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Construction of an Integrated Teaching Chain of "Drawing – Modeling – Simulation": Exploration of Teaching Reform Based on Digital Design Concepts

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Abstract: With the deep integration of intelligent manufacturing and digital design technologies, the traditional drawing-centered teaching paradigm of engineering drawing courses can no longer meet the demands of emerging engineering talent cultivation. Aiming at the prominent problems of fragmentation and disconnected knowledge among engineering drawing, 3D modeling, and simulation analysis courses, this paper proposes an integrated teaching chain of "Drawing – Modeling – Simulation". Taking the complete workflow of digital design as the logical backbone, it integrates 2D drawing expression, 3D parametric modeling, and finite element simulation analysis into a progressive knowledge chain, forming a cognitive path of "from drawing to shape, from shape to field". Based on analyzing the dilemmas of the traditional teaching mode, this paper systematically expounds the construction scheme of the integrated teaching chain from three dimensions: reconstruction of teaching philosophy, modular reorganization of curriculum content, and consistent design of project carriers. It also prospects the expansion directions of the future integrated teaching system.

Keywords: Engineering drawing; 3D modeling; Simulation analysis; Integrated teaching; Digital design; Teaching reform

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1. Introduction

Engineering drawing is a core foundational course for mechanical and related majors, responsible for cultivating students' spatial imagination, drawing expression ability, and engineering literacy [1]. For a long time, the course has centered on manual drafting and 2D drawing reading, forming a mature and stable teaching system. However, with the widespread application of CAD/CAE technologies in manufacturing, the engineering design workflow has undergone fundamental changes: shifting from the traditional mode of "drawing first, manufacturing later" to the digital design paradigm of "3D modeling → virtual simulation → iterative optimization → drawing output". In this context, teaching goals that end with 2D drawings have clearly lagged behind industrial practice [2].

Meanwhile, higher engineering education is undergoing a paradigm shift from discipline-oriented to outcome-based education (OBE). The construction of emerging engineering clearly requires students to develop comprehensive abilities to solve complex engineering problems, rather than isolated drafting or software operation skills [3,4]. This poses dual challenges to traditional courses: on the one hand, digital tools must be integrated into single courses; on the other hand, organic connections must be established among related courses to form a coherent ability-training chain.

2. Dilemmas of the traditional teaching mode

2.1. Curriculum isolation: Disconnected knowledge chains

In the current teaching system, engineering drawing, 3D modeling (e.g., SolidWorks, CATIA), and simulation analysis (e.g., finite element analysis, motion simulation) are usually offered in different semesters or even by different departments [5]. The three courses operate independently in syllabi, case selection, and assessment methods, making it difficult for students to establish internal connections among "drawing – shape – field". Taking a typical reducer housing as an example: in engineering drawing, students learn sectional views to express internal structures; in modeling, they rebuild an entirely new 3D model, often unrelated to the drawing case; in simulation, they use a different example for meshing and stress analysis. The three learning objects are disconnected, and students never experience a complete design closed loop.

2.2. Cognitive gap: Difficulty transitioning from 2D to 3D

Traditional engineering drawing emphasizes the "dimension-reduction projection" ability from 3D objects to 2D drawings, which is a core competency for engineers [6,7]. However, when students only practice on 2D planes, the development of spatial imagination heavily relies on personal talent, leading to uneven teaching effects. Many students struggle to understand the spatial configuration of complex parts. When entering modeling courses, they must "reconstruct 3D from 2D", which imposes excessive cognitive burden and reduces learning motivation.

2.3. Ability deficit: Staying at expression, lacking engineering verification awareness

The endpoint of traditional teaching is "drawing a correct diagram" or "building a seemingly correct model" [8]. In real engineering design, however, whether a component is qualified depends not only on correct shape expression but also on whether it meets strength, stiffness, thermal deformation, and other performance requirements under actual working conditions. The lack of this "verification" step in the current teaching system leads students to form the inertia of "finishing after drawing", lacking the closed-loop awareness of engineering design.

3. Design philosophy of the integrated teaching chain

3.1. Core concept: From "Drawing-Centered" to "Digital Twin"

The design philosophy of the integrated teaching chain can be summarized as: enabling students to experience the complete digital design process of a product from "drawing expression → digital modeling → performance verification" during their studies [9]. The essence is to expand the teaching goal from "mastering drafting skills" to "understanding and initially practicing the digital design workflow", aligning course content with modern engineering practice. Specifically, “integration” includes three layers: First, logical integration - the three teaching links are not in a parallel relationship but a progressive one: “Drafting” addresses the issue of “how to express”, “Modeling” tackles the problem of “how to construct”, and “Simulation” resolves the question of “whether it is feasible”. The three together form a complete cognitive chain of “expression - construction - verification” [10]. Second, carrier integration - all three links revolve around the same set of engineering cases. Students first draw, then model, and finally conduct simulation analysis on the same part or assembly. Third, tool integration - integrated software platforms (such as SolidWorks, which supports 3D modeling, engineering drawing, and Simulation analysis) are used as much as possible to reduce the learning cost for students when switching between different software.

3.2. Reorientation of ability-training objectives

The ability-training objectives corresponding to the integrated teaching chain are divided into three progressive levels: The first level is spatial cognition and graphic expression ability, corresponding to the mapping stage. Students can accurately understand the spatial configuration of three-dimensional entities and express them in a standardized two-dimensional format in accordance with national standards. The second level is parametric modeling and design implementation ability, corresponding to the modeling stage. Students can use three-dimensional CAD software to transform design intentions into precise digital models. The third level is engineering analysis and design verification ability, corresponding to the simulation stage. Students can apply working condition constraints to models and conduct preliminary static structural analysis to determine if the design meets performance requirements. These three levels of ability build upon each other in a progressive and interrelated manner, all aiming towards a comprehensive training objective: to enable students to initially possess the engineering practice ability to complete the “design - expression - verification” closed loop using digital tools.

4. Specific construction of the integrated teaching chain

4.1. Modular reorganization of curriculum content

The integrated teaching chain reorganizes the core content of the original three courses into five teaching modules. Each module integrates knowledge points of drawing, modeling, and simulation, forming a spiral-up learning path.

Table 1. Five teaching modules of the integrated teaching chain

Module	Name & Hours	Core Content	Teaching Design Highlights
Module 1	Engineering Cognition & Basic Graphics (16 class hours)	Projection principles, views of basic solids, composite solid drawing	Introduce 3D visualization to establish intuitive “3D→2D” mapping
Module 2	Part Expression & Standards (12 class hours)	Sectional views, cutaway views, dimensioning, national standards	Use the same part for subsequent modeling and simulation to ensure continuity
Module 3	3D Parametric Modeling (16 class hours)	Sketching, feature creation, assembly constraints, engineering drawing	Model parts already drawn; compare automatically generated drawings with manual drawings
Module 4	Introduction to Simulation Analysis (8 class hours)	Material properties, boundary conditions, meshing, solving & post-processing	Use built models to observe stress nephograms and identify weak points
Module 5	Comprehensive Project Practice (12 class hours)	Group projects covering drawing to simulation	Submit full results: drawings + model + simulation report + improvement suggestions

4.2. Consistent design of project carriers

The selection of project carriers is critical to the success of the integrated teaching chain [11]. A good project carrier should meet the following standards: First, its structural complexity should be moderate, capable of covering the main graphic expression methods without making modeling and simulation overly difficult. Second, it should have a clear engineering background and practical functions, which can stimulate students' interest in learning and engineering awareness. Third, the simulation analysis should be intuitive, allowing students to obtain "visual engineering feedback" from stress cloud diagrams or deformation animations.

Taking a bench vise as an example, it contains various typical structural features: the movable jaw involves sectional views and extrusion modeling; the lead screw involves threaded representation and helical scanning; the vise body involves fillet representation and shell analysis. In the simulation stage, clamping force can be applied to analyze stress distribution and deformation, evaluating strengths and weaknesses. Such a carrier naturally connects all core knowledge points of drawing, modeling, and simulation.

4.3. Cognitive path: "From Drawing to Shape, From Shape to Field"

The cognitive path of the integrated teaching chain is vividly summarized as "from drawing to shape, from shape to field" [12].

(1) From drawing to shape (first half): connects drawing and modeling. Students first establish 2D expression ability through manual drafting, then "stand up" the lines on paper into rotatable, sectionable, measurable digital models via 3D modeling. Repeated switching between 2D and 3D efficiently trains spatial imagination.
(2) From shape to field (second half): connects modeling and simulation. Students assign material properties and apply loads to built 3D models, observing responses in "force fields" and "thermal fields". The model is no longer static geometry but an "active" engineering entity in physical fields [13,14]. This cognitive leap helps students truly understand the essence of engineering design: design is not only drawing "what it looks like" but also ensuring "whether it works".

5. Conclusion

The construction of the integrated teaching chain is a systematic project that cannot be accomplished overnight. It requires continuous investment from the teaching team, institutional support from teaching management departments, and effective integration of industry-education resources [15]. In the future, with the maturity of immersive technologies such as virtual reality (VR) and augmented reality (AR) and the popularization of AI-aided design tools, the integrated teaching chain is expected to further expand into a full-chain system of "Drawing – Modeling – Simulation – Intelligent Manufacturing", providing a more solid curriculum foundation for emerging engineering talent cultivation.

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