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A Preliminary Study on the Progressive-Driven Metalworking Practice Teaching Mode Combining Virtual and Real Training—Taking CNC Lathe Training as an Example

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Abstract: Taking CNC lathe training in metalworking practice as a research object, this paper addresses the prominent problems of high equipment investment, high practical operation risks, and insufficient hierarchical teaching, and explores a progressive-driven practical teaching mode integrating virtual and real training. The progressive framework of "virtual simulation teaching + physical operation + CAXA CAM CNC lathe programming + actual machining" realizes the organic integration of online and offline teaching. The acquisition of CNC lathe proficiency is divided into four progressive levels: overall perception layer, skill practice layer, comprehensive application layer, and capability leap layer. A compound teaching form of self-study + collective lecture + group rotation + individual tutoring is adopted to ensure students fully master all knowledge points of CNC lathe operation. The results show that this mode can significantly improve students' comprehensive CNC lathe operation ability. It can deliver differentiated teaching coverage for students with varied foundations, consolidate their theoretical foundation, and strengthen their professional literacy.

Keywords: Combination of virtual and real training; Metalworking practice; Teaching mode; CNC lathe

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1. Introduction

Metalworking practice is a vital practical link in engineering education, serving as a bridge for students to connect theoretical knowledge with actual production. Its core status has become more prominent under the construction of emerging engineering disciplines [1]. As a typical representative of advanced manufacturing technology, CNC lathes integrate precision transmission, computer control, and precision cutting, featuring high machining accuracy, high efficiency, and stable performance. They have been widely applied in manufacturing, aerospace, shipbuilding, and other industries. CNC lathe training is a practical platform for students to master modern programming methods and establish digital machining thinking, and its teaching quality directly determines students' cognitive depth and skill level of modern manufacturing technology.

Nevertheless, current CNC lathe training in universities faces multiple challenges. Firstly, CNC lathe equipment requires huge investment and high maintenance costs, resulting in a severe shortage of machine tools per student. Secondly, new learners are exposed to safety hazards during operation; improper manipulation may lead to tool collision and workpiece scrapping, which wastes training time and limits students' exploration space. Moreover, traditional training adopts a single teaching flow of "lecture – demonstration – imitation," lacking hierarchical design. Students receive knowledge passively, which hardly stimulates their innovation and problem-solving thinking. With the continuous improvement of virtual simulation technology, its introduction into practical teaching can bring multiple advantages. On the one hand, students can get familiar with equipment, programming codes, and tool setting, and conduct simulation verification without equipment loss or safety risks. On the other hand, the simulation process intuitively displays the dynamic visual effect of each code, as well as tool paths and workpiece cutting processes. In addition, students can lower trial-and-error costs, cultivate interest through the cycle of "trial and error – learning – optimization," and transform from passive participants to active simulators, laying a solid foundation for subsequent physical operation [2].

Based on the above considerations, this paper takes CNC lathe training as the entry point to explore a progressive-driven practical teaching mode combining virtual and real training. The integration of virtual simulation, theoretical lectures, and physical operation can improve the teaching effect of metalworking practice and provide valuable references for practical teaching reform.

2. Curriculum and student analysis

2.1. Curriculum overview

This course is designed for engineering students in the second semester of their freshman year or the first semester of their sophomore year. At this stage, students have finished studying Mechanical Drawing and Advanced Mathematics, laying a solid knowledge foundation for subsequent mechanical drawing interpretation, CNC programming, and machining operations. Referencing the competition standards for the CNC Turning event of vocational skills competitions and incorporating research findings on talent demands from equipment manufacturing enterprises, the course defines its core competency objective: enabling students to independently complete drawing creation, process analysis, CNC programming, simulation verification, and physical machining of moderately complex rotary parts, as well as equipping them with the awareness and capability for quality inspection and process optimization. For pre-class simulated practice, students use the open virtual simulation experiment teaching management platform accessible via the one-stop service hall on the university's official website. On-site practical training is carried out on existing CK6150 CNC lathes, covering component recognition, tool setting, familiarization with control panel functions, and machining with self-written simple programs. Students generate machining programs for finished drawings through CAXA CAM Turning installed on computers, transfer the exported CNC programs to the CNC lathes, and machine parts on actual equipment. Qualified inspected parts constitute complete practical training deliverables [3].

2.2. Student analysis

Students taking this course have mastered the reading of part drawings, selection of tolerance fits, and use of basic measuring tools. Due to their engineering majors, they hold clear learning objectives and strong learning initiative. Growing up in the digital era, they naturally adapt to various online learning platforms and mobile software. However, most students are accustomed to individual learning and lack team cooperation awareness during practical operation; some students passively accept knowledge and have weak active learning ability. Besides, students have insufficient safety awareness, lacking intuitive perception of injuries caused by high-speed rotating spindles, which requires repeated emphasis during teaching.

3. Teaching design

3.1. Ladder-step progressive internship content

Traditional metalworking practice courses adopt a one-size-fits-all teaching model. Aligned with students' cognitive rules, this course divides the learning process of CNC turning technology into four progressive stages. The first stage is the holistic perception stage: students get familiar with the basic structure, operation panel, and safety regulations of CNC lathes via a virtual simulation platform, and finish simple manual programming and simulated cutting tasks. The second stage is the skill practice stage: students manually learn modules including tool setting, assembly, external cylindrical cutting, and end face cutting to cultivate operational proficiency, integrating theories, simulation exercises, and hands-on practice. The third stage is the comprehensive application stage: students can independently complete the full workflow of process planning, programming, and practical machining for rotary parts with multiple combined features. The fourth stage is the capability leap stage: after learning CAXA CAM for CNC turning, students are guided to implement software-based programming, complete drawing sketching, tool path planning, cutting parameter configuration, and simulated cutting independently, generate program codes, and proceed with actual machining.

3.2. Toolbox-style internship resource allocation

Drawing on the toolbox concept, the course matches diversified internship resources to meet the demands of students with varied learning foundations. Abundant learning resources are provided, including the online simulation module of the open virtual simulation experimental teaching management platform, CAXA CAM CNC lathe programming software, physical CNC lathes, micro-lesson videos, programming handbooks, and process parameter lookup tables.

Diversified organizational forms are adopted: self-study + collective lecture + group rotation + individual tutoring. Before class, students use the simulation module to strengthen cognitive reserve. In class, teachers deliver collective lectures on common knowledge, then guide students to conduct physical tool setting and simple cutting in groups of 3 to 4 to finish assigned programming tasks with CAXA CAM. In spare time, students can machine self-interested workpieces under teachers' guidance according to their own learning progress.

3.3. Clock-style integration of curriculum ideology and politics

Ideological and political theories incorporated into practical training teaching must never be applied in a forced and rigid manner; instead, the integration should be as precise and well-timed as a clock, natural and appropriate. First, before the skill practice phase, this course plays videos of typical cases covering equipment damage and personal injuries caused by operational errors, while explaining standard safety operation rules to guide students in building safety awareness and internalizing standardized operation as conscious personal conduct. Second, prior to the comprehensive application phase, inspiring stories of national master craftsmen who devote themselves to researching NC machining technology and pursuing ultimate precision of mechanical parts are introduced, alongside physical displays of previous works to foster students' emotional recognition of the pursuit of excellence and the craftsman spirit. Before the competency advancement phase, students are encouraged to form groups freely and collaborate to complete the full machining workflow of parts from blueprint design to finished products. They are required to hold thorough discussions for every step of the workflow, assist one another during practical operations, and conduct error analyses in an open and candid manner [4–5].

4. Teaching implementation

4.1. Pre-class stage

Students log into the one-stop service hall on the school's official website and access the virtual simulation teaching and resource management platform to enter the CNC lathe simulation module. The platform contains dozens of virtual simulation experiments, especially a simulated CNC lathe operating environment. Students can master basic knowledge including operation panel introduction, power-on and power-off procedures, emergency stop buttons, and simple codes via virtual operation. A concluding test and safety operation examination are set on the platform to consolidate students' basic knowledge and safety awareness.

4.2. In-class stage

First, intensive theoretical lectures are delivered in the CNC lathe training area of the engineering training center. Teachers systematically explain CNC lathe composition, working principles, coordinate systems, tool setting procedures, code definitions, code formats, and programming for simple parts. Then teachers demonstrate physical operations including tool setting, program input and dry running, as well as the machining of stepped shafts. After demonstration, students independently finish practical tasks under guidance. Every student must master tool setting, as well as programming and operation for outer circle turning, end face turning, grooving, and thread cutting. Each student is required to practice repeatedly to grasp basic operational skills.

After students master manual programming, CAXA CAM CNC lathe teaching is launched. Teachers demonstrate the full workflow from part modeling, blank definition, machining scheme selection, tool and cutting parameter setting, to tool path generation and post-processing. Students are assigned part machining tasks and required to independently complete 3D modeling, machining parameter configuration, and tool path simulation. After successful simulation, CNC codes are generated and imported into lathes for dry running and physical machining under teachers' confirmation. After machining, students measure workpiece sizes with vernier calipers and micrometers, and analyze errors against engineering drawings.

4.3. Post-class stage

Teaching evaluation and summary reflection are the core work after class. Students score and comment on course content, teaching arrangement, organizational forms, teacher tutoring, and simulation platform experience via the school's teaching evaluation system to provide improvement references. Teachers conduct comprehensive grading based on attendance, classroom performance, practical operation effects, workpiece quality, and training report completeness. Before the next round of teaching, teachers summarize experience, sort out teaching deficiencies, and continuously optimize teaching schemes.

5. Teaching effects

5.1. The ladder-step mode improves students' skill mastery

The ladder-step progressive teaching mode significantly lifts students' comprehensive CNC lathe proficiency. Students can independently machine medium-complexity workpieces within a specified time. Some students are able to identify error causes, optimize processes, and adjust cutting parameters rapidly to improve precision and shorten machining cycles. The pre-class virtual simulation link greatly reduces machining accidents, tool collisions, and workpiece scrapping. Students stay calm and operate standardly when facing real CNC lathe equipment.

5.2. Diversified learning demands of students are satisfied

The toolbox-style resource allocation meets the learning needs of students with different foundations. Students with weak foundations can repeatedly study via the open virtual simulation platform and micro-lessons, and finish training tasks after theoretical lectures and physical practice. Advanced students adopt CAXA CAM for automatic programming and process optimization; some of them take part in the "Zhe-A Vocational Skills Competition" CNC lathe event under teachers' guidance.

5.3. Cultivation of students' professional literacy

The clock-style accurate integration of curriculum ideology and politics remarkably improves students' professional literacy. During training, students take initiative to check tools and three-jaw chucks and wear protective equipment before tool setting. No safety or equipment damage accidents occurred throughout the training period. Group training spontaneously forms a clear division of labor: programming – tool setting – operation – inspection, cultivating students' teamwork awareness.

6. Conclusion

This teaching mode lowers students' cognitive threshold via virtual simulation. The ladder-step content system conforms to the law of skill formation, and the toolbox-style resource allocation meets differentiated learning demands. It stimulates students' active exploration through the cycle of "trial and error – learning – optimization." On the other hand, CNC lathe training equips students with machining skills and digital manufacturing thinking. The combination of virtual and real training eases the school's pressure in equipment, teaching, and safety management. In the future, this concept can be extended to more practical courses to provide transferable reform paradigms for engineering training teaching.

Disclosure statement

The author declares no conflict of interest.

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