoring, and evaluation. Practice shows this approach significantly boosts student engagement and engineering identity, fosters multidisciplinary knowledge integration, and enhances problem-solving skills, offering a viable solution to the fragmentation dilemma in materials education.

However, broader implementation faces challenges: faculty interdisciplinary expertise, sustainable industry partnerships, software licensing costs, and the need for accessible teaching toolkits. While currently validated within a single institution, future work will pursue a phased roadmap: (1) piloting the model in related majors (e.g., mechanical engineering); (2) cross-institutional collaborations for comparative validation; and (3) developing open-access teaching resources to facilitate broader adoption. Through iterative refinement, the CCPE model can evolve into a scalable framework for engineering education reform.

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