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Teaching Reform and Reflections on Industrial IoT Curriculum under the Dual Needs of Industry 4.0 and New Engineering Construction

Zhao Xinyi[a,*], Lv Liye[b]

School of Mechanical Engineering, Zhejiang Sci-Tech University, No. 2 Street, Qiantang District, Hangzhou, China

[a]x-zhao@zstu.edu.cn, [b]lvliye@zstu.edu.cn

**Corresponding author*

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Abstract: Facing the transformative wave of Industry 4.0 and the demands of China's Emerging Engineering Education, this study proposes an integrated reform framework addressing core issues in Industrial Internet of Things (IIoT) pedagogy: fragmented interdisciplinary knowledge systems, outdated teaching methods, and disconnects between academia and industry. Centered on a Project-Based Learning (PBL) project—"IIoT-based CNC Machine Tool Vibration Monitoring System"—the curriculum content is modularized into technical units aligned with the three-layer IoT architecture: the perception layer, network layer, and application layer. Adopting a "problem-driven + blended teaching" model, pre-class engineering problems are released via teaching platforms, in-class flipped classrooms incorporate AI-assisted validation, and post-class industrial solution iterations are implemented. A three-tier ecosystem of "virtual simulation–semi-physical debugging–industrial practice" is constructed, integrating Siemens Process Simulation for digital twins, enabling RFID/AGV operations on smart production lines, and transforming enterprise demands into capstone projects. Faculty development employs a "Dual-Teacher Dual-Entry" mechanism: full-time teachers complete six-month industry rotations every three years to update teaching content, while corporate mentors co-develop practical industrial cases. The assessment system shifts from single examinations to a three-dimensional competency evaluation encompassing knowledge mastery, engineering practice, and innovative collaboration. The reformed PBL-based IIoT curriculum focuses on practical industrial applications of IoT, emphasizing the enhancement of students' comprehensive and innovative capabilities. It holds significant importance for cultivating interdisciplinary talent under the dual demands of Industry 4.0 and Emerging Engineering Education.

1. Introduction

Driven by a new wave of technological revolution and industrial transformation centered on artificial intelligence, big data, and the Internet of Things (IoT), human society is accelerating its entry into the Industry 4.0 era characterized by pervasive intelligence, interconnectedness, and digitalization [1]. This transformative momentum is propelling global manufacturing systems from localized automation toward globally integrated intelligent collaboration, evolving from singular technological breakthroughs to systemic innovation competitions encompassing technology integration, organizational restructuring, and ecosystem evolution. Within this process, the quality and structure of talent reserves emerge as the decisive factor for national industrial competitiveness—demanding both engineers proficient in cyber-physical systems (CPS) and digital twin technologies, and interdisciplinary talents equipped with integrated knowledge synthesis capabilities, innovative engineering practice literacy, and global industrial perspectives [2-3]. Nevertheless, China's manufacturing transformation faces acute challenges: structural misalignment in talent supply has become a critical bottleneck hindering industrial advancement toward higher value chains, particularly in frontier domains such as Industrial IoT architecture design and edge intelligent device development [4].

To address the global competitive landscape, "Made in China 2025" clearly emphasizes intelligent manufacturing as a primary focus, aiming to reshape the manufacturing ecosystem through digital, networked, and intelligent technologies. Concurrently, the Ministry of Education promotes the development of new engineering disciplines, urging the higher education system to transcend traditional disciplinary boundaries and establish a talent cultivation paradigm characterized by "cross-disciplinary integration and iterative innovation." As a leading field in the reform of new engineering disciplines, the core mission of the intelligent manufacturing engineering major is to cultivate interdisciplinary talents equipped with the ability to integrate knowledge from various fields, innovate in engineering practices, and possess an international outlook. Notably, the Industrial Internet of Things (IIoT), as the core technology of Industry 4.0, deeply integrates physical manufacturing systems with digital twin technology, becoming a key driving force in reshaping the manufacturing ecosystem [5]. Thereby, the course "Industrial Internet of Things" (IIoT) serves as a bridge connecting physical manufacturing systems and digital twin technology, thus becoming a foundational course for this major [6]. The course objectives require students to not only master the architecture and core technologies of the IoT but also to develop the capability to translate theoretical knowledge into practical industrial solutions.

Nevertheless, the current teaching of the "Industrial Internet of Things" course faces several challenges [7]. Firstly, significant disciplinary barriers and difficulties in interdisciplinary integration. The course content spans multiple disciplines, including mechanical engineering, information science, and control theory, requiring students to simultaneously master knowledge related to intelligent sensors, radio frequency identification technology, industrial communication protocols, and cloud platform integration. This complexity makes it challenging to construct a coherent technical framework, placing high demands on the integration of interdisciplinary teaching resources. Secondly, a lack of diverse teaching methods and outdated content. The traditional "teacher-centered" approach is inadequate for adapting to the rapid technological advancements, leading to passive knowledge absorption by students, which limits their innovative thinking and fails to stimulate their motivation for autonomous learning. Additionally, there is a shortage of "dual-qualified" educators who possess both industrial experience and cutting-edge academic insights, and some teaching materials remain based on classic examples from several years ago, lacking incorporation of emerging technologies. Thirdly, insufficient authenticity in practical scenarios and rigid evaluation mechanisms. The practical components are often disconnected from industrial demands, with experiments frequently limited to simulation software, lacking real-world training in equipment debugging and fault diagnosis. Moreover, the evaluation system overly relies on theoretical examinations, neglecting the assessment of essential skills such as project design and teamwork, resulting in a pronounced "high scores but low abilities" phenomenon among students.

Project-Based Learning (PBL), with its interdisciplinary integration, practice-driven nature, and competency-oriented focus, provides an innovative pathway to address teaching challenges in Industrial IoT education [8-10]. Its core advantage lies in utilizing authentic engineering projects to break down rigid disciplinary boundaries among mechanical engineering, information science, and control theory, enabling students to autonomously construct systematic knowledge frameworks while solving complex engineering problems. Simultaneously, it emphasizes the "learning-by-doing" concept, transforming abstract theories into actionable industrial solutions that effectively bridge the gap between academia and industry. To address the aforementioned issues, this project introduces the Project-Based Learning (PBL) approach guided by the dual demands of Industry 4.0 and Emerging Engineering Education. We explore curriculum reform measures for Industrial IoT, providing methodological references for Industrial IoT course development, aiming to cultivate engineering leaders capable of navigating the complex ecosystem of smart factories.

2. Current issues in course teaching

2.1. Difficulties in integrating interdisciplinary knowledge systems

The architecture of the Internet of Things (IoT) involves the perception layer, network layer, and service layer. The Industrial Internet of Things (IIoT) requires applications in industrial scenarios, thus the overall course encompasses interdisciplinary fields such as mechanical engineering, information science, and control theory. Students are required to simultaneously master knowledge in perception and recognition technologies, network integration and access technologies, and intelligent processing technologies. However, current teaching exhibits fragmentation: on the teacher's side, mechanical engineering instructors have insufficient understanding of edge computing algorithms, computer science teams lack awareness of the physical characteristics of industrial equipment, and there is a disconnect between control theory courses and industrial network protocol teaching. On the student side, the IIoT course is scheduled in the first year of the major, where students have only studied foundational courses in mechanical engineering, lacking support from knowledge in other disciplines, making it difficult to understand and grasp the systematic IoT architecture. This fragmented teaching model prevents students from constructing a systematic framework for IIoT technologies, directly impacting their ability to solve complex engineering problems.

2.2. Disconnection between traditional teaching models and innovation capability development

The current course primarily follows a "teacher-centered" approach, characterized by one-way knowledge transmission, resulting in low classroom interaction rates. In the context of Industry 4.0, where technology iteration cycles have shortened to 6-8 months, this model reveals serious lag: the 5G industrial application cases used by teachers are outdated compared to current Time-Sensitive Networking (TSN) technology standards, and the teaching content on digital twins remains at a conceptual level without incorporating real-time simulation tools like Unity3D. More critically, the passive learning mode stifles students' critical thinking. Evidence from existing course assignments shows that students' proposed IIoT-based production line optimization solutions remain at a superficial conceptual level. This teaching approach of "knowledge replication" rather than "knowledge creation" struggles to cultivate innovative talents capable of adapting to rapid technological evolution.

2.3. Insufficient connection between experimental teaching and industrial demand

The existing course comprises a total of 32 class hours, with 24 hours dedicated to theoretical courses and 8 hours to experimental courses. Experimental teaching primarily relies on existing small-scale intelligent manufacturing demonstration production lines, focusing on perception and recognition, network construction, service management, and comprehensive applications. However, this model, which depends on established experimental environments, allows students to only complete basic debugging tasks, with most experiments still relying on Siemens simulation software, leaving real industrial challenges rarely addressed in teaching. More critically, students cannot experience the full lifecycle project management from demand analysis, system deployment to operational optimization, resulting in a disconnect in the ability to translate theory into practice.

2.4. Structural shortage of dual-qualified teaching staff

Teaching the IIoT course requires instructors to possess both cutting-edge academic knowledge and industrial field experience. However, the intelligent manufacturing engineering program is relatively new, with many faculty members being young and lacking over three years of experience in industrial enterprises; very few have participated in actual IIoT projects. This directly results in outdated teaching content, such as the continued explanation of ZigBee wireless sensor networks, while the industry has widely adopted LoRaWAN and NB-IoT technologies. The lack of diverse faculty expertise severely restricts the synchronization of the course with industrial technological developments.

2.5. Absence of a multi-dimensional capability evaluation mechanism

The current assessment system overly relies on closed-book examinations (accounting for 60%), with questions focused on conceptual memorization and simple calculations, such as asking students to recite the IoT architecture, RFID working principles, or compute network positioning. However, the core competencies required for IIoT talents—such as demand-driven system architecture design capability, multi-protocol device integration and debugging ability, and interdisciplinary team collaboration skills—are not adequately reflected in the current evaluations. Furthermore, the high proportion of practical assessments (40%) does not match the class hour distribution (8/32). Therefore, establishing a multi-dimensional evaluation mechanism that considers students' comprehensive abilities has become an urgent need for teaching reform.

3. Course teaching reform

3.1. Constructing a PBL-centered course system

Project-Based Learning (PBL), grounded in constructivist situated learning, engages students in artifact development through active problem-solving and collaborative solutions. This project integrates PBL into the Industrial Internet of Things course, deepening students' understanding of IIoT architecture and industrial applications. Using the "IIoT-Based Machine Bed Vibration Monitoring System" as a framework, it follows a problem-driven, team-collaborative, iterative optimization approach. This design enhances content relevance and innovation, shifts focus from knowledge acquisition to skill development, and cultivates Industry 4.0-ready talent. The specific course system construction is illustrated in Figure 1.

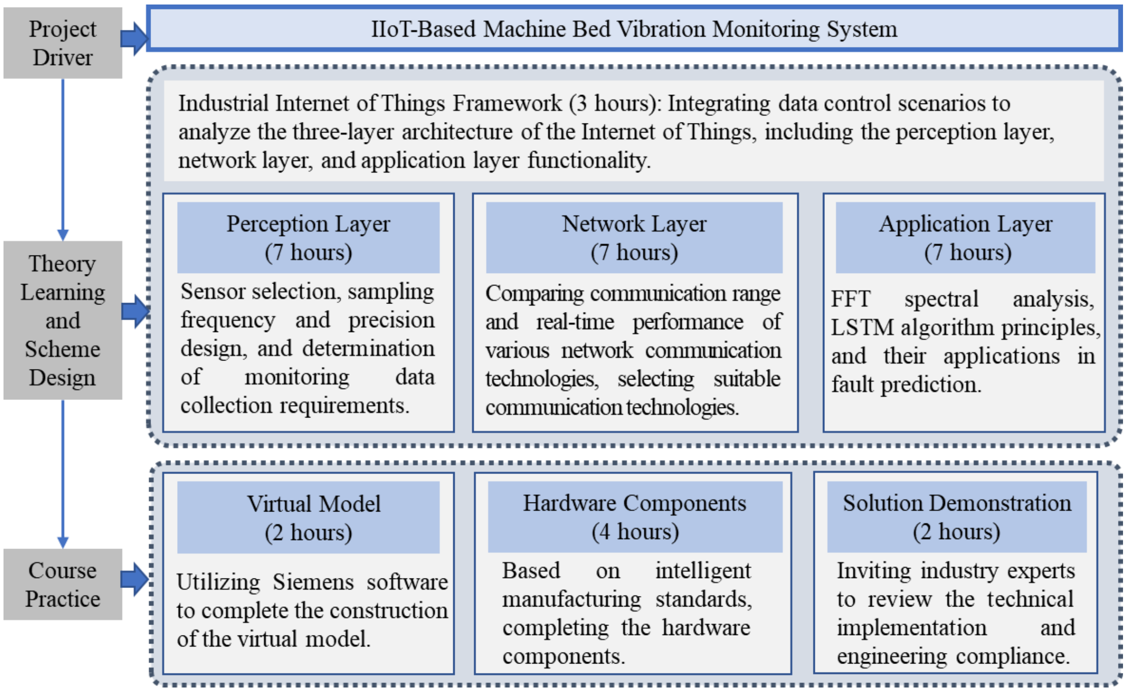

Figure 1: Construction of the 'industrial internet of things' curriculum system based on PBL.

The IIoT course consists of a total of 32 class hours, with 24 hours dedicated to theoretical instruction and 8 hours to experimental learning. Therefore, the PBL-based course structure is driven by projects and mainly includes theoretical learning and solution design (24 hours) along with course practice (8 hours). The theoretical component is further divided into IoT architecture (3 hours) and seven hours each for the perception layer, network layer, and application layer. The specific mapping between project phases and course knowledge points is shown in Table 1.

Table 1: Mapping of project phases to course knowledge points.

Project Stage	Core Tasks	Knowledge Points
Problem Definition	Investigate scenarios of equipment failures in factories	Typical failure modes of industrial equipment (e.g., bearing wear, motor overheating)
Data Acquisition	Identify monitoring parameters and data collection requirements	Perception layer: Sensor selection (vibration, temperature), sampling frequency and precision design
Network Topology	Define network transmission methods and communication protocols	Network layer: Selection of network transmission methods and construction of network topology
Application Implementation	Build hardware and apply appropriate data analysis algorithms	Application layer: Data processing, FFT spectrum analysis, LSTM fault prediction
Results Presentation	Write a report and conduct a defense	Technical specifications

3.2. Implementing a "problem-driven + blended" teaching model

To break through the traditional one-way teaching model and construct a teaching loop of "pre-class exploration - in-class deepening - post-class expansion," we aim to stimulate students' autonomous learning and innovation capabilities. By utilizing a real industrial IoT project that spans the "full lifecycle" of course learning, relevant engineering problems are published on learning platforms such as Superstar before class. During class, based on the proposed problems, relevant theoretical knowledge is taught, and students are guided to propose solutions. Additionally, a "flipped classroom" mechanism can be introduced, where students present their solutions and utilize AI systems like DeepSeek to simulate enterprise engineers, providing feedback on the technical feasibility of their proposals. After class, students can further refine outstanding solutions based on real enterprise needs.

3.3. Establishing a "virtual-real integration" practical teaching ecosystem

We aim to construct a three-tiered practical platform of "virtual simulation - semi-physical training - real-world combat" to bridge the gap between theory and practice. First, in the virtual simulation phase, tools like Siemens Process Simulation are introduced to create a digital twin environment for intelligent manufacturing production lines. Students can use the software for comprehensive analysis of data collection, synchronization, and processing, and propose optimization solutions based on their findings. Second, real debugging activities are conducted using a small-scale intelligent manufacturing demonstration production line, such as modifying RFID tag content, controlling AGV vehicle movement commands, and arranging processing workflows. Finally, by collaborating with relevant enterprises to establish an industry-education integration base, we can transform enterprise needs into course experimental project topics or course design/graduation project topics.

3.4. Implementing a "dual teacher dual entry" faculty development plan

The "Dual-Track Faculty Development" initiative enhances faculty capabilities through bidirectional industry-academic integration. By inviting enterprise technical experts as course advisors, practical IIoT projects such as RFID warehouse tracking systems and PLC-based conveyor control can be co-developed. These focused cases, each addressing 1-2 core technical challenges, combine theoretical instruction with live industrial demonstrations, significantly boosting student engagement and competency. Concurrently, full-time teachers undertake six-month industry immersions every three years, documenting real-world engineering challenges and solutions to transform frontline experience into cutting-edge teaching content. This dual approach ensures faculty mastery of both applied engineering practices and emerging academic frontiers, directly cultivating industry-ready versatile talent.

3.5. Establishing a "competency-oriented" dynamic assessment mechanism

Table 2: "Competency-oriented" dynamic assessment mechanism.

Dimension	Weight	Core Competency Goals	Assessment Methods and Tools
Knowledge Mastery	60%	Understanding of theoretical systems, awareness of technical standards	Closed-book exam (80%) + Classroom performance (20%)
Engineering Practice	20%	Basic equipment operation, on-site debugging skills	Experimental report (60%) + Classroom practical (40%)
Innovative Collaboration	20%	Team collaboration skills, self-directed learning abilities, technical sensitivity	Group discussions (50%) + Peer evaluation (50%)

In response to the deficiencies of the existing assessment criteria (60% for closed-book exams and

40% for experimental and classroom performance), and considering the requirements for composite competencies in the Industrial Internet of Things course, a "competency-oriented" dynamic assessment mechanism is established. Recognizing that IIoT professionals require a balanced integration of theoretical knowledge, hands-on engineering skills, and collaborative innovation, the new mechanism adopts a three-dimensional evaluation structure, as detailed in Table 2.

In the knowledge mastery dimension, closed-book exams will account for 80% of the assessment. The focus will be on reducing the number of rote memorization questions while increasing the proportion of comprehensive scenario-based analysis questions. These will cover core theories such as the architecture of the Industrial Internet of Things, principles of sensors, fundamental communication protocols, data processing, and their comprehensive applications. Classroom interaction will contribute to 20% of the assessment, utilizing activities like rapid-fire questioning and group tasks to create chapter mind maps, which help students engage more effectively in class and grasp essential knowledge.

In the engineering practice dimension, we will introduce time-limited challenges, which will account for 40% of the evaluation and will be scored by teachers on-site to boost student participation and motivation. Students will also be required to submit experimental reports, representing 60% of the assessment, evaluated based on data accuracy, content completeness, and formatting correctness to encourage the development of good habits.

In the innovative collaboration dimension, relevant case studies will be integrated into theoretical courses, where groups will submit solutions that will be assessed based on the completeness and feasibility of their technical approaches. Additionally, classroom discussions will be organized around current issues, such as "The Open Sharing of Industrial Data vs. Privacy Protection," and will be scored based on the logical coherence of their arguments and supporting technology, accounting for 50% of the assessment. Furthermore, a peer evaluation system within groups will also account for 50%, promoting effective collaboration among team members.

A comparison of the old and new assessment strategies is presented in Table 3. As shown, the optimized approach aligns more closely with the actual allocation of class hours, reducing the emphasis on engineering practice while preserving the core competency orientation, ensuring it meets time constraints while comprehensively evaluating student capabilities.

Table 3: Comparison of old and new assessment strategies.

Indicator	Original Plan	Optimized Plan
Knowledge Mastery	Single closed-book exam (60%)	Closed-book exam (48%) + Classroom performance (12%)
Engineering Practice	Primarily experimental reports (40%)	Experimental report (12%) + Classroom practical (8%)
Innovative Collaboration	Not reflected	Group discussions (10%) + Peer evaluation (10%)
Adaptability	Excessive weight on experiments	Total practical weight of 25%, aligned with 8 class hours

4. Conclusion

Industry 4.0 demands interdisciplinary talent proficient in Industrial IoT (IIoT) technologies. This paper addresses the challenges facing the IIoT course under the dual demands of Industry 4.0 and the new engineering education framework and five aspects of curriculum reform methods are proposed as detailed below:

(1) Curriculum Reconstruction: Modularize content into "Fundamental Theory-Technical

Modules-Comprehensive Applications," integrating mechanical, IT, and control disciplines. Implement dynamic updates (20% per term) to align with IIoT frontiers.

(2) Teaching Innovation: Adopt problem-driven learning anchored in real IIoT challenges. Combine micro-lectures (e.g., Superstar platform), flipped classrooms, and collaborative projects.

(3) Practical Enhancement: Develop digital twins via Siemens PS and physical production lines, enabling cost-effective virtual-real experiments that build practical skills.

(4) Faculty Development: Deploy dual-track mentoring—industry experts teach; faculty complete industry rotations—to strengthen teaching relevance and student employability.

(5) Assessment Revolution: Shift from exams to competency-based evaluation (knowledge mastery, engineering practice, innovation).

The curriculum reform methods proposed in this paper can bridge theory-practice gaps by replacing score-centric metrics with competency badges and embedding blockchain-verified learning trajectories. The mechanism bridges academia and industry, transforming passive learners into agile, solution-driven engineers, ensuring graduates meet the rapidly evolving demands of Industry 4.0.

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