Reform of the Basic Course on Intelligent Manufacturing Technology and Exploration of Teaching Models for the New Engineering Education Era

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Abstract: In response to the profound transformation demands of the intelligent manufacturing industry, this paper establishes a "three-dimensional collaboration and four-in-one" integrated curriculum system and teaching model tailored for new engineering disciplines. By employing dual-track teaching with typical applications to address fragmented disciplinary knowledge, and leveraging classroom instruction, case-driven learning, experimental practice, and interactive reflection-based chain teaching to bridge the industry-academia gap, the study innovatively develops a virtual-real integrated practice platform to enhance engineering scenario immersion. Through interdisciplinary projects — including digital twin development with virtual-real feedback, role-based collaborative design, industry challenge resolution, competitive simulation exercises, and zero-carbon factory planning — the study systematically reconstructs students technical integration capabilities. A closed-loop evaluation system is implemented, utilizing three-dimensional data flows from classrooms, laboratories, and projects to drive process assessment, employing competency mapping for diversified evaluation, and employing data mining techniques to continuously optimize teaching content.

***Keywords*:** intelligent manufacturing; curriculum reform; integration of virtual and physical worlds; new engineering disciplines; competency-oriented education

1. Introduction

Against the backdrop of rapid advancements in intelligent manufacturing technology, the manufacturing industry is undergoing a profound transformation from digitalization and networking to intelligentization. New-generation information technologies are increasingly integrating with traditional manufacturing processes, driving the restructuring of industrial and value chains. Talent serves as a critical factor in this process, necessitating that universities cultivate high-caliber interdisciplinary professionals with cross-disciplinary backgrounds, comprehensive mastery of key intelligent manufacturing technologies, strong engineering practice capabilities, and an innovative spirit. The course "Fundamentals of Intelligent Manufacturing Technology" was established precisely under these circumstances as a core professional course.[1]

2. A three-dimensional, collaborative advancement-based curriculum system that integrates foundational knowledge with practical applications

To collaboratively enhance students foundational competencies, systematic thinking, and engineering practice skills, while deepening their comprehensive understanding of core intelligent manufacturing technologies and industry demands, a "three-dimensional collaborative" integrated curriculum system has been established.[2] This curriculum system aims to promote the comprehensive integration and balanced development of course content, teaching processes, and student competencies. Dimension One: Parallel advancement of foundational knowledge and practical application. The course adopts a dual-track approach combining "fundamental theories with typical applications." Dimension Two: Coordinated development of competencies and learning processes: Based on students learning pathways, the course establishes four progressive competency objectives — "cognition, mastery, transfer, and innovation." Dimension Three: Holistic development through individual and collaborative learning. The teaching process integrates "individual reinforcement" and "team collaboration" methodologies. Emphasizing a student-centered, competency-oriented, and engineering problem-driven approach, this system strives to achieve systematic course content, multidimensional teaching processes, and comprehensive competency development, providing a clear pathway for cultivating foundational talents in intelligent manufacturing.

3. The Integrated Teaching Model with Four Components

In terms of teaching methodology, the course adopts a four-in-one design comprising "classroom lectures — case-driven learning — experimental practice — interactive reflection."[3] Classroom instruction involves teachers systematically explaining key concepts, emphasizing theoretical frameworks and logical relationships to help students develop a systematic understanding of the discipline; case-driven approaches enhance students perception and interest in technology applications by introducing real-world examples such as smart factories, robotic implementations, or production line upgrades; hands-on experiments utilize laboratory platforms and virtual simulation systems to conduct practical exercises like robot path planning and CNC machining process simulations, enabling students to learn by doing; interactive reflection methods — including flipped classrooms, group discussions, and in-class questioning — foster intellectual exchange and independent exploration, thereby boosting learning engagement and critical thinking skills.

4. Systematic Development of Teaching Resources: From Micro-video Resources to the Construction of an Integrated Virtual-Physical Practice Platform

In the foundational course on intelligent manufacturing technology, the development of teaching resources is crucial for enhancing students learning outcomes and practical skills. To this end, this course establishes a diversified resource system across three dimensions: the knowledge platform, the practical platform, and the virtual platform.

4.1 Knowledge Platform Development

The course has developed a series of instructional micro-videos covering core concepts of intelligent manufacturing, helping students establish a systematic theoretical framework. This aligns with the content emphasized in the aforementioned "Fundamentals of Intelligent Manufacturing Technology Course," which prioritizes the integration of theory and practice, focuses on case-based teaching, and cultivates practical skills.

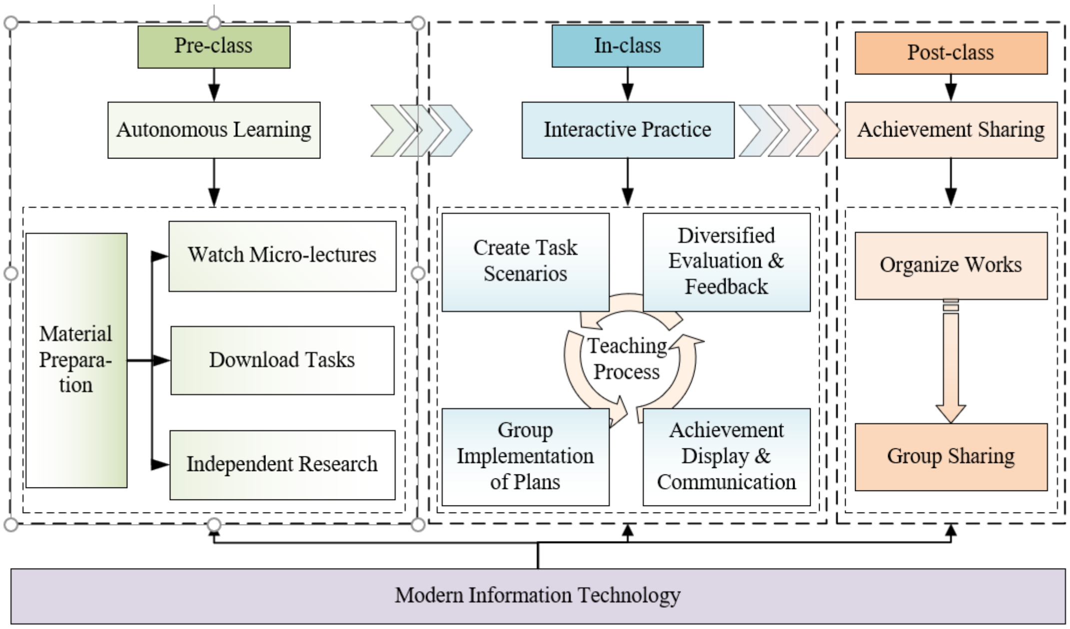

Figure 1. Flowchart of the Flipped Classroom Teaching Model

4.2 Development of a Practical Platform

Leveraging the Intelligent Manufacturing Basic Laboratory, a desktop-based ABB robot training platform and an intelligent logistics system have been established, enabling students to conduct experiments and training in real-world environments. This aligns with the description in the study "Research on the Talent Training Model for New Engineering Mechanical Majors Based on Intelligent Manufacturing," which states that "the intelligent manufacturing laboratory is equipped with industrial robots, CNC machine tools, 3D printing equipment, and other facilities to facilitate hands-on practice for students."[4]

4.3 Virtual Platform Development

The course incorporates a virtual simulation teaching system, enabling students to virtually operate intelligent manufacturing production lines through virtual simulation software, thereby enhancing their practical skills. Examples of such applications include the teaching utilization of virtual simulation software in areas such as intelligent manufacturing production lines, robotic operations, and digital twins.

4.4 Teaching Methods and Evaluation System

The course emphasizes the integration of theory and practice, employing methods such as case-based teaching, virtual simulation, and blended online-offline instruction to foster students practical skills and innovative thinking. The teaching methodologies and evaluation system outlined in "Research and Practice on Teaching Reform for the Basic Course of Intelligent Manufacturing Technology" align with the teaching reform directions described in the relevant section.[5]

5. Exploration of the Comprehensive Assignment Model

In the teaching of the "Fundamentals of Intelligent Manufacturing Technology" course, major assignments serve as a central component spanning the entire curriculum, playing a vital role in enabling students to systematically grasp knowledge and enhance their practical skills. While the existing "multi-task-driven" major assignment model effectively guides students to progressively master key concepts through various tasks, it has certain limitations. Consequently, the course team has explored and developed several innovative major assignment design approaches.

5.1 Digital Twin Operation Paradigm with Real-World and Digital Feedback Interaction

The digital twin methodology developed in this course is centered on the core concept of "virtual mapping – entity validation – dynamic optimization," forming a closed-loop teaching framework. Students first complete the digital modeling of intelligent manufacturing units in a virtual environment, constructing precise models that include geometric structures, motion constraints, and control logic using industrial-grade simulation software. The program emphasizes cultivating students ability to abstractly transform physical parameters into information space.[6]

5.2 Construction of Collaborative Design Tasks for Role Immersion

From the project initiation phase, students engage in a multi-role collaboration framework: Process planners analyze product BOM drawings and define workflow sequences; production line architects design equipment layouts and logistics routes; control engineers develop PLC ladder logic and human-machine interfaces; and data engineers establish data acquisition channels via OPC-UA protocols.

5.3 Challenge-driven solutions for real pain points

The student team tackled the classic challenge of "rapid model switching and adaptation for small-batch, multi-product manufacturing," beginning with on-site workshop observations to analyze the entire production process: tracking the distribution of non-value-added labor hours during mold switching on injection molding machines, mapping bottleneck points in material flow paths, and statistically analyzing fluctuations in first-inspection defect rates caused by inadequate tooling and fixture compatibility.

5.4 Competitive Mechanism: A Simulated Exercise

The curriculum design incorporates the "Intelligent Warehouse Scheduling Optimization Competition" as a training ground for capability enhancement. A unified digital factory model — including aisle layouts, warehouse coordinates, and AGV parameters — is made available, with a dynamic order pool imported simultaneously. Each team develops the core scheduling algorithm under specified computational constraints: the path planning module must balance the shortest distance with traffic control rules; the task allocation logic should optimize equipment load distribution while ensuring operational timeliness; and the energy control unit must dynamically optimize motor start-stop strategies in real time.

5.5 Interdisciplinary Collaborative Integrated Project

Using the "Zero-Carbon Smart Factory Plan" as a framework, the knowledge value chain is restructured to break down disciplinary barriers between mechanical engineering, information technology, and energy systems. Students integrate the concept of product lifecycle management to complete plant-level optimization designs at a macro level; Manufacturing Execution System (MES) architects interface with supply chain simulation models to achieve dynamic alignment between production scheduling and photovoltaic power generation curves; process engineers employ topology optimization techniques to optimize component structures, reducing energy consumption in machine milling; environmental analysts develop a "Carbon Flow Tracking Engine" to quantitatively assess the marginal impact of coolant recovery rates on carbon footprint.

6. Reconstruction of the closed-loop feedback-based teaching evaluation system

6.1 Process Evaluation System

The process evaluation system establishes a three-dimensional data collection network encompassing "classroom–experiment–project," utilizing information technology to comprehensively document the entire learning trajectory, as illustrated in Figure 2 below.

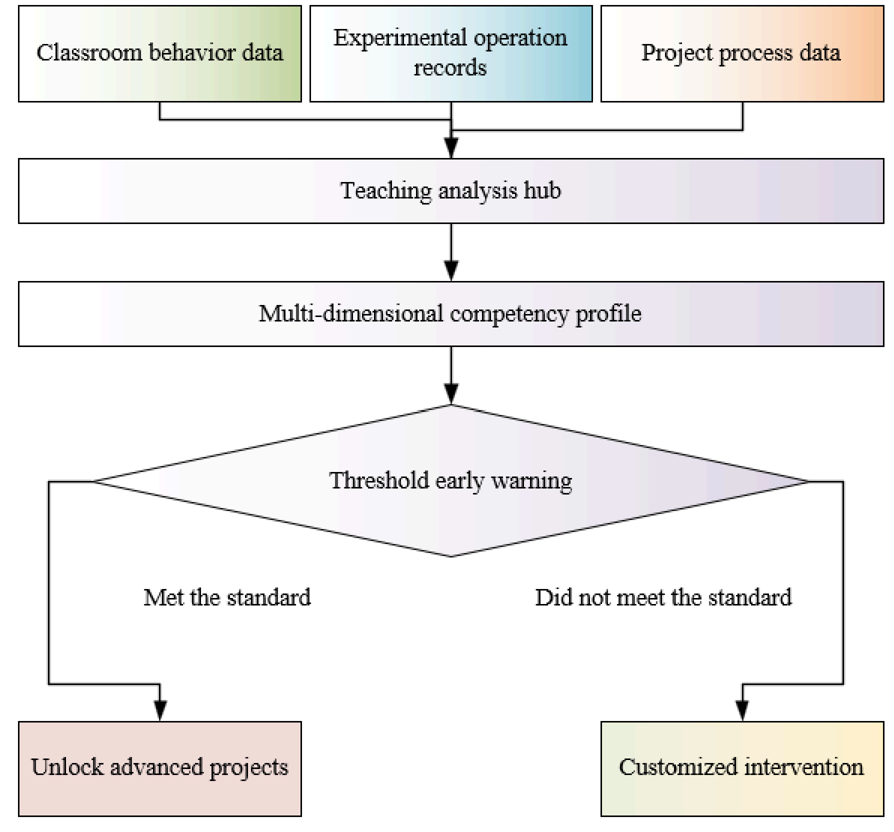

Figure 2. Process Evaluation System

Intelligent sensing devices are deployed in classroom teaching sessions to automatically monitor behavioral metrics such as students pre-class preparation completion rates, classroom interaction engagement levels, and frequency of advanced question poses. During experimental and practical training phases, an IoT sensor matrix precisely records equipment parameter configuration accuracy, operational procedure compliance, and anomaly response timeliness. The project implementation utilizes a collaborative development platform to continuously collect iterative design scheme versions, team task contribution heatmaps, and technical documentation completeness. When the system detects that the group mastery level for a specific knowledge unit consistently falls below the threshold, an automatic alert and intervention mechanism is triggered: this includes targeted micro-lecture delivery for weak modules, immersive virtual experiment reinforcement training for common difficulties, and group collaboration support plans for students exhibiting performance anomalies.

6.2 A Competency-Oriented Multidimensional Assessment System

A five-dimensional radial evaluation framework was established to transcend the conventional single-judgment logic of score aggregation. In the technical application dimension, a three-tier evaluation standard — "parameter configuration accuracy, system debugging efficiency, and fault diagnosis accuracy" — was implemented, leveraging the industrial control platform to collect real-time data on PLC program logic correctness and robot trajectory tracking errors. At the problem-solving level, a continuous evaluation chain encompassing requirement translation, solution innovation, and implementation validation was established, with project document version control systems tracking the remediation progress of design defects. For engineering innovation, a three-stage progressive scale was adopted, evaluating progress from basic solution replication to original mechanism improvements and finally to new process prototype development. Team collaboration capabilities were measured using social network analysis to quantify member interaction intensity and decision-making influence distribution. In the outcome presentation dimension, the logical rigor and terminological accuracy of reports were assessed using NLP tools in compliance with IEEE technical documentation standards.

The evaluation results present the topological structure of individual competencies through a radar chart, supplemented by cluster analysis to identify teaching weaknesses, while corporate mentors contribute industry perspectives via a remote review platform. This multi-dimensional evaluation paradigm transforms talent development quality into a measurable competency assessment system.

6.3 Continuous Teaching Improvement Mechanism

The Teaching Improvement Engine establishes an adaptive evolutionary closed-loop system comprising "data-driven analysis, attribution examination, and strategy validation." Each teaching cycle generates three types of critical data assets: the Learning Behavior Database comprehensively documents learners exploration paths within knowledge units; the Outcome Quality Data Warehouse stores multidimensional evaluation chains for assignments and projects; and Process Tracking Logs document typical challenges encountered during instruction implementation. The improvement mechanism achieves iterative refinement through three specific approaches: At the knowledge restructuring level, association rule mining algorithms identify patterns of knowledge module correlations — when teaching effectiveness for "Machine Vision Localization" shows significant positive correlation with "Industrial Robot Kinematics," the course module sequence is automatically adjusted; At the resource optimization level, heat map analysis identifies underutilized teaching materials — static courseware with click-through rates below 40% in 3D reconstruction courses is automatically replaced with augmented reality interactive models; At the methodological innovation level, A/B comparative trials are conducted: in the Intelligent Manufacturing System Design module, the control group employs traditional case-based teaching while the experimental group adopts a digital principal line-guided reverse decomposition approach, validating method effectiveness through project innovation index comparisons.

7. Conclusion

The profound reform of the Intelligent Manufacturing Systems curriculum centers on establishing a logically coherent new engineering education paradigm that integrates technological evolution, industrial demands, and competency development. Through dual-track iteration combining fundamental theories with practical applications, it breaks down disciplinary barriers to systematic understanding; employs a closed-loop design of the four-in-one teaching framework to bridge the gap between traditional classrooms and practical settings; introduces an innovative hybrid major assignment mechanism that enhances technical integration capabilities through digital twin development and collaborative project execution; and leverages a data-driven evaluation system to enable visual monitoring and precise intervention throughout the competency development process.

Acknowledgments

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