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AI and Digital Twin Technology in the Curriculum Reform of "Mechanical Processing Technology and Equipment"

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Abstract

The traditional teaching of the "Machining Process and Equipment" course faces constraints such as limited hands-on resources. To solve this, we propose a reform strategy leveraging AI and digital twin technology. We have developed a new instructional model characterized by virtual-physical integration, project-driven tasks, and blended online/offline delivery. With typical workpiece cases as the foundation, a "three-level progressive" curriculum framework is designed. Practical application shows that this approach notably improves students' practical engineering skills, creativity, and collaboration. Furthermore, it transforms the passive learning environment into a dynamic "teaching-learning-practice-evaluation" integrated system. This research provides a practical reference for modernizing mechanical engineering curricula in the era of AI.

Keywords

Mechanical Processing Technology and Equipment; Curriculum Reform; AI; Digital Twin Technology.

1. Introduction

"Mechanical Processing Technology and Equipment" is a core course for mechanical engineering and related majors. It primarily studies the complete process of transforming raw materials into finished parts. The course content covers key aspects such as processing methods, processing technology, machine tool equipment, selection of cutting tools and fixtures, and cutting parameter optimization [1-3]. In the context of AI development, this course not only requires students to deeply understand the basic principles and inherent laws of mechanical manufacturing but also focuses on cultivating their ability to use intelligent technologies like "AI + digital twin" for process design and optimization, laying a solid foundation for their future career development in the mechanical manufacturing field.

The course content is mainly organized around typical components, including shafts, disc/sleeve-type parts, and box-type parts. Starting from analyzing the drawing of a shaft part, students analyze its structural characteristics, technical requirements, and material properties, then select suitable processing methods [4-5]. They delve into the performance characteristics of machine tools like lathes (including CNC), milling machines (including CNC), and grinders, accurately grasp the selection principles and application scope of corresponding tools and fixtures, and learn to formulate scientific and reasonable mechanical processing procedures for standard parts and the design and application of specialized fixtures [6-7]. Using typical components as carriers, combined with existing AI + digital twin technology and a project-driven teaching model, this course enables students to gradually build a complete knowledge system and enhance their practical abilities while solving real problems.

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"Mechanical Processing Technology and Equipment" is an important professional course for the Mechanical Design, Manufacturing, and Automation major and the Mechanical and Electrical Technology Education major at the School of Mechanical and Electrical Engineering, Lingnan Normal University. Designed for second-year undergraduate students, this course aims to systematically consolidate, comprehensively apply, and effectively expand upon knowledge from previously studied courses such as Mechanical Manufacturing Fundamentals, Mechanical Drawing, and Interchangeability and Measurement Technology, serving to "review the old and learn the new" (see Figure 1). Through the study of theoretical knowledge and practical skills in this course, mechanical engineering students can lay a good foundation for further study of related professional courses, engaging in relevant professional work, and serving society.

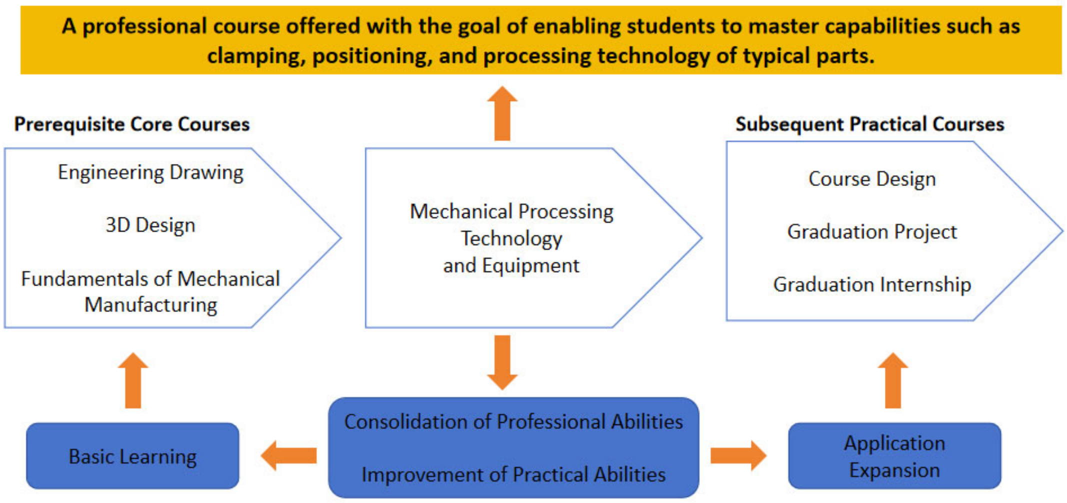

Figure 1. Schematic diagram of the course's position and its relationship with preceding and following courses

The course is offered as a professional course aimed at enabling students to master the abilities of clamping, positioning, and processing typical components.

2. Materials and Methods

2.1. Course Hour Adjustment

The total class hours for "Mechanical Processing Technology and Equipment" are 56 hours, consisting of 40 hours of theory and 16 hours of practice. Given the limitations of existing practical teaching hardware, which restricts students' deep understanding of mechanical processing technology and the improvement of their practical abilities, and to further expand the breadth and depth of the course content, AI + virtual simulation technology is planned to be introduced. The course is proposed to be increased to 64 hours, comprising 42 hours of theory and 22 hours of AI + digital twin practice. This virtual-real combination aims to enhance teaching effectiveness, compensate for the shortage of practical resources, and achieve the reform goal of project-based blended teaching.

2.2. Teaching Model Design

In traditional classroom teaching, the focus is on the teacher's instruction, leaving limited space for students' independent thinking and learning [8]. The mechanical processing technology course adopts an online and offline blended teaching method, effectively enabling students to internalize knowledge and form a closed loop of input and output. The AI + digital twin

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technology-assisted project-based teaching method further closely links teaching content with production practice. In this model, under the teacher's guidance, students independently choose topics that align with course objectives and their personal interests. They explore real project tasks through in-depth research, direct observation, and hands-on practice. This teaching method truly embodies the student-centered concept, achieving a shift from the "teacher-centered lecturing, student passive acceptance" indoctrination model to an open teaching model integrating "teaching, learning, doing, and evaluating." The key and difficult points of the course are addressed within authentic production contexts, significantly improving teaching effectiveness.

(1) Implementation of AI + Digital Twin Technology Project-Based Teaching Model

The course adopts a project-based teaching method, using actual mechanical part processing projects as carriers. AI analyzes students' learning levels and breaks down projects into subtasks of varying difficulty. While completing project tasks, students use a visual virtual simulation platform. They not only systematically learn the knowledge and skills of mechanical processing technology in a virtual environment but also cultivate their engineering practice ability, innovation ability, and teamwork skills. For example, in a shaft part processing project, students need to start with part drawing analysis (see Figure 2), sequentially complete tasks such as formulating the process plan, selecting tools and fixtures, determining cutting parameters, processing the part, and quality inspection. By experiencing the entire processing process firsthand, they deepen their understanding and mastery of the knowledge. Applying digital twin technology in the teaching process holds profound significance and substantial value for practical teaching. It breaks through the time and space limitations of traditional practice, reshapes the form of experimental teaching, and represents a profound change to traditional teaching models.

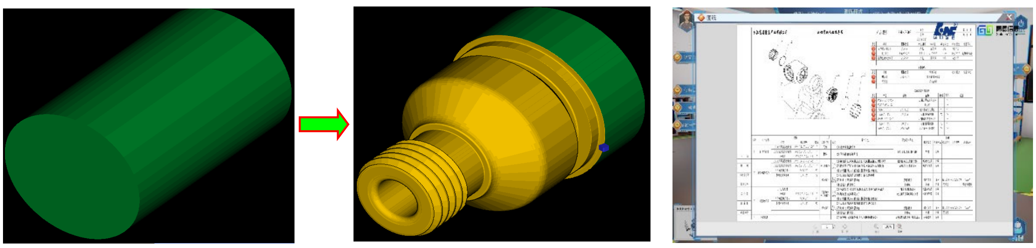

Figure 2. Stepped shaft simulation model

(2) Implementation of Online + Offline Blended Teaching Model

Based on the course characteristics, a design concept for blended teaching activities is proposed. This model features teacher-led learning processes and student-participant engagement, using methods like micro-lectures to guide learners from shallow to deep learning. A wealth of digital teaching resources have been developed, including online courses, virtual simulation experiments, instructional videos and electronic textbooks.

Students can study on an AI-assisted learning platform and arrange their learning progress flexibly. Digital twin and virtual simulation experiments allow students to conduct process optimization in a virtual environment. By watching online instructional videos to understand complex technological processes and consulting electronic textbooks for knowledge support, students can formulate fixture production processes with the aid of AI. They can also apply virtual simulation and digital twin technologies to carry out simulated fixture applications, thus forming an integrated learning environment that deeply integrates theory and practice.

(3) Implementation of Flipped Classroom

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The flipped classroom model based on collaborative learning emphasizes students working in small groups, leveraging rich digital teaching resources for autonomous learning, making students the leaders of the classroom. Students actively learn new teaching content before teacher instruction, and the teacher transforms from a traditional knowledge transmitter to a classroom organizer and guide. Diverse flipped classroom formats effectively break the traditional teacher-centered teaching structure. This not only improves students' learning outcomes and autonomy but also helps cultivate their cooperative spirit and communication expression abilities.

2.3. Curriculum System Restructuring

2.3.1. Core Objectives of Curriculum System Restructuring: Build a Digital Twin-Integrated Curriculum Ecology

Establish a curriculum system where "AI + Digital Twin Technology runs through the entire process": Achieve digital transfer of "Typical Component Processing Technology" and "Fixture Design" from theory to practice; Develop a "virtual-real synchronous" cluster of teaching resources; Students can complete the entire process workflow in a virtual scene with AI assistance; Implement a teaching model of "scenario-driven - virtual practice - dynamic optimization" to enhance the ability to solve process problems digitally; Form an evaluation system where the "process is traceable and capabilities are quantifiable," using AI + digital twin technology for precise feedback. By constructing real-time mapping between physical entities and virtual mirrors, students "experience" the entire process of fixture design, processing, and optimization in a virtual environment, forming a closed-loop education model of "virtual simulation - data feedback - practice improvement."

(2) Break disciplinary boundaries: Organically connect knowledge points from related courses such as "Mechanical Design," "CAD/CAM," and "Mechanical Manufacturing Fundamentals" through the digital twin thread, forming a systematic knowledge system centered on "part lifecycle process design."

(3) Specific Framework Design is as follows:

Break away from the traditional linear system and build a "three-level progressive" digital twin-integrated curriculum system:

Practice Project : Optimized Design of Robot Fixtures

Basic Level: Add a "Digital Twin Technology Fundamentals and Application" module covering core digital twin basics such as 3D modeling, virtual simulation, and data acquisition, laying a solid foundation for technology application.

Core Level: Restructure the "Fixture Design Core Module," deeply integrating AI + digital twin into key aspects like fixture design, processing application, and quality control.

Application Level: Set up a "Digital Twin Fixture Optimization Comprehensive Practice" module to carry out "Virtual Verification of Robot Fixture Optimization."

2.3.2. Course Teaching Design

A teaching model integrating "online-offline blended learning" and "AI & digital twin project-driven teaching" is adopted. The strengths of virtual simulation and digital technologies are fully leveraged, and the teaching is carried out in the following phases:

Scene Introduction Phase: Real industrial process scenarios (such as bearing faults) are reconstructed via digital twin technology to display the synchronous status of physical equipment and virtual mirrors, stimulating students’ interest in problem-solving.

Virtual Design Stage: Students complete the processing process plan design on the simulation platform (optimizing the process route within simulation software), including operation planning, equipment selection, parameter settings, etc. The platform automatically generates a 3D process flow chart and virtual machining paths.

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Dynamic Tracing Stage: Inject the 3D graphics into the digital twin system, display the dynamic changes during component operation, and synchronously collect key data such as vibration and temperature.

Optimization Enhancement Stage: Analyze data obtained online from the digital twin, derive fault results, modify the plan, and perform simulation verification again, forming a cycle of "design - simulation - optimization."

Teaching Process Design (using "Fixture Design" unit as an example): Integrate the competition requirements of the 2025 Industrial Collaborative Robot and Digital Twin Technology Innovation Application to achieve optimized design of robot fixtures and establishment of twin models.

① Theory Analysis Stage: Explain fixture design theory in class. Assign project requirements for fixture design after class.

② Virtual Prehearsal Stage: Based on the part drawings for which dedicated fixtures need to be designed, students design the processing workflow (refer to Figure 3 for details). After finalizing the plan, they assemble the fixture components. Run the software for modeling and virtual machining simulation (see Figure 4), observe its working effect, eliminate interference, and promptly correct the design scheme.

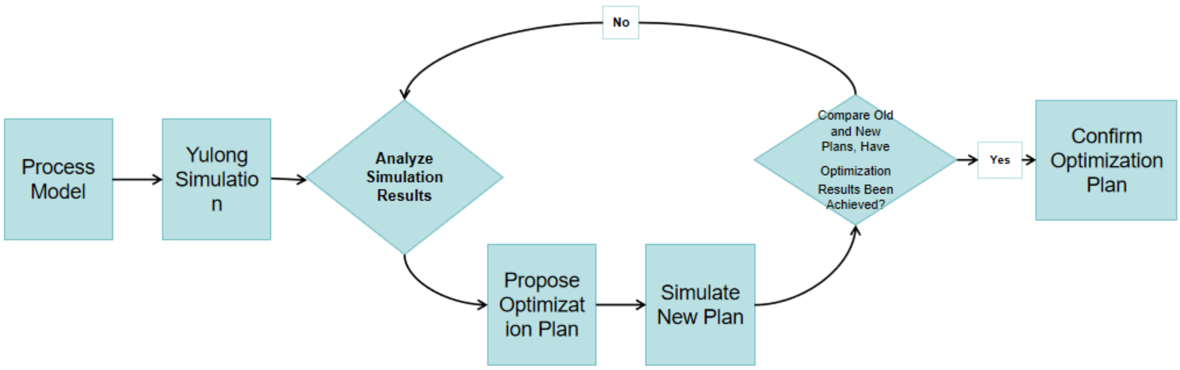

Figure 3. ProcessSimulation Diagram

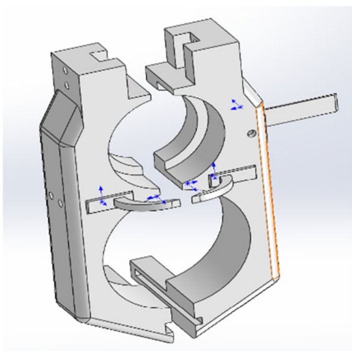

Figure 4. 3D Model of the Fixture

③ Virtual-Actual Practice Stage: Students import the optimized fixture into the Intelligent Manufacturing Digital Technology Comprehensive Application Unit (achieving virtual-real data synchronization via data interface, see Figure 5), observe whether the fixture meets design requirements, transmit data back to the virtual model, analyze "virtual-actual deviations," and correct model parameters.

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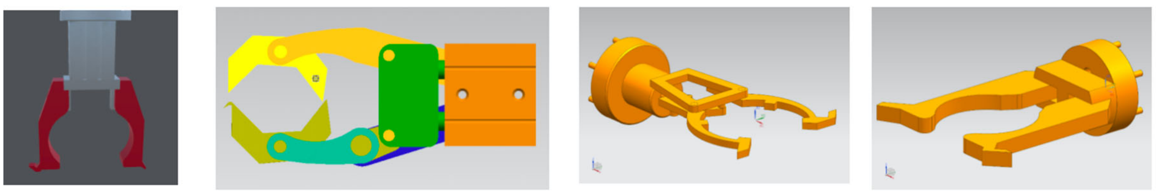

Figure 5. Importing the Fixture into the Comprehensive Application Unit

④ Summary and Iteration Stage: Groups report on the issues and solutions encountered throughout the entire "virtual simulation - physical processing (3D printing, see Figure 6)" process.

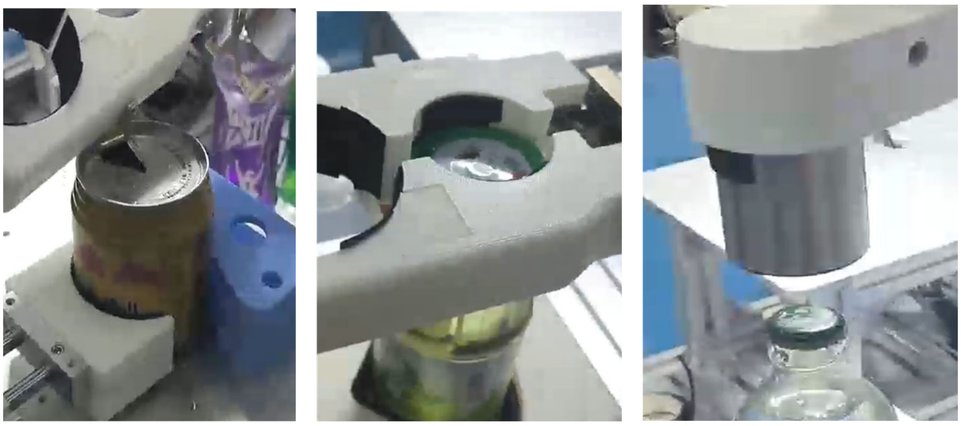

Figure 6. 3D Printed Fixture Entity</center>

3. Results and Analysis

3.1. Improvement in Learning Outcomes

With the introduction of AI + digital twin technology, students can repeatedly practice process design and simulation operations in a virtual environment, significantly enhancing their understanding of complex processes. In the fixture design project, students successfully identified and eliminated multiple design interference issues during the virtual pre-simulation stage, lowering the error rate in physical machining.

3.2. Effectiveness of Teaching Reform

The online-offline blended teaching mode improves learning flexibility and resource accessibility. Students have round-the-clock access to instructional videos, electronic textbooks and virtual simulation experiments, which significantly enhances their self-directed learning ability. The implementation of flipped classrooms boosts classroom interaction and student engagement. Group collaboration and presentation tasks cultivate students' communication, expression and teamwork skills.

3.3. Cultivation of Practical Ability and Innovation Capability

Students gradually develop systematic process design thinking from basic knowledge learning to practical projects. In the robot fixture optimization design project, students can conduct virtual verification with digital twin technology, demonstrating solid engineering practical capabilities.

3.4. Improvement of the Teaching Evaluation System

An evaluation system featuring "traceable learning processes and quantifiable competencies" has been established based on AI and digital twin technologies. The teaching platform automatically records students' operation data, scheme adjustment records and final achievements generated in virtual simulations, providing teachers with precise feedback on students' learning status.

4. Conclusion

This paper addresses the issues of insufficient practical resources and weak self-directed learning ability of students in the course Machining Technology and Equipment, this paper proposes a curriculum reform approach based on AI and digital twin technologies. Through teaching design innovations such as teaching mode optimization and curriculum system reconstruction, the teaching model has transformed from "teacher-centered lecturing with passive student reception" to an open integrated teaching framework of "teaching, learning, practice and evaluation". Practical results show that this approach effectively improves students' engineering practical capabilities, innovative awareness and teamwork skills, and offers a referable practical path for the teaching reform of mechanical specialty courses under the background of artificial intelligence.

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References

[1] Wang, X. K. (2019). *Mechanical manufacturing technology*. China Machine Press.

[2] Luo, H. Q. (2023). Teaching reform of mechanical manufacturing technology course under the background of engineering education professional accreditation. *China Modern Educational Equipment*, (17), 83–85.

[3] Shan, R. X., Yuan, C. J., & Qu, Y. J. (2026). Exploration and practice of industry-education integration curriculum system in the context of digital transformation: Taking the course "Mechanical Manufacturing Technology" as an example. *Industry and Information Technology Education*, (3), 54–58,64.

[4] Hu, J. B., & Wang, F. (2026). Construction and application of teaching resources for the mechanical manufacturing technology course based on knowledge graphs. *Modern Information Technology*, (10), 140–145.

[5] Bai, Z. X., Shen, M. X., Li, Q. P., Zhou, H. L., & Xiao, Y. L. (2025). Facilitating machine manufacturing technology course development through virtual reality technology. *Theoretical Research and Practice of Innovation and Entrepreneurship*, (12), 170–172.

[6] Zhang, Q. Z., Zhang, H. F., Yang, B. H., Liu, Y., Zhao, J. F., & Liao, J. A. (2025). Teaching design and exploration of mechanical manufacturing technology course based on project teaching. *Agricultural Technology & Equipment*, (2), 89–91,95.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202607_9(7).0002

[7] Zhang, J. N., Liang, H. C., He, H. K., Zhao, Y., Lyu, J. Q., & Pang, X. L. (2025). Research on teaching reform of "Mechanical Manufacturing Technology" course based on new engineering disciplines. *China Southern Agricultural Machinery*, 56(10), 179–182.

[8] Zheng, L. J., & Zhou, L. J. (2025). Analysis of the cultivation path for application-oriented mechanical talents under the background of emerging engineering education. *Sichuan Labor Security*, (4), 184–185.