Rethinking the Teaching Reform of Mechanical Control Engineering under the New Engineering Initiative

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Abstract: Mechanical Control Engineering is typically taught as a sequence of mathematical procedures: students learn how to perform calculations but cannot explain or apply them. This paper explores three structural causes of the persistent divide between classroom instruction and engineering practice under China's New Engineering initiative: theory-dominated course content, limited industrial experience among instructors, and predominantly idealized laboratory simulations with little access to representative mechanical systems. A comprehensive reform framework is proposed. Course content should be reorganized around authentic problems in servo motion, robot-joint control, vibration suppression, and intelligent manufacturing; faculty development should combine industrial placements with university-industry co-teaching; and laboratory instruction should integrate simulation-based rehearsal, remote access to physical equipment, hands-on experimentation, and iterative model refinement. Assessment should likewise move away from reproducing formulas and toward case analysis, commissioning plans or performance, project outcomes, and teamwork. The framework reiterates the central logic of engineering practice: engineering problems lead to mathematical models, which are analyzed and then used to improve systems. It is designed to strengthen students' systems thinking, engineering judgment, and ability to solve complex control problems.

Keywords: New Engineering; Mechanical Control Engineering; Teaching Reform; Virtual-Physical Integration; University-Industry Collaboration

1. Introduction

Control engineering is easy to teach too narrowly. Traditional instruction generally follows a linear sequence: Laplace transforms, mathematical modeling, block-diagram reduction, time-domain analysis, frequency-domain analysis, stability criteria, and compensator design. When these topics are treated as discrete mathematical modules connected only loosely through exercises, students may come to view control theory as merely an extension of advanced mathematics. This obscures the discipline's ultimate purpose: control theory arises from engineering problems and should ultimately inform engineering practice.

A coherent course could begin with engineering problems and the development of mathematical models, move through model-based analysis to identify system limitations, and then use application-oriented studies to guide improvements in structure, parameters, and performance. In many classrooms, however, the real-world context is increasingly stripped away. Students memorize formulas but cannot explain their physical significance; they perform calculations without knowing how to interpret the results. This is a serious limitation for students in mechatronics, intelligent manufacturing, and robotics. Anecdotal evidence suggests that when classroom examples do not extend beyond standard textbook transfer functions to DC motor speed regulation, servo positioning, mechanical vibration suppression, or robot-joint control, students struggle to relate automatic control theory to their own disciplines. Similarly, international work on control education emphasizes real-world problems, design activities, and hands-on experience so that mathematics contributes to systems analysis and engineering decisions [1,2].

Course feedback reflects the scale of this issue. In an online survey on Mechanical Control Engineering, 62.7% of respondents selected "not helpful at all" or "not very helpful" when asked how the course had helped them in their subsequent work, whereas only 11.4% said that the course had been "very useful." When asked about the textbook's core calculations, many graduates said that they rarely used them three to five years after graduation and described the course as difficult, time-consuming, and largely disconnected from employment. Reconnecting theory, mechanical systems, and engineering practice would therefore improve both the perceived and actual value of the course. This paper analyzes why the divide has emerged and puts forward an integrated reform framework.

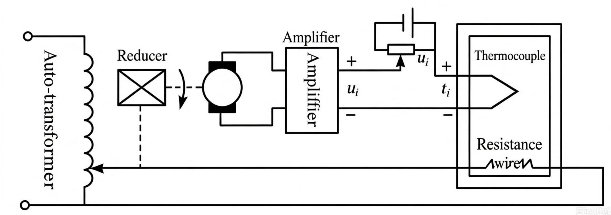
2. Causes of the Theory-Practice Disconnect

The gap between teaching and engineering practice is not the product of any single deficiency. It emerges from the combined effects of curriculum structure, faculty expertise, and laboratory conditions.

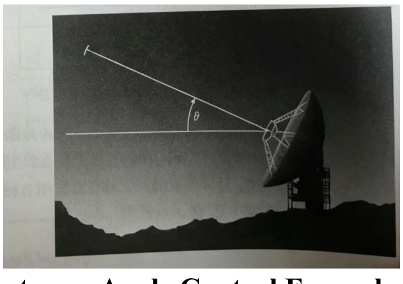
2.1 Theory-Dominated Teaching Materials

Studies of domestic Mechanical Control Engineering materials have identified a recurring pattern described as the "three emphases and three neglects": emphasis on theoretical completeness rather than engineering cases, on derivation rather than implementation, and on knowledge transmission rather than capability development [3]. Many examples and exercises are presented as purely symbolic manipulations unrelated to real manufacturing systems or machine elements. As a result, students may learn the equations but remain unable to explain how control algorithms operate in machine-tool drives [4], robotic systems, or other electromechanical equipment.

Introduction to Mechanical Engineering Control by Yang Shuzi and Yang Kechong is a standard textbook widely used in China. Although it is theoretically coherent and logically rigorous, its long-term use has also revealed the limitations of a curriculum focused primarily on mathematical content [5]. Greater emphasis is placed on Laplace transforms, transfer-function derivation, frequency-response analysis, and proofs of stability criteria. The engineering context can be lost in dense derivations and abstractions. Meanwhile, the slow pace of textbook revision leaves little room for intelligent automation, digital-twin technology, industrial communication, and other topics related to modern smart manufacturing. International textbooks follow a contrasting organizing principle. Ogata's Modern Control Engineering integrates rigorous theory with MATLAB examples and engineering design exercises, encouraging students to use computational tools to tackle real-world problems [6]. Nise's Control Systems Engineering, for example, introduces concepts through applications such as spacecraft attitude control and disk-drive positioning, thereby establishing a problem-theory-verification loop [7]. As illustrated in Figure 1, comparisons of Chinese and international textbooks indicate that domestic materials emphasize comprehensiveness and academic rigor, whereas international materials focus more closely on implementation [8]. The result is not that domestic students lack a theoretical foundation, but that they may lack skills in application, controller tuning, and system optimization.



(a) Heating-Furnace Illustration in a Chinese Textbook



(b) Antenna-Angle Control Example in an International Textbook

Figure 1. Comparison of the Engineering Contexts Used to Introduce Control Concepts in Domestic and International Textbooks.

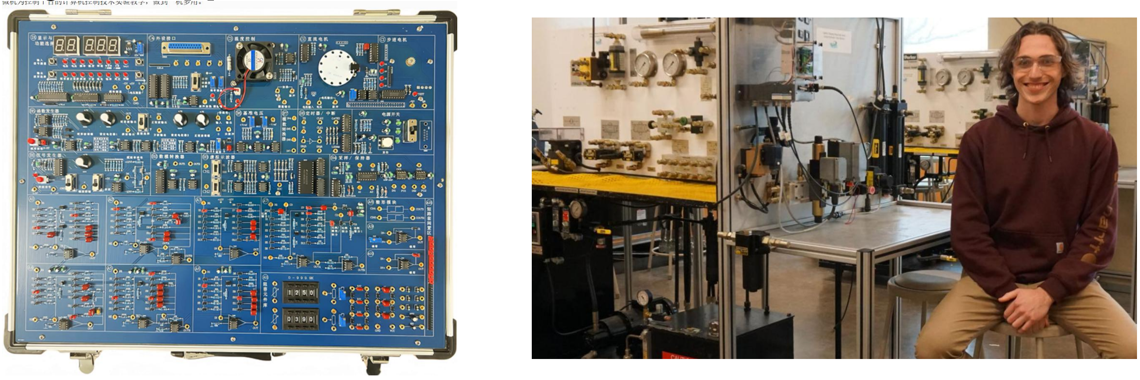
2.2 Insufficient Industrial Experience among Instructors

The emphasis of the teaching materials is reinforced when instructors have had few opportunities to commission industrial equipment, maintain operating systems, or tune controllers under production constraints. Expertise in derivation is indispensable, but it is not equivalent to experience with sensor noise, actuator limits, variable loads, servo setup, vibration, or fault isolation. Instructors who have encountered these effects only through idealized models have fewer concrete examples with which to explain them. They may also find it difficult to respond when students ask why a mathematically satisfactory design performs poorly on actual equipment.

Under these circumstances, control can become an exercise performed on paper. Analytical fluency develops, but the judgment needed to operate or commission an automated system receives less attention. The cost is shifted to employers, who must provide additional preparation before new graduates can work with limited supervision. Research on engineering education for Industry 4.0 supports a broader response: curriculum change, laboratory capacity, interdisciplinary project work, and cooperation with industry should be planned as mutually reinforcing measures [9].

2.3 Experiments with Limited Mechanical Relevance

Laboratory organization constitutes the third constraint. MATLAB tasks and simplified electrical trainers are common, while students may spend comparatively little time working with a mechanical plant. Simulations normally remove or simplify friction, backlash, compliance, delays, changing loads, external disturbances, and measurement noise. The resulting responses are easy to interpret but do not resemble the uneven, iterative work of commissioning. An engineering laboratory should therefore do more than confirm a concept. It should also cultivate measurement practice, interpretation of imperfect data, decision-making about models and designs, collaboration, and professional conduct [10].



(a) A Conventional Automatic-Control Training Kit Used in Chinese Laboratories **(b) A Parker-Hannifin Laboratory Workstation at Western Michigan University**

Figure 2. Comparison of laboratory Platforms with Different Levels of Mechanical Authenticity and System Integration.

This argument does not imply that virtual laboratories lack educational value. Reviews show that carefully designed virtual and remote experiments can support conceptual learning as effectively as conventional laboratories, and sometimes more effectively. The evidence is less consistent, however, for hands-on skills, inquiry, troubleshooting, and familiarity with real equipment [11,12]. Simulation is therefore most useful as one stage in a broader experimental design. Students can rehearse safely in software, operate a physical plant remotely, and then work directly with the equipment. Existing remote-control laboratories demonstrate that network access can still expose learners to the measured dynamics of a real plant [13].

As shown in Figure 2, the choice of plant is particularly important in a mechanical engineering program. Students' disciplinary frame includes motion, mechanisms, drives, rigid-body dynamics, and structural behavior. A circuit trainer or numerical model alone can conceal the fact that the controller acts through a mechanical assembly. Equations may be verified without observing how damping, compliance, friction, and delay affect stability and precision. This helps explain why a student who produces convincing simulations may still be unsure how to tune a servo axis, reduce machine-tool vibration, or diagnose positioning errors in a robot. Experiments in which every component is known and every response is clean give a misleading impression of engineering practice, in which uncertainty, faults, and repeated adjustment are normal.

3. Reform Strategies

The preceding weaknesses are cumulative.

Abstractly organized materials make the subject harder to enter; limited industrial experience further narrows the supply of credible explanations; and mechanically unrepresentative experiments leave little room for translating knowledge, creativity, and design into engineering capability. Reform will therefore remain piecemeal unless course content, faculty development, experimental work, and assessment are redesigned in relation to one another.

3.1 Redesigning Course Material Around Engineering Problems

Content can be reorganized in three complementary ways: focus the core theory, refresh the case base regularly, and introduce selected emerging technologies. Focusing the theory does not mean eliminating mathematics. Rather, it means reducing the verification of known results or the performance of calculus with little engineering insight while preserving the concepts needed for modeling, design, and interpretation. A task might begin with the response of a machine-tool feed axis, a robot joint, or a vibrating structure. Analytical tools can then be introduced as required. This sequence can turn abstract concepts into tangible skills and lower the initial barrier to understanding [5,8].

Selected cases can also introduce digital twins, intelligent PID tuning, mechatronic coupling, data acquisition, and industrial communication without turning the course into a catalog of fashionable terms. Tasks can be graded on an openness scale: early exercises test a concept, later exercises require a design choice, and final exercises ask students to defend performance under nonideal conditions. In this way, students follow a complete cycle of inquiry: they identify a physical object, construct and test a model against observations, identify limitations, propose an intervention, and repeat the design-test-analysis cycle.

3.2 Strengthening Faculty Engineering Competence

Knowledge moves in both directions between universities and engineering organizations, but this exchange must be sustained as part of faculty development. Instructors could undertake placements in intelligent manufacturing enterprises, where they would maintain equipment, commission servo systems, adjust key parameters, or integrate control systems. The educational return is not merely familiarity with a factory. Recorded failures, constraints, and design compromises can be transformed into cases, demonstrations, and project briefs when instructors return to campus.

Co-teaching provides a second channel. Practicing engineers can participate in case discussions, project critiques, and laboratory supervision, while university instructors connect practical experience to analytical principles. Co-teaching should be linked to shared learning outcomes and planned across the course; an isolated guest lecture rarely changes curriculum practice. Sustained participation allows industrial reasoning to shape what students do and how their work is evaluated through repeated exposure to the diagnosis and optimization of authentic systems.

3.3 Constructing a Virtual-Physical Experimental System

Simulation and hardware should be treated as sequential, interrelated forms of evidence in laboratory design. For example, students can obtain data from a physical device and then construct a provisional simulation model. Differences between predicted and measured responses can then guide parameter adjustment or the inclusion of nonlinear effects. The revised model is tested again, making modeling and experimentation an iterative loop rather than separate tasks. Small robotic mechanisms, inverted pendulums, and vibration rigs are suitable plants because their behavior is mechanically interpretable and their parameters can be explored safely [14].

Digital twins can expand the range of conditions that students can study by reproducing operating states, disturbances, and faults in expensive or hazardous machine tools and robotic systems [15]. Their educational value extends beyond three-dimensional visualization. An operational twin uses data links to maintain a dynamic correspondence between the physical asset and its computational representation, supporting diagnosis, prediction, and iterative improvement [16,17]. Team projects should take students through the entire process, from modeling and commissioning to fault analysis and redesign. This approach is consistent with evidence that active, collaborative, and problem-based learning can improve engagement and conceptual understanding [18].

3.4 Reforming Assessment

Assessment must make the desired engineering practices explicit. A single final examination or traditional simulation report cannot demonstrate whether a student can reason about an entire system and respond appropriately. Assessment can therefore include case interpretation and model explanation; experimental planning and tuning on physical equipment; traceability and test records produced during implementation; demonstrations of fault diagnosis; technical documentation; individual contributions to collaborative work; structured analysis; and oral defense. Fundamental concepts should still be tested in a written examination, but routine calculations can be replaced by interpretation, evidence-based justification of design choices, and predictions of system behavior. By awarding marks for both the process and the result, assessment encourages students to explore and solve problems rather than reproduce a procedure.

4. Conclusion

In recent years, China's New Engineering initiative has sought to integrate theory, systems thinking, innovation, and the practical competence of graduates. When course content emphasizes derivation over application, instructors have little industrial contact, and laboratories rely on idealized simulation, Mechanical Control Engineering falls short of that expectation. The combined result is well known: students may manipulate a model correctly but cannot always interpret its physical meaning or implement a solution on actual equipment.

Authentic mechanical control problems should provide the common thread for reform. Core analytical content should be retained, while cases should include servo drives, vibration control, robotics, and digital-twin applications. Faculty development can be strengthened through industry placements and university-industry co-teaching. In experimental work, a progressive workflow from simulation to remote access and direct testing can use data from each stage to improve the model. Assessment should reward case-based reasoning rather than formula reproduction, together with commissioning performance, project outcomes, strategy, and collaboration.

The aim is not to diminish mathematics, but to connect it to the systems it represents and to the decisions that engineers must make. The challenge is to make the course sufficiently credible through problem-based, industry-connected, virtual-physical experimentation while preserving intellectual rigor. Most importantly, the reformed course should enable students to test complex physical systems and justify control decisions in smart manufacturing, robotics, and intelligent mechatronic systems.

Acknowledgments

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