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Original Paper

AI-Empowered Reform of the CNC Programming and Machining Course in Secondary Vocational Education

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Abstract

This study addresses the need to integrate AI literacy into secondary vocational education, using the "CNC Programming and Machining" course as a case. It argues that traditional education must shift from knowledge transmission to cultivating cognitive capacities for collaborating with AI. The core contribution is a comprehensive curriculum framework that embeds AI literacy across competencies like AI-assisted design and intelligent process planning. Innovative, project-based methods employing human-AI challenges and AR simulations are proposed. A dual-focus assessment system combines formative evaluation (60%) with a summative assessment (40%) that uniquely includes a dedicated AI literacy component. This model aims to bridge the gap between training and smart manufacturing, enhancing students' professional adaptability and competitiveness.

Keywords

AI-empowered education, Secondary vocational education, CNC programming and machining, Curriculum reform, Literacy assessment

1. Significance of the Research

The development of artificial intelligence has undergone a complex evolutionary trajectory, progressing from conceptual germination to technological breakthroughs. Beginning in the mid-20th century with Turing's philosophical inquiry—"Can machines think?"—the early theoretical foundations were laid by the two paradigms of symbolism and connectionism, which over decades of scholarly accumulation gradually constructed the disciplinary framework. Subsequently, AI experienced the rise and decline of expert systems, followed by the rapid emergence of machine learning—particularly deep learning—in the early 21st century, marking a critical leap from laboratory research to widespread societal application. In recent years, technological leaps represented by large language models and generative artificial intelligence have further propelled AI toward becoming a general-purpose enabling technology, continuously permeating various domains of society. Today, artificial intelligence has become a core driving force of the Fourth Industrial Revolution, profoundly reshaping human capability systems and social structures.

The educational paradigm formed during the traditional industrial era—characterized primarily by knowledge impartation, skill repetition, and standardized assessment—has increasingly revealed its inherent limitations within the progressively intelligent and collaborative environment. This shift not only marginalizes certain traditional vocational skills but, more importantly, underscores the urgent need for a systemic transformation of humanity's deep cognitive framework: the core objective of education must shift from "transmitting existing knowledge" to "cultivating the mental capacity to navigate uncertainty"—that is, shaping thinking agents capable of forming a creatively symbiotic relationship with artificial intelligence.

This transformation entails a profound adjustment at the level of educational philosophy: learning is no longer a passive adaptation to a deterministic world, but an active exploration of complex possibilities; innovation capability should no longer be confined to a select few elites, but must become a fundamental literacy for all citizens. Therefore, the education system must systematically integrate AI literacy across dimensions such as curriculum design, assessment mechanisms, and teacher-student relationships, while emphasizing the cultivation of distinctively human cognitive abilities. In doing so, it can construct an "human differential advantage" that remains irreplaceable in the era of machine intelligence. This process is not merely a technical upgrade of the educational system, but a deep-seated cognitive paradigm shift for human civilization in the age of intelligence—signaling a fundamental turn from adapting to established orders toward shaping future possibilities.

In the current secondary vocational education system, the "CNC Programming and Machining" course remains insufficient in cultivating artificial intelligence-related competencies. Despite undergoing multiple rounds of reform and optimization—including the introduction of CAD/CAM integrated technology, enhanced training in CNC simulation and multi-axis machining, the implementation of project-based teaching centered on typical components, and the deepening of industry-education integration through school-enterprise collaboration, all of which have yielded notable progress—the existing curriculum generally lacks systematic integration of AI literacy against the backdrop of rapid advancements in artificial intelligence technologies. Specifically, cutting-edge content such as intelligent programming assistance and AI-driven optimization of process parameters has not been adequately incorporated into instruction, leading to a discernible gap between students' comprehensive technical application abilities and the demands of industry-wide intelligent transformation. Consequently, there is a clear need to further reform this course toward an AI-oriented direction, thereby enhancing the employability and competitiveness of vocational students in the new generation of smart manufacturing environments.

2. Research Content

2.1 Course Objectives

This study aims to equip students with core theoretical knowledge and practical skills in CNC machining while elevating their AI-related literacy, thereby cultivating intermediate technical talents capable of meeting the demands of an increasingly intelligent modern manufacturing sector. Through systematic learning, students will gain an in-depth understanding of the structure, operational principles, and machining processes of CNC machine tools, master programming methods for CNC systems, and develop preliminary capabilities in applying AI technologies to support learning and process optimization. Emphasizing the integration of theory and practice, the course employs extensive simulation exercises and hands-on machine operation to enable students to independently complete the entire workflow for machining moderately complex parts—such as shaft, disc-cover, and cavity-type components—covering process analysis, program development, tool selection, tool setting, machining, and quality inspection. The specific objectives of the secondary vocational "CNC Programming and Machining" course are outlined in Table 1-1.

Table 1. Vocational Secondary School 'CNC Programming and Machining' Course Objectives

1. Demonstrate the ability to interpret and draft part drawings for moderately complex shaft-type and disc-type components, and apply computer-aided design (CAD) software proficiently.
2. Interpret machining process documents for complex parts in CNC turning operations, and formulate CNC machining process documentation for simple shaft-type and disc-type parts. Utilize universal fixtures for workpiece clamping and positioning; select, install, and adjust commonly used CNC lathe tools based on machining process specifications, and perform correct grinding of turning tools as required.
3. Develop CNC machining programs for two-dimensional contours composed of lines and arcs, as well as programs for internal and external threads. Apply canned cycles and subroutines proficiently during programming.
4. Execute turning operations on CNC lathes to machine external profiles, internal holes, grooves, threads, and other features, ensuring compliance with dimensional and tolerance requirements specified in drawings.
5. Perform scheduled and unscheduled maintenance of CNC lathes according to operational manuals, including inspection and routine servicing of mechanical, electrical, pneumatic, hydraulic, and CNC systems.

Although recent pedagogical reforms have substantially improved the teaching outcomes of this course, students still lack access to relevant artificial intelligence (AI) knowledge in the classroom, which hinders the development of their AI literacy. In response to this gap, the author has initiated the development of course objectives for the secondary vocational program "CNC Programming and Machining" that integrate AI literacy, as outlined in Table 1-2.

Table 2. Vocational College 'CNC Programming and Machining' Course Objectives Integrated with Artificial Intelligence Literacy

1. Demonstrate the ability to interpret and create part drawings for moderately complex shaft-type and disc-type components using computer-aided design (CAD) software, and apply AI-assisted design tools for modeling optimization, parametric design, and intelligent drawing review. Understand the application of generative AI in reverse engineering and design innovation.
3. Interpret machining process documents for complex CNC turning parts and, with the aid of AI-based process planning systems, analyze and optimize the manufacturing processes for simple shaft-type and disc-type components to generate intelligent CNC machining process documentation. Operate universal fixtures for workpiece clamping and positioning. Select, install, and adjust common CNC lathe tools based on process specifications, and utilize intelligent tool management systems to monitor tool conditions while making informed tool grinding decisions based on data feedback.
4. Develop CNC machining programs for two-dimensional contours consisting of lines and arcs, as well as for internal and external threads, proficiently applying canned cycles and subroutines. Utilize AI-assisted programming systems for code generation, optimization, and simulation verification, and demonstrate the ability to review and modify AI-generated programs.
5. Perform CNC turning operations to machine external profiles, internal holes, grooves, threads, and other features in accordance with drawing accuracy requirements. Apply machine learning and real-time sensor data to enable intelligent monitoring, quality prediction, and adaptive adjustment during machining processes. Understand the role of AI in precision control and defect detection.
6. Perform scheduled and unscheduled maintenance of CNC lathes as outlined in operational manuals, including the inspection and routine servicing of mechanical, electrical, pneumatic, hydraulic, and CNC systems. Employ predictive maintenance platforms and AI-driven fault diagnosis expert systems for intelligent equipment condition analysis and health management.

The "CNC Programming and Machining" course is guided by the principle of "promoting employment and meeting the developmental needs of the manufacturing industry." It emphasizes the creation of authentic vocational scenarios and embodies the vocational education philosophy of "learning by doing and teaching through practice." The curriculum integrates AI literacy and prioritizes the cultivation of CNC programming capabilities. Taking the machining of a simple transmission shaft part as an example, this project can be organized into four tasks aligned with the four key stages of CNC machining: programming-related knowledge, machining process design, part programming, and CNC machining operations, with AI methodologies and literacy embedded throughout. These AI approaches are designed to enhance students' artificial intelligence competencies. The specific framework is outlined in Table 1-3.

2.2 Teaching Methods

Table 3. AI Teaching Methods

Project		Content	AI Teaching Methods	AI Literacy Goals
Project: Simple Drive Shaft Part Machining	Task 1: Related Knowledge Points	1. Axial Cutting Fixed Cycle Command	Human vs. AI: A Cutting Parameter Challenge This learning activity is designed to compare programming approaches: one student group develops the machining program based on practical experience, while another employs artificial intelligence for program generation. The key performance metrics for comparison are total machining time and the extent of tool wear incurred.	1. The ability to use artificial intelligence correctly 2. Ability to apply disciplinary knowledge
	Task2: Processing Technology Design	1. Analysis of the Processing Technology 2. Design and Process WorkCard 3. Design CNC Machine Tool Holder	1. AI Template Generator Input part features (e.g., “stepped shaft with threaded holes”), and automatically generate a process sheet template via ChatGPT integrated with Excel add-ins. 2. Ethical Integration Discussion on whether the use of enterprise historical process data by AI infringes upon the intellectual property rights of experienced craftsmen’s knowledge.	1. The ability to use artificial intelligence 2. Ability to analyze disciplinary knowledge 3. Understanding Ethical Guidelines for Artificial Intelligence
	Task 3: Part Programming	1. Base Point Coordinate Calculation 2. Write a machining program	AI-Assisted Verification In this verification exercise, students first program a part by applying knowledge acquired in class, then use one AI tool to assist in checking the code, followed by another AI system to further validate the correctness of the first AI’s analysis.	1. The ability to use artificial intelligence 2. Ability to apply disciplinary knowledge 3. Understanding Ethical Guidelines for Artificial Intelligence
	Task 4: CNC Machini	1. Part clamping alignment and tool setting	AR Clamping Challenge Students use a mobile device to scan the fixture platform, thereby activating an augmented	1. 1.The ability to use artificial intelligence 2. Possess

ng of Parts	2. Process Program Editing and Verification 3. Parts Processing and Inspection	reality (AR) virtual workpiece (implemented via EasyAR). An AI system then evaluates clamping stability in real time.	human-machine collaboration awareness 3. The ability to transform subject knowledge into personal knowledge

2.3 Teaching Evaluation

To comprehensively evaluate learning outcomes, the course employs a combination of formative and summative assessments, which are weighted at 60% and 40%, respectively, in calculating the overall grade.

(1) Formative Assessment：

a) Module I: Learning Attitude and Professional Competencies (25%)

Class Participation (10%): Evaluated based on attendance, attentiveness during lectures, initiative in responding to questions, and active engagement in group discussions.

Assignment Completion & Preparedness (10%): Assessed according to the punctual and independent completion of written and practical preparatory/review assignments, as well as the readiness of required tools, materials, and instruments.

Professional Conduct and Norms (5%): Focuses on adherence to workshop safety protocols and equipment operating standards. It also assesses the demonstration of responsibility, discipline, teamwork, and the foundational development of 5S management practices (Sort, Set in order, Shine, Standardize, Sustain).

B) Module II: Process of Knowledge Acquisition and Skill Mastery (50%)

Unit/Module Skill Assessment (20%): Conducted upon completion of each instructional unit or skill module, this involves targeted practical operation tests or product manufacturing. Evaluation emphasizes the standardization of operational procedures, proficiency in skill execution, and the quality of the final output.

In-Class Practical Training Performance (15%): Pertains to performance during regular practical sessions, assessing hands-on ability, operational compliance with standards, troubleshooting capacity, and the quality of practice exercises.

Application of Theoretical Knowledge (15%): Evaluates the student’s ability to apply theoretical knowledge to guide practical operations through methods such as classroom questioning, group discussions, and case study analysis.

C) Module III: Project Tasks and Integrated Practice (25%)

Comprehensive Project Assignment (15%): Requires completion of an integrated project encompassing multiple knowledge points and skills (e.g., assembling a circuit, designing a promotional poster, machining a component). Assessment covers planning, implementation, problem-solving, final presentation, and report-writing abilities.

Collaborative Group Project (10%): Within group projects, evaluates competencies in task division and cooperation, communication, individual contribution, as well as leadership or supportive teamwork skills.

(2) Final Evaluation:

The summative assessment accounts for 40% of the total course grade and consists of two components: knowledge evaluation and artificial intelligence literacy assessment. Specifically, 90 points are allocated to knowledge-based questions, focusing on examining students' mastery of the core course content. The remaining 10 points are designed around artificial intelligence literacy, which may be assessed through AI-related project deliverables or case analysis reports to comprehensively evaluate students' practical competencies in AI knowledge, skills, awareness, and ethics.

This study centers on the systematic integration of artificial intelligence (AI) literacy into secondary vocational education, with a focus on the design of corresponding curriculum standards and the innovation of pedagogical approaches. By restructuring teaching processes, introducing intelligent instructional tools, and implementing scenario-based practical training, the research aims to enhance students' comprehensive AI literacy, practical skills, and professional adaptability in the context of advancing AI technologies. This will better equip them to meet the demands of future industrial developments and grow into highly skilled talents capable of addressing real-world technical challenges. Furthermore, this study provides teachers with a referential theoretical framework and practical pathways for course design and instructional implementation in the era of AI-empowered education.

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