Reconstruction of CNC Machining Teaching System from the Perspective of Industry Education Integration Course Design and Practical Ability Improvement Guided by Real Production Tasks in Enterprises

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ABSTRACT Current CNC machining teaching in vocational colleges often faces a "learning-doing separation" problem: curriculum content is disconnected from real enterprise production tasks, and students have difficulty completing process design, machining operation, and quality inspection for complex parts. To solve this problem, this study reconstructs a CNC machining teaching system from the perspective of industry-education integration. First, typical enterprise production tasks are extracted and decomposed into modular teaching projects in cooperation with key manufacturing enterprises. Second, a progressive curriculum system of "basic skills-specialized training-comprehensive production" is developed to form a full-chain teaching process. Third, a dual-mentor mechanism and workshop-based management mode are introduced. Finally, a competency evaluation system is constructed using product qualification rate, process specification execution, time completion, and teamwork performance. Experimental results show that the experimental group achieves a first-pass yield of 94.5%, 18.3 percentage points higher than the control group. The job adaptation period is reduced by 9 days, and the conversion rate of process improvement suggestions reaches 76.5%, verifying the practical value of the reconstructed system.

INDEX TERMS CNC machining, industry-education integration, real production tasks, practical ability, vocational education

I. INTRODUCTION

At present, CNC machining teaching in vocational colleges are usually arranged according to the main line of "knowledge logic", and the order is "machine tool cognition - basic instructions - simple part programming - simulation". The content of practical training usually uses standardized "simulation parts" or "teaching parts" (such as cuboids, stepped shafts, etc.). They are totally different from the real parts with curved surfaces, multi-axis links and strict process parameters in enterprise production (such as new energy vehicle motor housings, aerospace thin-walled parts, etc.) [1,2]. Students can finish the basic operation, but they demonstrate a deficiency in comprehensive competencies, specifically in systematic process analysis, tool path optimization, machining parameter calibration, and autonomous quality inspection. There is a "skill mismatch" between the supply side of vocational college talent training and the demand side of enterprise. They need 3 to 6 months of retraining after graduation before they can work alone [3]. How to break the "learning and doing separation" dilemma and connect teaching and production in a accurate way has become a key issue that needs to be solved urgently in the field of CNC machining vocational education.

Domestic scholars have conducted extensive research on CNC machining teaching reform, mainly focusing on two directions: curriculum system construction and practical training model innovation. For example, Lu explored the application path of information technology in CNC machining teaching from the perspective of smart classroom [4]; Rao analyzed the optimization of CNC course teaching organization based on the concept of work-integrated learning [5]; Jiang et al. verified the promotion effect of simulation and practical operation integration on teaching effect through virtual and real training mode [6]; Lan et al.

expanded the teaching system of CNC machining course from the perspective of ideological and political education [7]. In the context of industry-education integration, Ouyang proposed the idea of intelligent manufacturing-oriented curriculum reform and emphasized the importance of enterprise participation [8]; Cai further constructed a multi-axis machining integrated teaching model and strengthened the cultivation of complex machining capabilities [9]; Zhou and Zhu explored the optimization path of curriculum structure in the localization practice of dual system [10]; Mao et al. promoted the theory-practice integrated teaching reform with product orientation as the core [11]; Luo analyzed the implementation path of CNC machining teaching reform from the overall level of vocational colleges [12].

However, the aforementioned studies largely remain at the formal level of industry-university cooperation, failing to fully transform real-world production tasks into teaching projects. They lack a systematic integration of production elements such as process specifications, time quotas, and quality standards, resulting in a gap between course content and actual job requirements. Current research in solving the "learning-doing separation" problem adopts superficial methods such as extending practical training time and adding company visits, or uses only individual part examples for supplementing teaching, which cannot form a task-oriented system from teaching to practice. Although the above methods can enhance students' practical operation ability to some extent, it is impossible to improve students' ability to coordinate the process, quality self-inspection consciousness and job adaptation when encountering complex production tasks. Therefore, this paper takes "Curriculum Design and Practical Ability Training Oriented to Real-World Production Tasks" teaching reform scheme as the research object, uses realworld parts as the carrier of teaching, reconstructs the curriculum system, dual-mentors system and multidimensional evaluation method from the perspective of teaching links, and realizes the integrated cultivation of teaching and production.

This paper aims to solve the problem of "learning-doing separation" in CNC machining teaching and constructs a curriculum teaching system oriented to real-world production tasks. Firstly, it collaborates with first-class equipment manufacturing enterprises in the region to choose typical real-world production tasks and decomposes them into modular teaching projects. Secondly, it re-builds a new curriculum system of "basic skills - specialized training - comprehensive production" hierarchy three levels. Thirdly, it implements a mechanism for enterprise mentors to enter the school and real-world workshop management, and constructs a "dual mentor + job rotation system". Finally, it constructs a multi-dimensional competency evaluation system that prioritizes process specifications over time quotas to ensure the formation of standardized professional habits among students.

II. SELECTION AND PEDAGOGICAL APPLICATION OF REAL-WORLD ENTERPRISE PRODUCTION TASKS

To connect school teaching and enterprise production, this study invited cooperation from three wellperforming local equipment manufacturing enterprises (parts for automobiles, precision molds, structural components for aerospace, respectively). A list of typical parts was mined from the production plan of the last two years in these three enterprises. The selection of typical parts followed the following three principles: first, process integrity, i.e., selected parts should include basic processes such as turning, milling, drilling and threading; secondly, difficulty degree should meet the initial level of vocational college students. While the introductory phase excludes simultaneous five-axis linkage to match the students' initial cognitive load, the selection criteria prioritize parts that require 3+2 positional machining and complex four-axis indexing. This approach ensures students master the high-precision requirements of modern industrial components on the available three-axis and four-axis machining centers, providing a realistic bridge to advanced multiaxis manufacturing. Parts with ultra-precision (tolerance requirements of IT5 level and above) should also be excluded; finally, selected parts should not involve flammable and explosive materials.

However, considering the common sense requirements of modern CNC machining, tasks involving High-Pressure Cutting Fluids are specifically included. This ensures students are exposed to standard industry cooling systems essential for deep-hole drilling and high-speed milling, allowing them to manage actual workshop safety hazards they will inevitably face in professional environments. Based on this, the school and enterprises jointly selected 8 items from the initial 20 parts as teaching materials, including end caps for new energy vehicle motor housings, cavity parts with lateral dies, and multi-step shaft threaded parts. Each task was accompanied by the company's original process card, tool list, cutting parameter table, and quality inspection standards. To adapt it to the teaching scenario, we carried out three teaching-oriented transformations: First, we removed non-teaching content such as confidential part numbers and customer information, retaining only the core process logic; second, we appropriately relaxed the enterprise standard working hours according to the teaching pace, while retaining the time quota as a basis for student efficiency evaluation; third, we broke down the processing of each part into five sub-modules: "Process Analysis Card–Programming Code Segment–Simulation Verification Sheet–Processing Operation Card–Self-Inspection and Mutual Inspection Table," facilitating students' step-by-step mastery. The transformed teaching task package was jointly reviewed by enterprise technicians and school teachers to ensure that it reflected both real production requirements and conformed to teaching principles. The final eight teaching task case libraries provided a foundation for the implementation of this curriculum system.

III. RECONSTRUCTION OF A THREE-TIER PROGRESSIVE CURRICULUM SYSTEM: "BASIC SKILLS - SPECIALIZED TRAINING - COMPREHENSIVE"

This study reformed the curriculum system into the following three stages: "Basic Skills - Specialized Training - Comprehensive Production," and students can step by step attain the ability of whole process coordination by the following task sequence from simple to complex and single feature task to comprehensive feature task. The basic skills stage is scheduled from week 1 to week 8. The single feature tasks are selected as basic machining tasks, including stepped shaft external turning, planar contour milling, drilling and tapping. Each machining task is matched with 2 or 3 programming instructions and 2–3 operational points. The teaching organization adopts the form of "teacher demonstration - student imitation practice - group peer evaluation." The aim of this stage is to cultivate students' ability of basic CNC machine tool operation, tool setting and program input & debugging, and skill basis for following complex tasks.

The specialized training stage is scheduled from week 9 to week 16. The composite tasks including 2 or 3 process features are selected, such as multi-step shaft thread machining, three-axis surface milling, cavity machining with lateral slides and core-pulling mechanisms. The focus of teaching is changed from singleoperation to sequence of process and parameter matching. Students are required to finish a process analysis card after receiving an assignment and then can carry out the programming & simulation. The teachers will gradually reduce the direct instruction and let students determine the processing plan by themselves through group discussion. The regular feedback from industry technicians is also introduced to build students' sense of process standardization.

The comprehensive production stage is scheduled from week 17 to week 32. The complete batch order of parts (10 pieces per batch) from company is selected as task vehicle, including the whole process of material to finished product according to the time quota offered by company. The time of this stage is carried out in the form of "team system." The students can rotate in group and play the roles of programmer, operator & quality inspector. They will experience the enterprise production mode of rotating every 4 hours (halfday shifts). This adjustment ensures that students have sufficient time for complex CNC operations, including machine setup and tool-path verification, which typically exceed short intervals. This stage no longer sets the assessment items of individual skills, but utilize the batch product qualification rate, time quota adherence, and process specification compliance as the comprehensive assessment framework for the entire team. The enterprise will evaluate the quality according to the standard of enterprise, and let students experience the quality awareness and efficiency requirement of enterprise. The class time ratio for the three stages is approximately 2:3:5. As the stages progress, the teacher's guidance role gradually decreases, while students' autonomy and job adaptability gradually increase, forming a complete training path from skill mastery to job competence. A summary of the class time arrangement and key teaching points for the three stages is shown in Table 1.

IV. OPERATION OF THE DUAL-MENTOR COLLABORATION AND WORKSHOP-BASED REAL-SCENE MANAGEMENT MECHANISM

A teaching team composed of college faculty and enterprise technicians operates under a "dual-mentor system." College faculty primarily focus on explaining process theory, providing CAM software modeling and simulation guidance, and undertaking the main teaching tasks during the basic skills and specialized practical training phases. Enterprise technicians, on the other hand, emphasize machine tool operation standards, tool wear assessment, on-site safety, and 5S management. During the comprehensive production phase, they reside in the training workshop, participating in shift work alongside students. Both sides hold a joint lesson planning meeting weekly, adjusting task arrangements based on the teaching progress and actual enterprise production to ensure that the teaching content remains synchronized with the latest enterprise process standards.

The training workshop is realistically remolded to be similar to the actual enterprise production environment.The workshop is divided into raw material area,operation area,inspection area and finished product area according to the production workshop standard of the partner company. The raw material area, operation area, inspection area and finished product area are marked clearly.The width of aisle and area where placing materials and waste disposal are all followed the 5S regulations of the enterprise.In terms of equipment, we choose the same model of CNC lathe, three-axis machining center and four-axis machining center used by the company. The cutting tool and fixture are also chosen to be the same brand and same specification used by the company. Students can become familiar with the equipment and tool used at the working position before they go to school.

In terms of teaching organization, the comprehensive production stage adopts the "team system" mode. There are 6 students in each production team. There are 3 positions in each team: programmer,operator and quality inspector. They will change the working position every 4 hours to reflect a realistic production cycle where setup and debugging are integral to the task. This mode simulates the way of company's team works. The technician from the company is the team leader. He will give process briefing to the team, confirm first piece and do process inspection. The school teacher will act as the technical consultant. If the students have any problem on programming or process, they can ask the school teacher for help. After completing the whole process of making one batch, the company technician will do finished product inspection according to the quality inspection regulation of the company and record the working time achieved by the students. This is the basis of the stage

TABLE 1. Three-Tier Progressive Curriculum Structure: Basic-Specialized-Comprehensive

Stage	Teaching Weeks	Credit Hours	Percentage	Task Characteristics	Example Tasks	Instructor Guidance	Main Assessment Points
Basic Skills	1–8	48	25%	Single feature, 2–3 G-codes	Stepped shaft turning, planar contour milling	Demonstration → Imitation → Peer evaluation	Operational proficiency, tool setting accuracy
Specialized Training	9–16	48	25%	Composite with 2–3 process features	Multi-step shaft with thread, 3D surface milling	Group discussion, technician feedback	Process sequencing rationality, parameter matching
Comprehensive Production	17–32	96	50%	Full batch of parts (10 pcs/batch)	Batch machining of motor housing end cover	Team system, job rotation, technician as team leader	First-pass yield, process standardization & safety (Higher Weight), cycle time achievement, process compliance

grade of the students.

V. CONSTRUCTION OF A MULTI-DIMENSIONAL COMPETENCY EVALUATION SYSTEM BASED ON REAL COMPANY DATA

The evaluation system consists of four dimensions, with weightings consistent with the company's actual assessment standards for skilled workers. The first dimension is the product qualification rate, accounting for 40% of the total score. The first dimension is based on data measured by the company's quality inspectors using a coordinate measuring machine. The pass/fail status of each product is determined according to the tolerance requirements of the drawings, and the pass rate is calculated by batch. After each student completes a comprehensive production task, the company's technicians conduct on-site inspections and record the data to ensure the objectivity and authenticity of the evaluation. The second dimension is the process specification execution rate, accounting for 30% of the total score. In a vocational learning environment, professional methodology and safety habits are prioritized over raw speed to prevent "trial and error" learning. For this indicator, company technicians record violations on-site against the company's process card, including failure to operate in the correct process sequence, failure to replace tools as required, failure to perform safety confirmation, and failure to perform first-piece self-inspection. This indicator uses the company's standard working hours as a benchmark, comparing the student's actual processing time with the company's standard working hours. The calculation formula is (standard working hours / actual working hours) $\times$ 100%. Students must complete production tasks according to the company's time quota during the comprehensive production stage. Those exceeding the time quota by more than 20% will not score above the passing mark in this dimension. This design aims to guide students to develop an efficiency awareness and adapt to the company's production rhythm.

The third dimension is the process time completion rate, accounting for 20% of the total score. This indicator uses the company's standard working hours as a benchmark. While efficiency is a key industrial metric, its weight is adjusted in the curriculum to ensure students do not sacrifice standardized operational procedures for speed. Students exceeding the time quota by more than 20% will still see a significant impact on their score, guiding them to eventually adapt to the company's production rhythm. Fourth dimension is the team work performance (worth 10% of the total score). This indicator is evaluated by technician based on overall observation of team rotation and continuity of work performance as well as students' communication and cooperation, job hand over and mutual assistance among team members. For each batch of work, after completion by the team, the technician will let the team members to evaluate each other on their performance and the final score is based on this.

VI. CORE EVALUATION INDICATORS FOR CURRICULUM REFORM EFFECTIVENESS

A. COMPARATIVE EXPERIMENT OF TRADITIONAL TEACHING AND REAL-WORLD TASK-ORIENTED TEACHING

Two classes of CNC technology majors were chosen. The experimental class (n=40) implemented the real task driven curriculum system, and the control class (n=40) implemented the traditional teaching mode. To ensure the validity of the comparative results, both groups were strictly equalized in terms of total credit hours (192 hours), machine access time, and teacher-to-student ratios. This control ensures that the observed 18.3 percentage point improvement in yield is attributed to the pedagogical design rather than variations in hands-on duration or resources. This study was approved by the Ethics Committee of Shanghai Business and Information College, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form.After two semesters of instruction, the two classes of students completed the machining task of a real part from an enterprise independently. The real part from the enterprise was "new energy vehicle motor housing end cover" (processes: drilling, boring, milling, threading, etc.).The quality inspectors and technicians from the enterprise blindly inspected and recorded the first-pass yield, single-piece machining time and the number of process violations., as shown in Table 2:

The experimental group achieved a first-pass yield of

TABLE 2. Comparative Evaluation of Traditional Teaching and Real-Task-Oriented Teaching

Indicator	Experimental Group (n=40)	Control Group (n=40)
First-pass yield of parts (%)	94.5	76.2
Average machining time per part (min)	38.6	52.3
Average number of process violations per person	1.2	3.8

94.5%, compared to 76.2% in the control group, with the former exceeding the latter by 18.3 percentage points. The average processing time per piece was 38.6 minutes in the experimental group, a reduction of 13.7 minutes compared to the control group's 52.3 minutes, representing a 26.2% increase in efficiency. The average number of process violations per student was 1.2 in the experimental group and 3.8 in the control group, a reduction of 2.6 violations. These results indicate that the real-task-oriented curriculum significantly improves students' processing quality and efficiency, while enhancing process standardization, effectively addressing the problem of the separation of learning and doing in traditional teaching.

B. PRE- AND POST-ADAPTATION PERIOD TRACKING EXPERIMENT FOR STUDENTS

Forty students were allocated to the experimental group and 40 students to the control group. They were sent to the cooperating company for on-the-job training. Starting from the 4th day of the internship, the students in the experimental group worked independently on the production job. Every day, the processing pass rate and working hours were recorded by the company technicians. The criterion for independent on-the-job training qualification was "5 consecutive products with a pass rate of 100% and the working hours of a single product not exceeding 120% of the company's standard working hours". The number of days it took each student to reach this criterion were recorded.

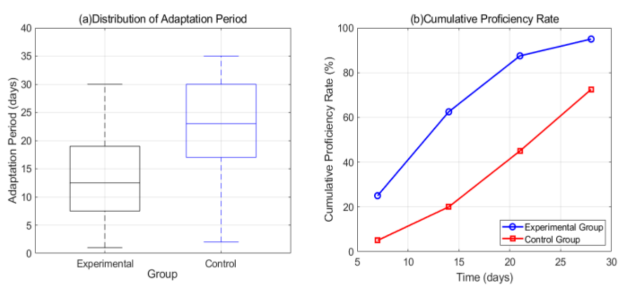

FIGURE 1. Pre- and Post-Adaptation Period Tracking Evaluation

Figures 1 (a-b) show the box plot distribution of the students' on-the-job adaptation period and the curves of cumulative qualification rate over time. The tracking experiment results showed that the average on-the-job adaptation period for the experimental group was 13.3 days, while it was 22.3 days for the control group, a reduction of 9 days. The cumulative qualification rates for the experimental group on the 7th, 14th, 21st, and 28th days of the internship were 25%, 62.5%, 87.5%, and 95%, respectively, while the corresponding rates for the control group were 5%, 20%, 45%, and 72.5%. Independent samples t-test showed a highly significant difference between the two groups ($p < 0.001$). The above data demonstrates that the real-task-oriented curriculum significantly shortens students' job adaptation period, enabling them to reach the standards for independent employment in enterprises more quickly.

C. CASE TRANSFORMATION AND TRANSFER EXPERIMENT ON THE CONTRIBUTION OF INDUSTRY-EDUCATION INTEGRATION

Forty students were assigned to the experimental group and divided into eight groups. In the integrated production practice, each group was expected to make at least one suggestion for process improvement that was accepted and implemented by the enterprise technicians and process engineers. In addition, an entirely new part was offered by an enterprise not involved in the course collaboration. The process design and programming simulation of the part had to be completed independently by students in both the experimental group and the control group. The technical supervisors from the three collaborating enterprises scored the answers based on the enterprise review standards.

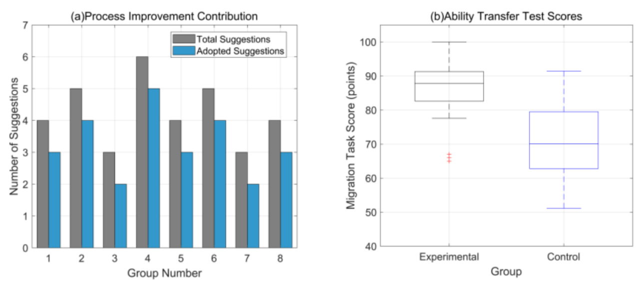

FIGURE 2. Case Transformation and Transfer Evaluation of the Contribution of Industry-Education Integration

Figures 2 (a-b) show the comparison of the proposal and adoption of process improvement suggestions in each group, and the box plot comparison of the transfer task scores between the experimental and control groups.

The results of the industry-education integration contribution experiment show that students proposed a total of 34 process improvement suggestions, of which 26 were adopted by the enterprises, achieving an effective conversion rate of 76.5%. In the transferability test, the average score of the experimental group was 86.4 points, while that of the control group was 70.9 points. The pass rate of the experimental group was 92.5%, while that of the control group was 55.0%, with a highly significant difference between the two groups ($p < 0.001$). These data indicate that the real-task-oriented curriculum effectively stimulated students' awareness of technological innovation, and their solution design capabilities could be successfully transferred to new production tasks.

VII. CONCLUSION

Taking real production tasks as the carrier, this study revised the CNC machining teaching system, and formed the reform scheme of "task deconstruction–system reconstruction–dual-mentor cooperation–production line evaluation". The experimental results show that the reform scheme obtained good effects in improving students' processing quality and efficiency, job duration time, technological innovation ability, etc., and solved the problem of "separation of learning and doing" in traditional teaching. This study only carried out the pilot in one school, and the sample size is small. Despite the limited participant pool, the high significance of the results ($p < 0.001$) is substantiated by the high degree of intra-group consistency and the substantial effect size observed across multiple performance indicators, which minimizes the likelihood of random variance. In addition, teachers and enterprise technicians need to work together at a high level. In the future, we will expand the pilot schools, and extend the follow-up time to verify the reform effect.

AUTHOR CONTRIBUTIONS

Mingjuan Ma designed, collected and analyzed the data, and drafted the manuscript. Mingjuan Ma conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Mingjuan Ma participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

HUMAN RESEARCH SUBJECTS

This study was approved by the Ethics Committee of Shanghai Business and Information College, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form.

FUNDING

This research received no external funding.

ACKNOWLEDGEMENTS

Not applicable.

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