Project-based Teaching Practice Based on OBE-CDIO Model: a Case Study of CNC Machining and Programming Course

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Abstract. As industry demands shift toward skilled professionals, education must align with industrial standards to cultivate talent that truly meets market needs. This paper addresses challenges in CNC Machining and Programming course by implementing the OBE-CDIO project-based learning framework. Through progressive instructional design and hands-on practice, it effectively resolves issues like fragmented knowledge systems and disconnects between theory and real-world application in traditional teaching methods. The approach significantly enhances students' practical skills and innovative capabilities, establishing a new pathway for developing high-quality CNC professionals who meet industry needs.

Keywords: OBE-CDIO; Project-based teaching; CNC machining and programming

1 Introduction

With the rapid advancement of artificial intelligence technology and the ongoing implementation of the "Made in China 2025" strategy, industry demands for CNC professionals have intensified, placing greater emphasis on practical application skills and digital innovation capabilities[1]. The CNC Machining and Programming course is a highly practical course for Mechanical and Electronic Engineering majors, aiming to cultivate students' abilities in CNC process analysis, programming, and machining practice while enhancing their hands-on skills and problem-solving competencies.

Jin X. etc.[2] innovatively integrated the OBE and BOPPPS teaching models for the course "CNC Programming and Part Machining," constructing a three-stage, six-loop teaching structure that significantly improved students' overall performance and classroom engagement. Lian C.Y.[3] conducted project-based teaching research using the CDIO model in CNC technology courses. By implementing a three-tier project structure, they achieved organic integration of knowledge points, significantly improving student skill examination pass rates. Geng J.H.etc.[4] validated the effectiveness of the OBE-CDIO blended teaching model in engineering drawing courses. Through

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implementing a reform pathway of "goal-driven, project-driven, and multi-dimensional evaluation," they enhanced students' digital design capabilities.

Addressing shortcomings in prior research, this paper takes the applied undergraduate course "CNC Machining Programming" as a case study. It deeply integrates OBE with CDIO, aligns with industry demands, and adopts a learning outcomes-oriented approach. The four critical stages of product development and operation—conceptualization, design, implementation, and application—are incorporated into instructional design. Competency assessment metrics are closely linked to course objectives to implement project-based teaching.

2 Current State of CNC Machining and Programming Instruction

2.1 Students' Understanding Remains Fragmented, Lacking Systematic Integration

Through university-level "vitality classroom" initiatives and the introduction of Learning Pass online courses, the program has largely enhanced student engagement and interactivity[5]. However, amid rapid advancements in artificial intelligence and the technological revolution and industrial transformation within the smart manufacturing sector, the course demands heightened practicality and innovation. Teaching reforms must accelerate to align instructional content with industry development. However, during instruction, each course operates in isolation. After mastering knowledge points in individual courses, students often cannot integrate them independently or comprehend the product design and manufacturing process. Knowledge points fail to form a coherent system, preventing comprehensive understanding.

2.2 Overemphasis on Knowledge Point Explanation, with Theory-Practice Integration Remaining Unrealized

CNC machining programming is a highly practical discipline. Teaching often sees theory and practice operating in isolation: theoretical instruction relies on textbooks, while practical training focuses on certification exams. Though theoretically aligned, their case studies and projects frequently diverge. This creates barriers for students with weaker foundations, dampening their enthusiasm and engagement in class. Instructors still need to spend a lot of time to explain the knowledge in the classroom, and the students' acceptance is uneven. The interaction between teachers and students and between students is mainly reflected in the simple listing of knowledge, and the learning effect of students is not satisfactory.

2.3 Lack of Industry-Aligned Practical Projects in Teaching

Due to the complexity of real-world corporate projects, it is challenging to ensure comprehensive coverage of all knowledge points when decomposing teaching project tasks. Consequently, most projects used in teaching practice remain based on simple adjustments or adaptations of traditional case studies and exercises. This makes projects resemble straightforward applications of existing knowledge rather than substantive, task-oriented projects, diminishing their authenticity. As a result, students lack sufficient understanding of the technical requirements in actual work and struggle to integrate their knowledge with real-world application scenarios.

3 The Essence of Project-Based Teaching Models Grounded in OBE-CDIO Principles

The OBE (Outcome-Based Education) teaching philosophy, which emphasizes that the purpose and standard of teaching lie in the learning outcomes students ultimately achieve, adopts a student-centered approach. It involves designing the teaching process backward from learning outcomes and places significant emphasis on formative assessment[6].

CDIO (Conceive-Design-Implement-Operate) is an engineering education model closely integrated with engineering practice. It uses projects as a vehicle to guide students in active learning, employing flexible classroom teaching modes to achieve integrated cultivation of knowledge, skills, and competencies[7].

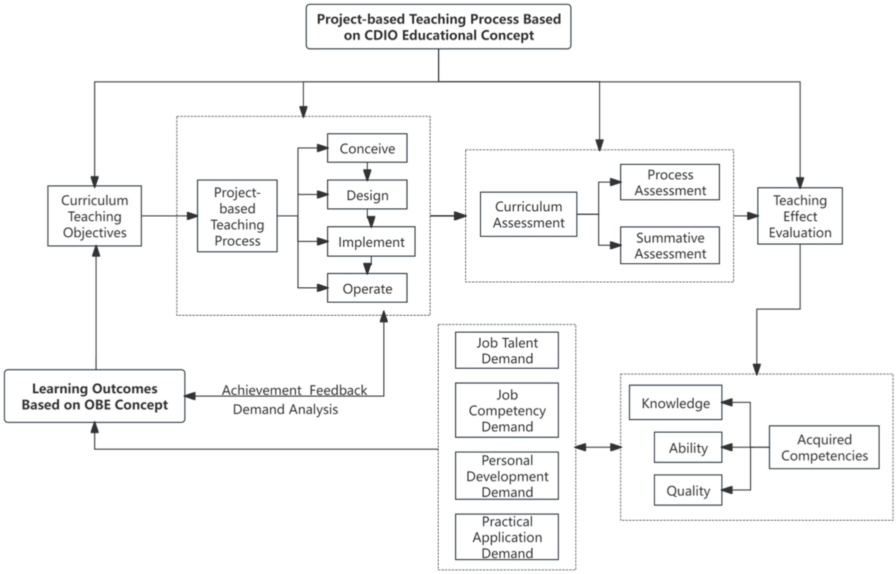

Fig. 1. Design Framework for OBE-CDIO Project-Based Teaching Model.

The design approach for project-based teaching grounded in OBE-CDIO principles is illustrated in Figure 1. This methodology begins with corporate talent requirements, aligns with job competency demands, integrates practical course applications and individual skill development, and designs learning outcomes consistent with OBE principles. It then adjusts instructional objectives, reorganizes teaching content, and designs project-based teaching processes. This process adheres to CDIO's four stages—"Conception-Design-Implementation-Operation", and implements progressively structured project modules within the course. Following OBE principles, it emphasizes process assessment and enables student-driven evaluation of teaching effectiveness, ultimately aligning with the "knowledge-skills-qualities" requirements set in the course objectives.

This outcomes-driven approach integrates engineering design thinking throughout course instruction and every practical project, enabling students to systematically grasp the engineering design process and better connect theory with practice. The four key design phases of each project—C-D-I-O, are embedded in every project, forming a fully closed-loop project-based teaching cycle.

4 Teaching Design and Practice of CNC Programming Under the OBE-CDIO Framework

4.1 Progressive Project-Based Instructional Design

Guided by OBE-CDIO principles, the curriculum first integrates industry job competency standards with practical CNC machining needs to define learning outcomes, ensuring students master core CNC programming and machining skills. Project-driven tasks centered on typical part fabrication guide students through the entire workflow—from drawing analysis and process planning to program writing and machine operation. Emphasis is placed on teamwork and engineering practice, enabling students to enhance real-world problem-solving abilities through "learning by doing." The course employs a multi-dimensional assessment approach, combining process performance with outcome quality to provide comprehensive feedback on student learning achievements, ensuring alignment between teaching objectives and industry demands.

The project-based teaching framework implemented in this course is illustrated in Figure 2, which decomposes course content into three progressive tiers: foundational, advanced and application.

In practice, the foundational knowledge layer is further divided into three major projects: programming fundamentals, CNC lathe programming, and CNC milling machine/machining center programming. Each major project comprises several sub-projects, integrating key knowledge points into each sub-project. The instructional design and implementation of each sub-project follow the four key phases of CDIO (Conception-Design-Implementation-Operation), embedding fundamental engineering design principles throughout the teaching process.The Advanced Layer builds upon the foundational layer, focusing primarily on simulated manual programming practice and automated programming. The application layer serves as the practical training phase, conducted in the CNC machining workshop. It focuses on CNC part processing using lathes and milling machines.

Using milling parts as an example (see Figure 3), the foundational level covers reading part drawings, developing programming processes, and writing milling programs. The advanced level involves virtual software simulation processing and operation to validate process and program effectiveness. The application level completes machine operation and processing, enabling students to authentically experience the entire journey from part design through manufacturing to finished product, thereby strengthening practical connections.

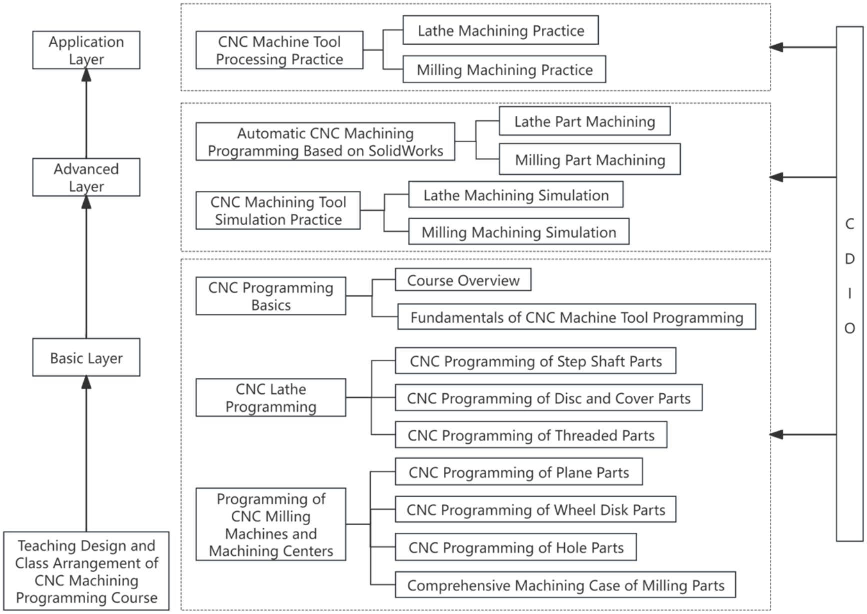

Fig. 2. CDIO Project-Based Teaching System for CNC Machining Programming.

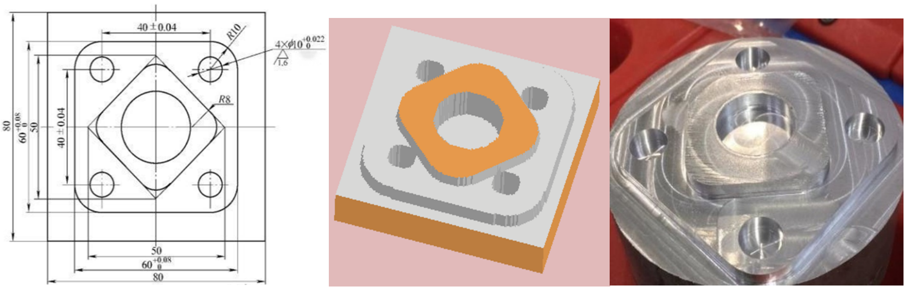

Fig. 3. Project-Based Teaching Practice for Milling Machine: Foundation-Intermediate-Application Levels.

4.2 Progressive Project-Based Teaching Practice

The CDIO teaching model, which uses projects as its vehicle, must be implemented through a complete "project"—a practical teaching activity aimed at producing a specific product. The project should be linked to the teaching content and relevant to enterprise production activities. Milling operations primarily involve parts combining machined planes and holes, while turning operations focus on threaded shaft components. Taking the machining of turned parts as an example, the implementation process of the CDIO teaching model is illustrated in Figure 4.

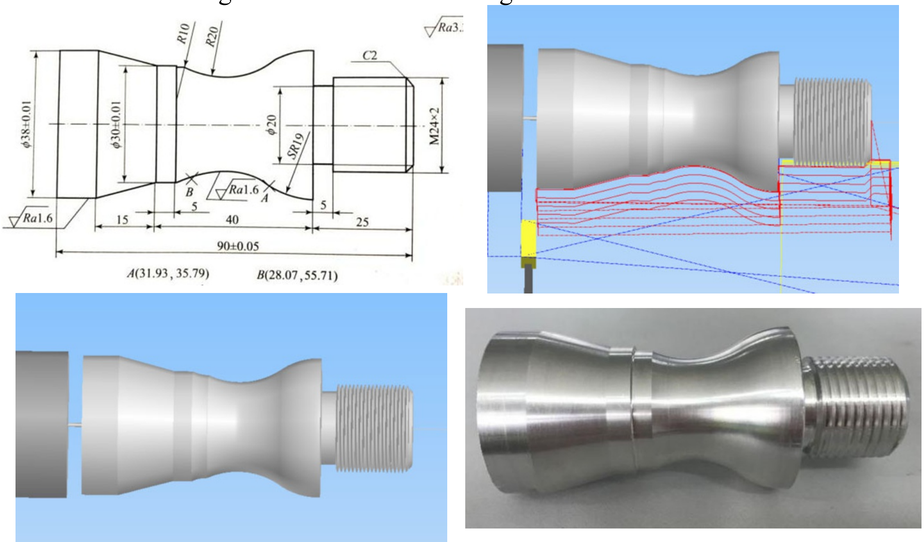

Fig. 4. Lathe C-D-I-O Project-Based Teaching Practice.

Project Conception (C) Phase: First, based on project requirements, key knowledge points, and instructional objectives, identify suitable turning components for practical application. Analyze and compare options considering material properties, machining geometries, and process specifications. Following thorough group discussion, make preliminary selections for materials, equipment, and process plans. This cultivates students' abilities in self-directed learning, exploration, and innovation. During this process, vigorous discussions among team members stimulate collective brainstorming and collaborative spirit. Under instructor guidance, students conceptualize machining processes, fostering values of mutual respect, knowledge sharing, and teamwork.

Project Design (D) Phase: Under instructor guidance, teams develop step-by-step implementation plans aligned with group objectives and teaching goals. They design and refine machining processes, programming strategies, and code development while mastering essential foundational knowledge, programming skills, and software operation. This phase cultivates meticulous, rigorous, and conscientious work habits through "careful cultivation."

Project Implementation (I) Phase: This phase involves optimizing the refined process flow, workflow, and programming solutions. Teachers guide students in using simulation software like Ulong and Swo to simulate machining routes, test process parameters, and experience the enjoyment of manual programming and automated machining. Students also utilize data communication interfaces to transfer programs between machine tools and computers. This phase cultivates students' ability to integrate theory with practice and solve real-world problems.

Project Application (O) Phase: Under safe conditions, this phase completes machining of parts and summarizes the entire project process, developing students' comprehensive engineering systems thinking.

4.3 Evaluation Feedback for the OBE-CDIO-Based Teaching Model

The OBE-CDIO project-based model, grounded in talent demand, employs a diversified assessment system emphasizing process evaluation and highlighting student learning outcomes[8].

Process assessments—including chapter task points, chapter quizzes, and online exams—are completed via the Learning Pass platform. Assignments and classroom activities are jointly managed through the platform and by instructors, complementing each other. Process-based assessment of students' foundational knowledge is conducted through evaluations on the online platform and in offline classrooms. Summative assessment is implemented through CDIO major assignments, primarily evaluating the quality of project reports on process analysis and program development for turning and milling parts, as well as group defense presentations, simulation videos, and physical machining outcomes. This assessment combines peer evaluation and instructor evaluation to assess students' practical application skills and group collaboration abilities. Specific evaluation indicators are detailed in Table 1.

Table 1. Evaluation Framework for CNC Machining Programming Course.

Evaluation Method	Evaluation Subject	Evaluation Criteria
Formative Assessment (40%)	System Self-Assessment	Chapter task points and learning frequency (20%) chapter quizzes (15%)
	Instructor Evaluation	Classroom Activities (25%)
	System Self-Assessment	Online Exams (20%)
	Instructor Evaluation	Assignments (20%)
Summative Assessment (60%)	Instructor Evaluation (70%) Peer Assessment (30%)	CDIO Project-Based Assignments: Process Analysis 20%, Programming 20%, Group Presentation 20%, Project Report 20%, Simulation Video 10%, Physical Fabrication 10%

Effectiveness Evaluation of Project-Based Teaching Model Based on OBE-CDIO Principles The 2022 cohort adopted this teaching model, while the 2020 cohort used the previous model. Both classes had comparable foundational knowledge and identical course hours. The percentage distribution of grades for both classes is shown in Table 2. After two years of implementation, overall course grades improved, with the pass rate rising by 17.5 percentage points and the pass rate continuing to increase. Following the course, students evaluated the teaching via an online platform, affirming the teaching model's effectiveness. This course will undergo continuous improvement to enhance students' knowledge acquisition and practical innovation capabilities.

Table 2. Student Grade Distribution.

Grade \ Percentage	Grade Distribution Percentage/%				
	<60 points	60–69	70–79	80–89	≥90 points
Class of 2020	0	14.8	44.6	27.1	13.5
Class of 2022	0	9.3	32.6	39.5	18.6

5 Conclusion

This paper applies the project-based model of OBE-CDIO to the CNC machining programming course. By using small projects as carriers, students engage in progressive practice from drawings to parts, achieving comprehensive enhancement in professional knowledge integration, innovative thinking, and practical operational skills. Another advantage of this teaching model is its industry integration capability, allowing flexible replacement of machined parts. It also forms a progressive system with preceding and subsequent courses, enabling students to rapidly grasp product design and manufacturing processes while enhancing practical innovation skills.

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