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Construction and exploration of a practical teaching system for automation majors in the context of emerging engineering education

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Abstract. As a new round of scientific and technological revolution and industrial transformation continues to accelerate, the development of emerging engineering education has placed higher demands on the engineering practice skills, interdisciplinary innovative thinking, and complex systems problem-solving abilities of students majoring in automation at higher education institutions. However, practical teaching in automation programs currently faces several persistent challenges, including a disconnect between course content and industrial technological advances, monotonous teaching methods, insufficient engineering experience among faculty members, and rigid assessment mechanisms. This study introduces the concept of a closed-loop educational ecosystem and develops a practical teaching system characterized by "three stages, four dimensions, and dual cycles". The three stages constitute a progressive competency development pathway of "foundational understanding–integrated practice–advanced innovation". The four dimensions—"institutional guidance, resource integration, methodological innovation, and dynamic assessment"—form an enabling framework that encompasses the entire teaching process. The dual cycles comprise an internal teaching–learning cycle centered on data-driven approaches and an external university–industry cycle characterized by the integration of industry and education. By restructuring modular curricula, implementing full-cycle project-based learning, fostering collaboration between university and industry faculty, and adopting multidimensional dynamic assessment, this study explores effective approaches to practical teaching reform. Preliminary empirical evidence indicates that the proposed system effectively improves students' hands-on engineering skills and innovative capabilities, providing a theoretical framework and practical model that may inform teaching reform in other engineering disciplines.

Keywords: emerging engineering education, automation, practical teaching, project-based learning, integration of industry and education

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1. Introduction

1.1. Research background

The development of emerging engineering education is driving profound changes in higher engineering education. As a key discipline connecting information and physical systems, as well as software and hardware, automation is undergoing a fundamental transformation in its technological landscape and application scenarios, driven by cutting-edge technologies such as artificial intelligence and multisource information fusion. These developments pose greater challenges to the knowledge structures and practical competencies required of future professionals [1-4].

A closer examination of current practical teaching reveals several underlying problems. First, course content updates lag behind technological developments. Laboratory experiments primarily focus on verifying established principles and are disconnected from rapidly evolving industrial technologies. Second, teaching practices remain rigid, relying heavily on standardized experimental kits and lacking authentic project-based learning. Consequently, students struggle to respond effectively to unstructured real-world engineering situations. Third, faculty members lack sufficient engineering experience, particularly young teachers who have limited hands-on experience in industry. Fourth, assessment methods rely excessively on summative examinations, with insufficient attention to continuous monitoring of students' learning progress and dynamic feedback. These problems fundamentally stem from the lack of dynamic adaptability and mechanisms for internal and external collaboration within the existing teaching system. Therefore, developing a new practical teaching system that promotes collaboration between internal and external resources and enables reciprocal support between teaching and learning has become an urgent priority.

1.2. Research objectives

This study aims to systematically address the bottlenecks in practical teaching for automation majors. Specifically, it pursues three objectives. First, it establishes a three-stage, progressive competency development pathway of "foundational understanding–integrated practice–advanced innovation". Second, it develops an enabling framework that encompasses the entire teaching process through four dimensions: "institutional guidance, resource integration, methodological innovation, and dynamic assessment". Third, it establishes a data-driven internal teaching–learning cycle and an external university–industry cycle based on the integration of industry and education, thereby enabling the system to adapt dynamically and evolve continuously.

Theoretically, this study introduces closed-loop educational ecosystem theory into practical teaching in engineering disciplines, enriching the methodological foundations of engineering education research. In practical terms, it proposes a modular reform framework that can be updated dynamically, providing an actionable model for similar academic programs.

2. Analysis of the current state of related research

2.1. Current state of research

In recent years, research on practical teaching systems in engineering disciplines has expanded considerably, focusing primarily on three areas: competency development, technology-enabled teaching, and industry–education collaboration.

In terms of competency-based education and curriculum restructuring, Yang Cao and Jing Luan proposed a three-tier framework of "foundational verification–integrated design–innovative exploration", supported by enterprise-level projects [2]. Chunyu Duan et al. developed a spiral model of "individual skills–system integration–engineering practice" [4]. The CDIO approach takes the entire product lifecycle as its starting point, while the Outcome-Based Education (OBE) philosophy emphasizes the backward design of teaching and assessment based on learning outcomes. Some education researchers have further advocated a shift from isolated skills training toward the development of interdisciplinary systems thinking [3–6]. These studies highlight the central role of progressive competency development and outcome-oriented design in practical curriculum development, providing theoretical references for the three-stage pathway proposed in this study.

In terms of technology-enabled teaching and project-based learning, Jiarong Wu et al. explored a practical teaching system integrating virtual and physical experiments. Technologies such as digital twins and remote operation and control have also been introduced into practical teaching [3]. However, these applications have largely focused on individual courses or laboratory modifications. Project-Based Learning (PBL) has become a mainstream pedagogical approach. S. Wang et al. developed an integrated support system comprising a "reference training system–course development platform–enterprise-based real-world workshop". Capstone design courses, meanwhile, require students to complete full-cycle, interdisciplinary projects [1], effectively strengthening their abilities to solve complex problems and collaborate in teams. Technology-enabled teaching and project-based learning have significantly enhanced the immersive and integrative nature of practical instruction, but systematic integration across the entire teaching cycle remains insufficient.

In terms of industry–education collaboration and quality assurance, various organizational models, including industry-oriented colleges, university–industry joint laboratories, and dual-mentor systems, have been widely explored [7-11]. However, most partnerships remain at the level of resource exchange, without achieving deeper collaboration in joint curriculum development, shared process management, and collaborative quality assessment. Regarding quality assurance, the European Network for Accreditation of Engineering Education (ENAEE) has established a multilayered learning-outcome assessment system that requires practical components to incorporate measurable indicators and closed-loop feedback. Learning analytics technologies are also being introduced to predict the extent to which practical competencies have been attained, providing a basis for personalized intervention. These developments indicate that increasing attention is being paid to industry–education collaboration and formative assessment, although institutionalized, in-depth collaboration and data-driven improvement still require further development.

2.2. Review of existing research and the focus of this study

Taken together, existing studies emphasize the integration of theory and practice, but three gaps remain in implementation. First, the translation of cutting-edge industrial technologies into teaching content is inefficient. Second, institutionalized pathways for interdisciplinary teaching and research collaboration are lacking. Third, teaching assessment tends to prioritize outcomes over process monitoring. To address these gaps, this study moves beyond a linear approach to incremental improvement and introduces the concept of a closed-loop educational ecosystem to propose a practical teaching framework characterized by "three stages, four dimensions, and dual cycles". The three stages respond to the principles of progressive competency development and establish the central competency development pathway. The four dimensions integrate institutional arrangements, resources, methods, and assessment to create an enabling platform that encompasses the entire teaching process. The dual cycles establish, respectively, a data-feedback mechanism connecting teaching and learning (the internal cycle) and a collaborative talent development mechanism linking universities and enterprises (the external cycle). Together, these elements enable the system to adapt

dynamically and evolve continuously, with the aim of organically integrating authentic industrial challenges, multidisciplinary advances, and the entire teaching process.

3. Analysis of the current state of practical teaching in automation programs

To accurately diagnose the key challenges in practical teaching, this study adopts a mixed-methods approach combining questionnaire surveys, semi-structured interviews, and teaching data analysis. The diagnosis focuses on four dimensions: course content, practical scenarios, faculty collaboration, and assessment mechanisms.

3.1. Lagging curriculum restructuring and a pronounced technological gap

The survey results show that 68% of students believe that core practical courses are disconnected from the needs of industries such as intelligent manufacturing, the low-altitude economy, and unmanned systems. Current courses continue to focus primarily on PID control and basic Programmable Logic Controllers (PLCs), with limited coverage of cutting-edge fields such as multisource information fusion, vision-based robot navigation, and intelligent sensing using metasurface sensors. As a result, students encounter technological barriers when seeking employment or participating in high-level competitions. The underlying cause is the absence of institutionalized channels for translating cutting-edge industrial technologies into teaching content [9–12]. In other words, the external university–industry cycle is not functioning effectively. Course updates lag behind the pace of industrial development, constraining students' progression toward advanced innovation.

3.2. Limited practical scenarios and a lack of project-based learning and engineering thinking

Practical teaching relies heavily on packaged laboratory kits. "Black-box" verification experiments make it difficult to demonstrate system architecture and underlying operational principles, thereby hindering inquiry-based learning. More than 75% of students do not know how to break down requirements, select hardware, or integrate systems when faced with open-ended engineering tasks, such as designing a ROS-based autonomous navigation vehicle [13-15]. This problem essentially reflects the absence of the methodological innovation dimension. Full-cycle project-based learning has not yet become routine, and authentic industrial projects, interdisciplinary platforms, and modular courses lack effective integration. Consequently, the current system struggles to support students in making the transition from integrated practice to advanced innovation.

3.3. Pronounced faculty silos and insufficient cross-disciplinary collaboration

Automation technology has become deeply integrated with electronic information engineering, instrumentation science, and computer science. Nevertheless, faculty members often work in isolation, and some instructors have been disconnected from front-line engineering practice for extended periods. This makes it difficult for them to guide students in addressing complex problems such as electromagnetic interference immunity and synchronous calibration of multiple sensors. This issue reflects deficiencies in both institutional guidance and resource integration. Regular mechanisms for collaborative teaching and research are lacking both across university departments and between universities and enterprises. The external university–industry cycle has not established channels for the two-way mobility of faculty members, resulting in the slow renewal of teachers' engineering competencies and directly undermining the effectiveness of guidance at all three stages of competency development.

3.4. Rigid assessment indicators and a lack of data-driven dynamic feedback

Assessment methods based on attendance and laboratory reports cannot adequately reflect students' innovative capabilities or practical skills. Team contributions, algorithmic rigor, and iterative processes involving trial and error are often overlooked. Without a mixed-method assessment system combining qualitative and quantitative measures, educators cannot accurately identify students' weaknesses. At the mechanism level, this problem points to the absence of dynamic assessment and a breakdown in the internal teaching–learning cycle. Data generated throughout the teaching process are not fed back into decision-making, making it difficult for teachers to adjust their instructional strategies and for students to receive personalized feedback. Consequently, a closed-loop mechanism in which teaching is guided by learning outcomes and continuously improved cannot be established.

The four structural contradictions identified above, together with the underlying deficiencies in coordination across the four dimensions and the breakdown of the dual cycles, constitute the practical starting point of this study. Accordingly, the next chapter develops a practical teaching system characterized by "three stages, four dimensions, and dual cycles" to address these challenges systematically.

4. Design and construction of the "three-stage, four-dimensional, dual-cycle" practical teaching model

To address the four structural contradictions identified in Chapter 3, this study develops a practical teaching system for automation programs characterized by "three stages, four dimensions, and dual cycles". Grounded in closed-loop educational ecosystem theory and integrating the principles of Outcome-Based Education (OBE) and Conceive–Design–Implement–Operate (CDIO), the model emphasizes progressive competency development, coordinated elements, and dynamic feedback. The three stages constitute the longitudinal competency development pathway, the four dimensions form the horizontal support framework, and the dual cycles serve as the driving mechanism. Together, these elements are coupled to form an extensible and adaptive ecosystem for practical teaching.

4.1. Overall model architecture and theoretical foundations

The model is designed according to three principles. The first is the progressive development of competencies: three successive stages are established in accordance with the spiral progression of cognition. The second is the systematic integration of supporting elements: the four dimensions of institutional guidance, resource integration, methodological innovation, and dynamic assessment are integrated to create an enabling framework that encompasses the entire teaching process. The third is the ecological nature of the operating mechanism: the internal teaching–learning cycle and the external university–industry cycle are coupled bidirectionally to achieve dynamic updating and continuous self-evolution. This architecture directly addresses the lack of coordination across the four dimensions and the breakdown of the dual cycles, seeking to move from localized improvements toward systemic restructuring.

4.2. The three progressive stages: design of the competency development pathway

The three-stage framework reflects the process through which automation professionals develop competencies, progressing from foundational understanding to advanced innovation. It spans undergraduate and postgraduate education, establishing a competency development pathway in which each stage builds on the preceding one.

The foundational understanding stage focuses on fundamental principles and toolchains. In addition to circuit analysis and C programming, the curriculum incorporates Python and MATLAB for control applications, Git version control, and CAN and I²C communication protocols. These components help students develop an end-to-end understanding of software, hardware, and communications, establishing the technical foundation required for integrated practice.

The integrated practice stage emphasizes the integration of multiple technologies and modular project-based training. For example, students may conduct data acquisition and feature extraction using metasurface sensors or carry out coordinated multi-motor control experiments in industrial process control. Students are required to complete hardware-in-the-loop simulations under complex interference conditions, progressing through requirements decomposition, hardware selection, algorithm design, and system integration. This stage addresses the problems of limited practical scenarios and insufficient engineering thinking.

The advanced innovation stage introduces projects such as "Human–Machine Collaboration and Complex Systems Design" and incorporates authentic enterprise research topics, such as optimizing multisensor resilient navigation algorithms for agile low-altitude aircraft. Students form interdisciplinary teams and complete algorithm derivation, code implementation, and physical prototype validation. Through these activities, they develop their ability to solve complex engineering problems and strengthen their innovative capabilities, directly addressing the deficiency in advanced innovation. The three stages are connected through curriculum articulation, progressively challenging projects, and competency certification, ensuring the continuous, spiral development of students' abilities.

4.3. Four-dimensional coordination: an enabling framework for the entire teaching process

To translate the objectives of the three stages into practice, this study establishes a four-dimensional support network comprising institutional guidance, resource integration, methodological innovation, and dynamic assessment.

The institutional guidance dimension provides support at the school and faculty levels for recognizing credits earned through modular courses and encourages joint course delivery across departments. It also incorporates teachers' industry-based practical experience into performance evaluations and establishes dedicated positions for industry–education integration, thereby providing organizational support and incentives.

The resource integration dimension develops a matrix of online and offline resources. Offline initiatives include establishing joint automation laboratories and interdisciplinary innovation workshops. Online, virtual teaching and research communities are established through the National Smart Education Platform to facilitate the sharing of practical project repositories, open-source code repositories, and industrial case libraries across universities and enterprises. These measures address the lack of effective channels for translating cutting-edge industrial technologies into teaching content.

The methodological innovation dimension addresses faculty silos by establishing a tripartite teaching and research community integrating ideological and political education, science and technology, and industry. A faculty development program is implemented, including project-based training led by enterprise technical experts. Full-cycle project-driven teaching is promoted to transform authentic industrial needs into focused teaching and research projects.

The dynamic assessment dimension introduces a dual-track assessment system. Quantitative indicators include algorithmic complexity, code execution efficiency, and hardware stability, while qualitative indicators cover teamwork, innovative thinking, and iterative processes involving trial and error. Learning analytics technologies are used to collect data on students' practical activities, generating formative assessments and

digital competency profiles that provide an evidence base for instructional improvement. The four dimensions reinforce one another: institutional arrangements provide safeguards, resources establish the necessary conditions, teaching methods offer implementation pathways, and assessment supplies feedback.

4.4. Dual-cycle driving mechanism: a closed-loop educational ecosystem

The dual-cycle mechanism represents the model's core innovation. It aims to establish channels for internal and external coordination and create an ecosystem-based operating mechanism. The internal cycle enables the dynamic optimization of teaching and learning. Throughout full-cycle project-based practice, data on competency improvement, trial-and-error rates, collaborative behaviors, and other relevant indicators are continuously collected to generate digital competency profiles for students. These profiles provide personalized feedback to students and, in turn, enable teachers to refine their teaching syllabi and instructional priorities. The revised teaching strategies are then tested in subsequent practical activities, forming a closed loop of "data collection–diagnostic analysis–instructional adjustment–subsequent practice". This mechanism addresses the breakdown caused by the lack of data-driven assessment and the absence of an evidence-based foundation for instructional improvement. The external cycle facilitates cross-sector collaboration between industry and education. A bidirectional mobility mechanism is established between universities and enterprises: enterprises provide industrial requirements and technical guidance, while universities contribute research solutions and qualified personnel. Through industry–education integration, joint laboratories, and collaborative curriculum development, the system ensures that ongoing industrial technological advances are continuously incorporated into teaching content, addressing the persistent problem of curricula lagging behind industrial development.

The two cycles interact to establish an ecosystem-based operating mechanism. The internal cycle improves teaching quality and learning effectiveness, while the external cycle injects industrial vitality and cutting-edge requirements into the system. Requirements generated by the external cycle feed into the internal cycle's teaching objectives and assessment criteria, while the talent and research outcomes produced by the internal cycle are fed back into the external cycle. This creates a closed loop of "requirements–teaching–feedback–updating", enabling the system to remain responsive and evolve continuously. The proposed model not only addresses the four structural contradictions identified in Chapter 3 but also provides a theoretical framework and operational blueprint for the subsequent design of implementation pathways, empirical validation, and wider adoption and replication.

5. Practical implementation pathways and a core case based on the dual-core curriculum of "perception–drive"

To verify the operability and effectiveness of the "three-stage, four-dimensional, dual-cycle" model, this study uses undergraduate teaching in the Automation program at Inner Mongolia University as a pilot. Two core courses, Sensors and Detection Technology (the perception component) and Power Electronics and Electric Drives (the drive component), are selected to establish a dual-core curriculum integrating perception and drive, exploring system-level restructuring across courses. This approach takes the three stages as its central pathway, the four dimensions as its support framework, and the dual cycles as its driving mechanism, breaking down the "information silos" between traditional courses.

5.1. Curriculum content restructuring: from isolated knowledge points to the integration of cutting-edge modular content

Traditional courses are constrained by textbook revision cycles, causing their content to lag behind industrial developments. Following the three-stage competency development pathway, this study breaks down the two courses into skill modules that can be updated dynamically and incorporates the research outcomes of the project team to keep the curriculum aligned with industrial technological advances. Perception-oriented restructuring of Sensors and Detection Technology: Moving beyond the conventional focus on traditional components such as thermocouples and strain gauges, the course draws on the strengths of instrumentation science to introduce modules on metasurface sensors, smart livestock sensing, and multisource information fusion. When teaching Inertial Measurement Units (IMUs) and vision sensors, the course also incorporates feature extraction and denoising algorithms for multisource data collected in complex low-altitude environments, such as Kalman filtering. This enables students not only to master hardware-based data acquisition but also to understand data processing. The restructuring strengthens the toolchain at the foundational understanding stage and promotes interdisciplinary integration at the integrated practice stage.

Drive-oriented restructuring of Power Electronics and Electric Drives: Moving beyond superficial verification exercises limited to MATLAB/Simulink simulations or laboratory kit wiring, the course incorporates a new "Motor Drives and Energy Management" module in line with advances in industrial coordinated control. The module combines power electronic converter design with the implementation of low-level drive code for brushless DC motors and servo motors, addressing the needs of the new energy vehicle and unmanned aerial vehicle industries. This enables students to progress from integrated practice toward advanced innovation.

These curriculum reforms directly address the disconnect between course content and industrial technological advances, demonstrating how the resource integration dimension systematically incorporates cutting-edge industrial resources into teaching.

5.2. Cross-course project-based learning: establishing a system-level closed loop from perception to decision-making and execution

The core initiative is to break down the barriers created by separate assessment systems for the two courses and implement joint Project-Based Learning (PBL) across both courses. Students progress from foundational understanding to integrated practice while gaining initial exposure to the requirements of advanced innovation.

Core case: "Design of a Perception and Drive System for an Agile Aircraft or Mobile Robot" is as follows.

During the middle and later stages of the semester, instructors from both courses jointly introduce an integrated project. Working in groups, students independently design a complete control system that forms a closed loop of "perception–decision-making–execution".

Perception component (assessed in the sensors course): Students select multiple sensors, including IMUs, LiDAR, and encoders; configure their interfaces and communication protocols; collect data containing real-world noise; and implement multisource sensor fusion algorithms for attitude estimation. Decision-making component (integrated across both courses): Based on the attitude estimation results and task objectives, students design control strategies using PID control, Field-Oriented Control (FOC), or model predictive control. Execution component (assessed in the electric drives course): Students design drive circuits or three-phase inverter circuits and implement motor control programs using FOC or PID control to achieve closed-loop control of hub motors or aircraft rotors. Through this case, students understand how sensor data are translated into motor torque, completing the reconstruction of their engineering systems thinking within a

closed-loop framework. This initiative corresponds to the methodological innovation dimension and lays the foundation for advanced innovation.

5.3. Establishing a tripartite teaching and research community of ideological and political education, science and technology, and industry: strengthening faculty capacity and the external university–industry cycle

Building on the external university–industry cycle, this study establishes a tripartite teaching and research community to address faculty silos. University-based academic mentors (science and technology dimension): Faculty teams specializing in sensors and metasurface technologies oversee the perception component, while young faculty members specializing in intelligent coordinated control oversee the drive component. Together, they establish an interdisciplinary collaboration mechanism. Industry engineering mentors (industry dimension): In collaboration with external automation enterprises, the university establishes a joint practical teaching and research center. Authentic industrial challenges, such as signal crosstalk suppression under strong electromagnetic interference and thermal management of high-power motors, are introduced into the classroom and transformed into inquiry-based projects. Teaching management team (ideological and institutional dimension): The team provides institutional support and value-oriented guidance, integrating engineering ethics, teamwork, and the spirit of innovation throughout the project process. The tripartite community shifts faculty engagement from isolated efforts toward collaborative education, providing an organizational structure and institutional channels for the external cycle.

5.4. Digital and intelligent empowerment of dynamic assessment: dual-track evaluation based on full-process monitoring

Assessment is upgraded from written examinations and laboratory reports to a dual-track evaluation system based on continuous monitoring. This corresponds to the dynamic assessment dimension and drives the internal teaching–learning cycle. Quantitative assessment track: Indicators include algorithmic complexity, code execution efficiency, and hardware stability, as well as students' performance in addressing specific engineering issues, such as compensating for sensor zero-bias errors and configuring motor dead time. Qualitative assessment track: Indicators include teamwork, innovative thinking, and iterative processes involving trial and error. Project presentations and peer reviews are used to assess interdisciplinary logical reasoning. Digital competency profiles and internal-cycle feedback: Data collected through full-process monitoring are used to generate digital competency profiles, which serve as a basis for final grades and provide feedback to course instructors. The profiles also inform dynamic adjustments to course syllabi in the following academic year, establishing an internal cycle of "data collection–diagnostic analysis–instructional adjustment–subsequent practice".

The pilot implementation indicates that this approach effectively shortens the cycle for translating industrial technologies into teaching content, enhances engineering systems thinking and complex problem-solving capabilities, and alleviates faculty silos. It also provides data to support continuous instructional improvement and can be extended to other course clusters, such as "control–communications" and "algorithms–execution".

6. Conclusion and prospect

6.1. Conclusion

To address the four structural contradictions in practical teaching for automation programs, this study developed and conducted a preliminary validation of a practical teaching system characterized by "three stages, four dimensions, and dual cycles". The conclusions are as follows. First, modular curriculum restructuring guided by cutting-edge industrial developments can effectively reduce the technological gap between course content and industrial advances by incorporating topics such as intelligent control and novel sensing technologies into the three-stage competency development pathway. Second, full-cycle project-driven, cross-course collaborative teaching, implemented through the dual-core curriculum of perception and drive, enables students to complete system integration and physical validation within a closed loop of "perception–decision-making–execution", thereby enhancing their engineering systems thinking and complex problem-solving capabilities. Third, coordination across the four dimensions and the dual-cycle mechanism are the core driving forces behind continuous quality improvement. The coordinated four-dimensional framework provides comprehensive support, the internal cycle enables data-driven improvement through digital competency profiles, and the external cycle keeps the system open through the tripartite teaching and research community. Their integration enables the system to adapt dynamically and evolve continuously. Fourth, preliminary results from the pilot implementation indicate that the model has a positive effect on students' practical engineering skills, innovative capabilities, and interdisciplinary collaboration. It can therefore serve as a reference for teaching reform in other engineering disciplines.

6.2. Research limitations and future prospect

This study has several limitations. The pilot covers a limited scope and sample size, and its generalizability requires validation across multiple universities. The pilot period is relatively short, and long-term tracking of graduates' career development remains insufficient. The data dimensions and algorithms used to generate digital competency profiles are still under development, while privacy protection and ethical safeguards require further improvement. In addition, the study relies primarily on case analysis, and further work is needed to strengthen causal inference and large-scale quantitative validation. Future research will expand the pilot to multiple universities and conduct long-term follow-up studies. Learning analytics and large language models will be introduced to optimize competency profiling algorithms. Operational guidelines for the dual-cycle mechanism will be refined through institutional arrangements such as industry–education integration committees and joint laboratories. Furthermore, the integration of OBE, CDIO, and educational ecosystem theory will be deepened to develop a localized theoretical framework for engineering practical education with greater explanatory power and broader applicability.

In conclusion, this study seeks to provide a system-level reform pathway for the development of emerging engineering education in automation programs through the proposed practical teaching system of "three stages, four dimensions, and dual cycles". Future research will continue to deepen empirical investigations and refine the model, providing theoretical and practical support for cultivating engineering professionals equipped with hands-on engineering capabilities, interdisciplinary innovative thinking, and the ability to solve complex systems problems.

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