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A Closed-Loop Practice-Oriented Teaching Reform Framework for Engineering Drawing Empowered by AI and Intelligent Robots

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Abstract: This paper addresses three key problems in engineering drawing teaching including superficial AI application, fragmented practical training and insufficient research achievement transformation, and proposes a closed-loop practical teaching model with intelligent robots as engineering carriers. The model covers AI-aided parametric modeling, 3D digital design, 3D printing manufacturing and intelligent verification, forming a full practice chain from conceptual design to physical prototype testing. Integrating AI parametric modeling, automatic drawing inspection and 24/7 intelligent tutoring functions, the study constructs a hierarchical robot project practice system and a research-teaching-competition linkage mechanism for research achievement transformation. Teaching practice proves the model effectively improves students' intelligent design ability, connects drawing design with physical manufacturing and functional verification, and enhances their comprehensive engineering competence and innovation performance. It provides a replicable scheme for the digital and intelligent upgrading of engineering drawing courses.

1. Introduction

Engineering drawing is a core compulsory course for mechanical and intelligent manufacturing majors, cultivating students' graphic expression, 3D modeling and engineering system thinking[1]. With the development of intelligent manufacturing and AI, the industry requires engineering talents with AI-enabled digital design capabilities.

Traditional teaching has three major defects[2]. First, AI teaching application is superficial, with students lacking parametric design and automatic drawing inspection abilities. Second, practical training is fragmented, without complete design-manufacturing-verification loops. Third, mature intelligent robot research results of the team have not been transformed into hierarchical teaching cases, resulting in weak research-teaching integration.

Current teaching reforms focus on single AI tool embedding or partial case optimization, lacking complete robot project-based teaching frameworks. Based on the team's surface intelligent robot research foundation, this study integrates AI technology, robot projects and 3D manufacturing to build a novel closed-loop teaching reform system[3-4].

2. Analysis of Existing Teaching Challenges and Learning Conditions

2.1 Three Major Teaching Challenges

(1) Insufficient AI-teaching integration. Current courses only provide basic CAD training without cross-disciplinary AI collaborative design. Surveys indicate 88% of students have no experience in AI-assisted multidisciplinary design, and 73% cannot implement intelligent drawing inspection, reflecting severe deficiencies in students' intelligent design thinking and digital tool application.

(2) Fragmented engineering practice. Practical teaching lacks complete product development cycles. Real engineering projects account for only 7% of training content, over 90% of tasks are simple drawing creation, and less than 10% of students participate in manufacturing and functional testing. Taking drawing completion as the final goal disconnects students from complete industrial engineering processes.

(3) Defective research-teaching transformation mechanism. The team has made mature achievements in robot modeling, 3D printing and autonomous control, yet these research outputs are not developed into hierarchical teaching cases. Classroom teaching rarely involves authentic research engineering problems, failing to exert multidisciplinary research educational value.

The above-mentioned three major teaching pain points are summarized visually in Figure 1, which presents relevant survey statistics and corresponding consequences of the existing teaching bottlenecks.

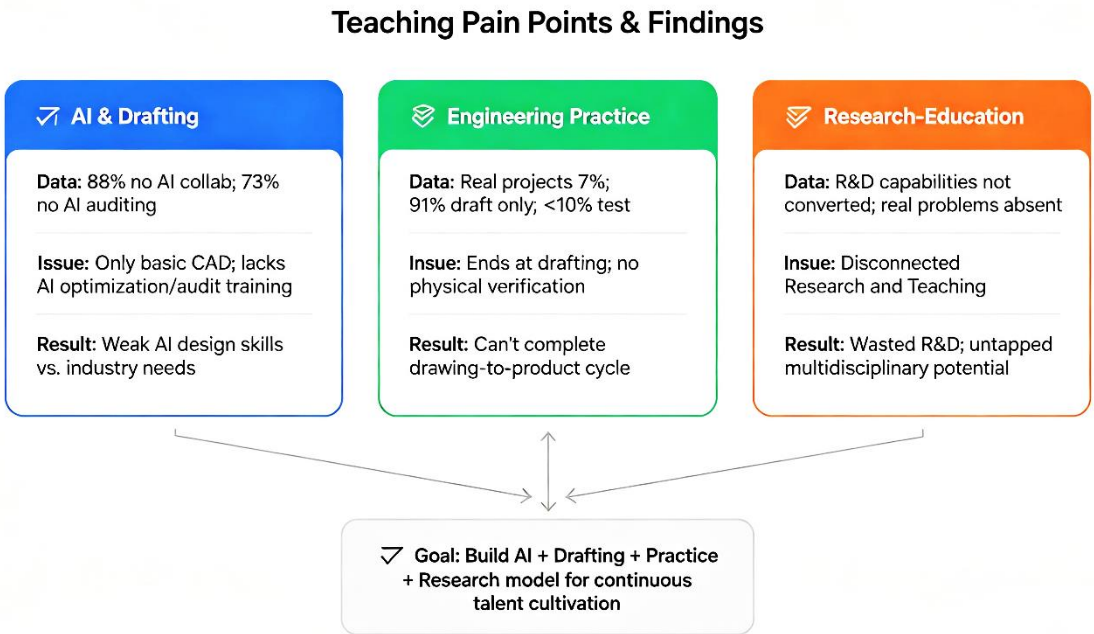

Figure 1: Framework of Teaching Pain Point Analysis

2.2 Analysis of Students' Competency Gaps

A competency comparison between industrial requirements and student abilities shows minor gaps in basic 3D modeling and drawing standardization, but prominent deficits in three emerging capabilities: AI tool operation (58-point gap), intelligent drawing inspection (54-point gap) and parametric design (41-point gap). Students' traditional drafting skills are competent, while intelligent design abilities are insufficient, making intelligent teaching system reconstruction urgent for adapting to industrial demands. Figure 2 intuitively illustrates the competency gaps between industry requirements and the actual performance of students from multiple dimensions.

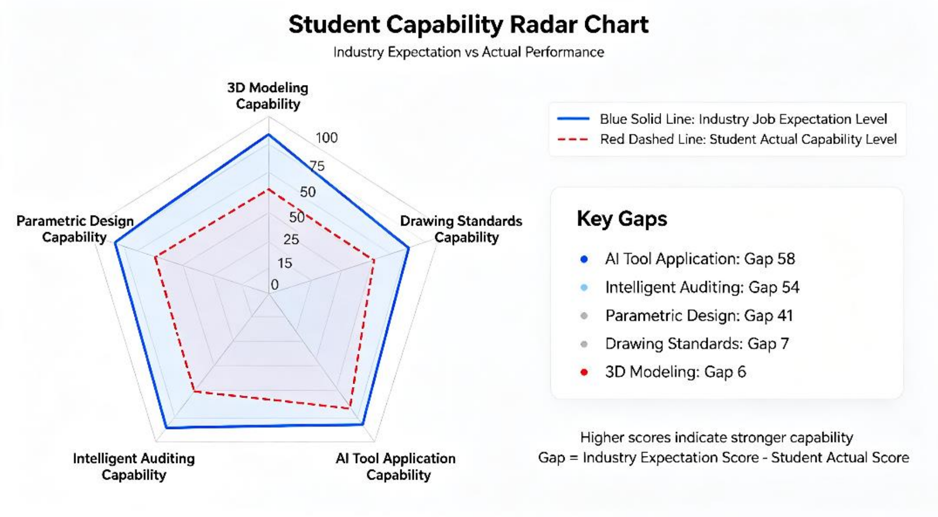

Figure 2: Radar Chart of Students' Competency Gaps

3. Construction of the Closed-Loop Practical Teaching System for "AI + Engineering Drawing"

Taking surface intelligent robots as unified practice carriers, this study constructs a four-stage closed-loop teaching framework based on AI empowerment, robot project-driven training and research-teaching resource conversion. The framework integrates AI and drawing teaching, covers the full R&D process of intelligent robots, and realizes sustainable transformation of research achievements into undergraduate teaching resources.

3.1 Development of an AI-Based Teaching Toolchain for Intelligent Design Assistance

The online teaching platform is upgraded to build a three-in-one AI teaching toolchain for intelligent design improvement. (1) AI parametric modeling module: It generates preliminary 3D models based on robot structural constraints, enabling students to optimize structures, annotate drawings and analyze manufacturability, realizing the shift from imitative drafting to demand-oriented intelligent design. (2) AI drawing tutoring agent: It automatically checks drawing specifications, provides 24/7 personalized error guidance and solves the problem of insufficient individual teaching in large-class teaching. (3) AI+Drawing project module: Centering on robot structural design, it covers parametric optimization, interference detection and drawing refinement to train students' integrated application of AI tools and drawing standards.

Supporting resources including 197 micro-lessons, integrated textbooks and 1,619 3D component models are developed to support students' independent AI-assisted design practice.

3.2 Four-Level Progressive Closed-Loop Practical Teaching System Based on Intelligent Robots

Based on surface unmanned vehicle R&D processes, a four-level progressive training system connecting drawings, models, prototypes and verification is designed. (1) Basic level: Students complete standard 2D part and assembly drawings to consolidate drawing principles and standards. (2) Advanced level: Students adopt AI parametric tools to build robot structural models and complete matching drawings and documents. (3) 3D printing stage: Students export STL models, set parameters and fabricate physical parts to understand digital-physical manufacturing logic. (4) Innovation level: Students assemble prototypes and conduct functional tests via Unity simulation platform, including obstacle avoidance and navigation verification. Training tasks are closely connected with national discipline competitions.

The full-cycle training helps students form systematic engineering cognition. Domestic unmanned vehicle cases are integrated into teaching to cultivate students' engineering responsibility and professional craftsmanship.

3.3 Research–Education–Competition Integration Mechanism

A sustainable research-teaching-competition integration mechanism is established. (1) Resource transformation: Robot research achievements including drawings, 3D printing processes and control cases are sorted into hierarchical teaching resources and supporting manuals. (2) Undergraduate research participation: Outstanding students participate in prototype design and debugging, experiencing complete engineering research processes. (3) Teaching-competition integration: Innovative training tasks correspond to national competitions, forming a positive cycle of research achievements, teaching optimization and student innovation improvement.

4. Three Major Innovations of the Teaching Reform

4.1 Teaching Model Innovation: Full-Chain Closed-Loop Practical Training Framework

Different from traditional drawing courses limited to graphic completion, this reform builds a full-chain closed-loop system covering AI design, 3D modeling, 3D printing and prototype verification. Students experience complete product R&D processes, bridging the gap between theoretical drawing learning and practical product development, and enhancing systematic engineering thinking and problem-solving abilities.

4.2 Technology Integration Innovation: Full-Process Embedding of AI Technology

This reform realizes full-process embedding of AI technology rather than isolated tool application. AI parametric design, drawing inspection and intelligent tutoring run through the whole teaching process, transforming teaching from simple software operation training to intelligent engineering design cultivation, and supporting interdisciplinary talent training with both traditional and digital design capabilities.

4.3 Research–Education Integration Innovation: Standardized Transformation of Research Results

The study establishes a standardized path for transforming research achievements into teaching resources. Taking mature intelligent robot research projects as carriers, it integrates cutting-edge research cases, technologies and algorithms into basic courses, realizing deep integration of scientific research, undergraduate teaching and discipline competitions, and forming a sustainable, replicable talent cultivation model.

The three core dimensions of teaching reform innovation, including teaching model, technology integration and research-education integration, are systematically sorted out in Figure 3, which also clarifies the ultimate talent-training goal of this reform.

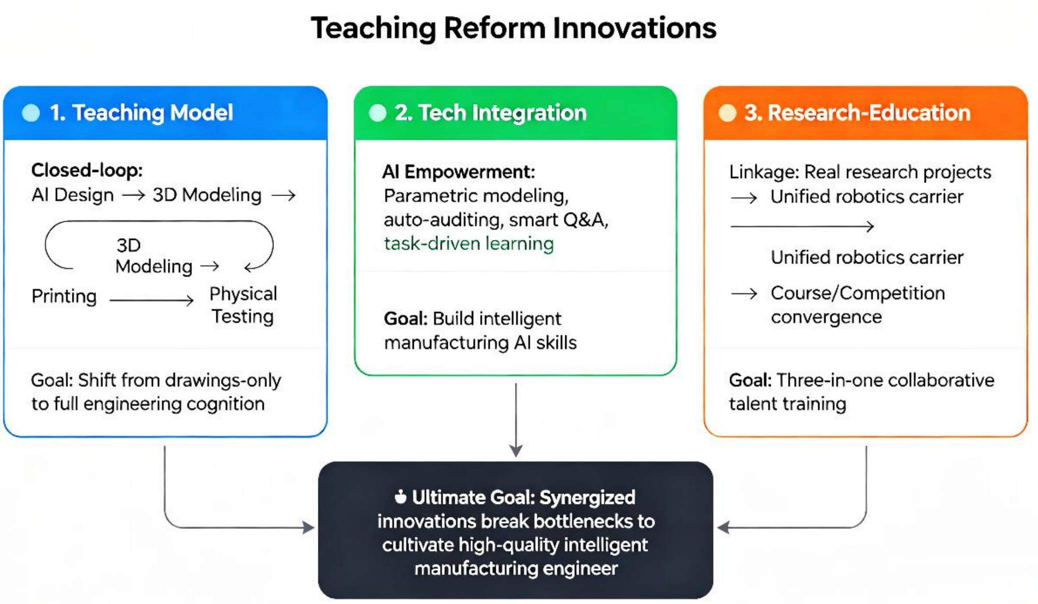

Figure 3: Framework of Teaching Reform Innovation System

5. Implementation Outcomes and Expected Educational Benefits

5.1 Preliminary Implementation Outcomes

The course is awarded Shanghai First-Class Undergraduate Course, with its textbook selected as a national 14th Five-Year Plan textbook. In recent five years, supervised students have won 9 first prizes in National Engineering Drawing Competition and multiple national-level innovation awards, with stable student teaching evaluation scores of 92–93.

Pilot teaching shows remarkable effects: students' drawing standardization and modeling efficiency are significantly improved, the number of students participating in 3D printing and prototype tests triples, and students' competition performance is steadily enhanced.

5.2 Expected Long-Term Educational Benefits

(1) Improved design ability: Over 10% improvement in course performance and 80% of students will master AI parametric design and intelligent inspection, adapting to intelligent manufacturing posts. (2) Better innovation outcomes: Annual acquisition of 3+ national first prizes, 3–5 provincial robot innovation awards and 1–2 undergraduate innovation projects. (3) Extended teaching influence: A standardized robot case library will be built, 2–3 high-quality teaching papers will be published, and the reform model can be popularized in engineering colleges.

6. Conclusions

Facing the demand for intelligent manufacturing talents, this study proposes an AI-driven closed-loop teaching reform system integrating full-process engineering practice and research-teaching integration. The AI toolchain compensates students' intelligent design deficiencies, the robot R&D process builds a complete practice loop, and the resource transformation mechanism guarantees high-quality teaching output.

This reform solves the core problems of traditional teaching including industry disconnection, fragmented practice and superficial AI application. Future research will optimize AI inspection algorithms, enrich robot teaching cases and build multi-dimensional evaluation systems to form a scalable AI integration scheme for basic engineering courses.

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