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Research on Teaching Reform and Practice of Empowering Mechanical Drawing Course in Vocational Colleges with Generative Artificial Intelligence

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Abstract: Against the backdrop of the "Made in China 2025" strategy, the Mechanical Drawing course in higher vocational education faces challenges where traditional teaching models are disconnected from the needs of industrial digitization. To address this, this study explores the deep integration of Generative Artificial Intelligence (Generative AI) into the Mechanical Drawing curriculum and proposes a new teaching model tailored for the modern era. The research first establishes the theoretical foundation by drawing upon Cognitive Load Theory and Constructivism Learning Theory, articulating Generative AI's role as a "Cognitive Scaffold." This function effectively reduces students' Extraneous Cognitive Load associated with tedious drawing tasks, allowing them to focus on Higher-Order Design Thinking. Based on this, we designed the "Human-Machine Collaboration and Virtual-Physical Integration" three-stage teaching model. This model reconstructs teaching objectives, shifting the focus from "mastering drawing skills" to "cultivating design thinking and human-machine collaboration capabilities." Implemented through three phases—basic guidance, AI-assisted innovation (concept generation and topology optimization), and deepening of engineering practice (standard correction and physical validation)—the model achieves a fundamental shift in teacher and student roles. The study utilizes an Action Research methodology, combined with quasi-experimental design and mixed methods, for practical validation. This research aims to provide a systematic theoretical framework, implementation pathway, and empirical reference for the intelligent transformation of engineering courses in vocational colleges.

Keywords: Generative Artificial Intelligence (Generative AI); Mechanical Drawing; Vocational Education; Human-Machine Collaboration; Cognitive Load Theory; Teaching Model.

1. Introduction

The "Made in China 2025" strategy has imposed higher demands on the innovation and digital literacy of technical skilled talents for smart manufacturing. However, traditional Mechanical Drawing courses in higher vocational education commonly suffer from bottlenecks, including monotonous teaching models, low student engagement, and difficulties in cultivating spatial visualization ability, leading to a disconnection from industry needs. In recent years, disruptive technologies represented by Generative Artificial Intelligence (Generative AI) have demonstrated immense potential in the design field, offering a critical opportunity to resolve these pedagogical challenges and modernize the curriculum. Therefore, exploring the deep integration of Generative AI into the vocational Mechanical Drawing course is of great theoretical and practical significance for cultivating innovative talents adapted to the future.[1]

A review of domestic and international literature shows that existing research largely focuses on algorithmic applications of Generative AI in specialized engineering fields or the general auxiliary functions of AI in education. A systematic study that integrates Generative AI as a core element, constructs a set of verifiable and operable teaching models for the vocational Mechanical Drawing curriculum, and empirically validates its effect, remains a gap. This forms the starting point of the present research.

To this end, this study aims to construct and implement a new "Human-Machine Collaboration" teaching model that integrates Generative AI. The research will employ an Action Research methodology, combined with a quasi-experimental design and mixed-methods approach. By utilizing classroom practice, questionnaires, and design output analysis, we will systematically evaluate the comprehensive effects of the new model on enhancing students' learning interest, innovative thinking, and drawing proficiency, ultimately providing valuable empirical reference and implementation pathways for the reform of vocational engineering courses in the new era.

2. Theoretical Foundation for the Integration of Generative AI and Mechanical Drawing Curriculum

This section delves into the theoretical cornerstones for integrating Generative AI technology into the Mechanical Drawing curriculum. The analysis focuses on three dimensions: the potential of core AI technologies, supporting learning theories, and models for curriculum integration, providing a theoretical basis for constructing a novel engineering education model.

2.1. Core Technologies of Generative AI and Their Educational Potential

The core concepts of Generative AI in mechanical engineering mainly include AIGC (AI-Generated Content) and Generative Design (GD). GD allows designers to define objectives and constraints, enabling AI algorithms to explore and automatically optimize the optimal geometric shape that meets the specified requirements. Its educational potential is immense:

1. Assisted Design and Rapid Iteration: AI quickly generates design drafts and models, shifting students' energy from tedious drawing operations to concept evaluation and

parameter optimization, significantly boosting design efficiency.

2. Solution Optimization and Performance Prediction: AI models can immediately conduct virtual simulation and performance analysis (e.g., stress distribution, lightweighting) on student designs. This provides quantitative feedback, deepening the students' understanding of engineering principles.

3. Intelligent Q&A and Personalized Tutoring: Generative AI tools based on Large Language Models (LLMs) can offer real-time answers to questions regarding drawing standards, geometric tolerances, and provide customized, immediate learning support.

2.2. Cognitive Load Theory and Constructivism Learning Theory [7][8][9]

The introduction of Generative AI aligns closely with two core theories in educational psychology: Cognitive Load Theory (CLT) and Constructivism Learning Theory.[7][8][9]

2.2.1. Cognitive Load Theory and "Cognitive Scaffolding" [7][8][9]

In traditional Mechanical Drawing instruction, memorizing complex CAD commands and performing tedious geometric operations contribute to Extraneous Cognitive Load that consumes working memory. Generative AI acts as a powerful "Cognitive Scaffold," taking over these lower-level tasks and thus reducing the extraneous load. This allows students to concentrate their working memory on the more critical Germane Cognitive Load (e.g., understanding design intent, applying engineering specifications), leading to more efficient schema construction—the shift from "how to draw" to "how to design." [7][8][9]

2.2.2. Constructivism Learning Theory and Knowledge Construction

Constructivism emphasizes that learning is an active process where learners construct knowledge and meaning through interaction with real environments and reflection on experience. AI provides a high-fidelity, low-risk environment for authentic problem-solving and offers instant feedback. This facilitates the "design-analyze-modify" cycle, prompting students to immediately reflect on design decisions, engage in active knowledge correction and skill construction, and expand the scope for exploratory learning.[6]

2.3. Curriculum Integration Models Analysis

The integration of Generative AI into the Mechanical Drawing course can be divided into three progressive levels:

1. Tool Integration: Treating AI as an efficient substitute for traditional drawing tools, focused solely on improving the efficiency of drawing and modeling.

2. Content Integration: Incorporating the principles behind AI, its application scenarios, and its limitations into the curriculum to foster students' critical thinking about the intelligent design process (e.g., teaching validation of AI outputs and ethical considerations).

3. Pedagogical Integration: Utilizing the characteristics of AI to reconstruct teaching objectives, processes, and assessment methods. Adopting Project-Based Learning (PBL) where AI serves as an intelligent tutor, shifting the assessment focus from drawing accuracy to design innovation and AI tool utilization strategies, thereby driving deeper learning.[12]

3. Design and Implementation of the Generative AI Integrated Mechanical Drawing Teaching Model

Guided by the theoretical foundation, this section details the design and implementation of a teaching model that deeply integrates Generative AI into the Mechanical Drawing course.

3.1. Reconstruction of Teaching Objectives

The teaching objective is fundamentally reconstructed from the traditional "mastering drawing skills" to "cultivating design thinking and human-machine collaboration capabilities," specifically including:

1. Higher-Order Design Thinking: The ability to critically evaluate, select, and optimize AI-generated solutions based on functional requirements, constraints, and manufacturability.

2. Human-Machine Collaboration Skills: Mastering efficient communication (Prompt Engineering) with Generative AI tools, and performing manual verification and in-depth correction of AI-generated outputs.[6]

3. Engineering Specification Application: The ability to accurately and standardly add necessary tolerances, geometric dimensioning and tolerancing (GD&T), and surface finish requirements based on AI models, ensuring the drawing's manufacturability and inspectability.[13]

3.2. Curriculum Content and Resource Repository Construction

To support the reconstructed objectives, curriculum content and resources must undergo intelligent upgrading:

3.2.1. Curriculum Content Adjustment

While retaining foundational knowledge like projection theory, the curriculum must integrate cutting-edge content: AI-assisted conceptual design, parametric modeling and topology optimization, and AI model validation and ethics (e.g., FEA verification, design bias).[2][3][4]

3.2.2. Digital Teaching Resource Repository Construction

A highly digitized resource repository must be built, featuring: Practical Guides for mainstream Generative CAD tools; Comparative Case Studies of AI-generated vs. traditional designs; and Complex Engineering Project Tasks with multiple constraints to drive project-based learning.

3.3. The "Human-Machine Collaboration and Virtual-Physical Integration" Teaching Model

This model adopts a three-stage progressive teaching approach:

1. Phase I: Basic Knowledge Guidance (Theoretical Foundation): The teacher lectures on core theories and standards; students engage in minimal basic drawing exercises (manual or simple CAD) to grasp geometric logic.

2. Phase II: AI-Assisted Innovation (Concept Exploration): Open-ended project tasks are introduced. Students use Generative AI tools for concept generation and solution exploration. The teacher transitions into an Inspirational Mentor, guiding students to think about "why AI generated this structure" rather than "how to draw it."

3. Phase III: Deepening of Engineering Practice (Validation and Entity Creation): Students engage in critical filtering,

detailed correction, and refinement of the AI-generated solutions; they complete the final Engineering Drawings that comply with national standards (including tolerances); and they may use 3D printing or simulation to convert the design into a physical or virtual model for validation, achieving a closed-loop learning experience through virtual-physical integration.[14]

3.4. Teaching Implementation Process

The successful implementation of this model relies on redefining teaching activities and the roles of teachers and students.

3.4.1. Research Subjects and Schedule

- Research Subjects: Select second-year students from a mechanical engineering major at a vocational college as the experimental group.
- Schedule: The teaching cycle spans weeks (e.g., 16 weeks), with Phase I (Basic Guidance) occupying weeks, and Phases II and III (AI Collaborative Project Practice) occupying weeks.

3.4.2. Teacher and Student Role Transformation

Table 1. Teacher and Student Role Transformation

Role	Function in Traditional Teaching	Function in AI-Integrated Teaching Model
Teacher	"Knowledge Imparter," "Standard Enforcer"	"Mentor" (Guiding design thinking, inspiring innovation) and "Evaluator" (Assessing design logic, collaboration strategy)
Student	"Knowledge Recipient," "Drawing Executor"	"Designer" (Defining problems, setting constraints) and "Critical Explorer" (Actively experimenting with AI tools, critically filtering results)

This transformation ensures that teaching is no longer a one-way knowledge transfer but a student-centered, project-driven process of Human-Machine Collaborative Exploration.

4. Conclusion and Outlook

This study constructs a comprehensive new teaching model integrated with Generative AI, aiming to bridge the gap between traditional Mechanical Drawing instruction and the demands of smart manufacturing talent.

Theoretically, drawing upon Cognitive Load Theory and Constructivism, the research establishes Generative AI's role as a "Cognitive Scaffold," redirecting students' cognitive resources from extraneous load to Germane Load—the construction of higher-order design thinking. Pedagogically, the "Human-Machine Collaboration and Virtual-Physical Integration" three-stage model is proposed, achieving a fundamental reconstruction of teaching objectives: shifting to "cultivating higher-order design thinking and human-machine collaboration skills."

The implementation of the model emphasizes role transformation and integrates cutting-edge content such as AI-assisted conceptual design and topology optimization. This provides a practical and verifiable empirical model for the reform of engineering courses in vocational colleges, holding significant value for cultivating innovative, digitally skilled talent for the "Made in China 2025" initiative.

Limitations and Future Work: Future research needs to systematically assess the quantifiable effect of the new model on improving students' spatial visualization ability, creative output quality, and collaboration efficiency using quasi-experimental data. Furthermore, investigation into the optimal timing and depth for introducing Generative AI tools, and more detailed adaptive adjustments for different engineering specialties, are warranted.

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