

Three-tier progressive teaching innovation and practice of the course “Principles and Interface Technology of Microcontrollers” from the perspective of emerging engineering education

Chao Chen^{1*}, Yuan Wang¹, Lin Tang¹

¹Geely University of China, Chengdu, China

*Corresponding Author. Email: 821277879@qq.com

Abstract. Against the backdrop of emerging engineering education, the teaching team of the course Principles and Interface Technology of Microcontrollers, guided by the demands of the intelligent manufacturing industry, addresses the core issues of traditional teaching where students “do not know what to learn, why to learn, or how to apply what they learn.” The team has proposed a teaching philosophy centered on “value orientation, competence-based education, and project-driven learning.” This has been implemented through the construction of a “Four-Fold Integration–Three-Level Progression” content system, the development of a “Three-Level Experimental Platform + Multi-Dimensional Resource Bank,” the implementation of a “Three-Tier–Three-Pivot–Multi-Process” teaching model, and the establishment of a “knowledge + competence” dual-helix evaluation system. Together, these form a progressive, three-tier teaching innovation pathway of “top-level design – mid-level implementation – bottom-level execution.” Post-reform, the course has seen a 12% increase in students’ achievement of course objectives, a 50% rise in academic competition awards, and significant enhancement in the innovation of graduation projects. Additionally, the teaching and research capacities of the faculty have improved concurrently. The innovative achievements of the course have further influenced the construction of course clusters and university-enterprise collaboration. This practice provides a replicable model for the reform of application-oriented engineering courses.

Keywords: project-based teaching, two-stage three-tier model, multi-dimensional assessment

1. Introduction

With the advancement of the “Made in China 2025” strategic initiative, the transformation of the manufacturing industry toward intelligence and digitalization places higher demands on talent competencies. As a core course for mechanical engineering majors, Principles and Interface Technology of Microcontrollers must overcome traditional teaching bottlenecks such as the overemphasis on theory at the expense of practice, content homogenization, and insufficient cultivation of innovation capabilities. However, several persistent issues currently plague the course:

Lack of learning motivation: Students lack awareness of the course’s value, with 52.17% showing less than 70% willingness to engage with the course;

Weak practical ability: 80% of students can only complete low-level imitative experiments, making it difficult to tackle complex engineering problems;

Absence of innovation pathways: The award rate in academic competitions is under 4%, and fewer than 35% of graduation projects demonstrate originality.

In response to these issues, the course team, drawing on the theory of meaningful learning (Ausubel, 1968) and under the framework of deep integration between industry and education, constructed an innovative “three-tier progressive” teaching system. This paper systematically outlines the logic behind this system’s design, its implementation path, and the outcomes of the reform, aiming to provide a useful reference for the reform of similar courses.

2. Student profile analysis

Using methods such as questionnaires, ongoing communication, learning data analysis, classroom observation, and field research in enterprises, the following characteristics of student learning were identified:

2.1. Lack of learning motivation and methods—passive engagement and ineffective learning

A pre-course survey showed that 52.17% of students demonstrated low motivation for this course (scoring under 70%). Although 98% of students completed the online preview videos, the average reflection rate was only 56%. Student participation in class was passive, resulting in only moderate learning outcomes.

2.2. Lack of engineering application ability—reliant on imitation

An analysis of past cohorts' performance in the course revealed that while students showed greater interest in practical content compared to theoretical material, their practice was limited to following instructions in the early stages and imitating guided examples later on. Even among top-performing students, independent completion was limited to basic tasks under teacher supervision, indicating a lack of ability to apply engineering knowledge to real-world problems.

2.3. Lack of engineering innovation capability—low initiative and weak creativity

Although students exhibit strong awareness of innovation, as evidenced by high participation rates in entrepreneurship and innovation competitions, the extremely low award rates, simplistic competition topics, and weak innovation performance in enterprise settings indicate that students lack both pathways and techniques for innovation. Their innovation attempts are often restricted to everyday knowledge, failing to meet the needs of industry transformation and upgrading.

3. Analysis of teaching problems

3.1. Lack of value-oriented course content and insufficient connection with prerequisite courses result in weak learning motivation and ineffective study methods

Previously, course content failed to provide value orientation aligned with the context of intelligent manufacturing, which hindered students from appreciating the importance of the course, thereby reducing their motivation to learn. As students' first exposure to a control-focused course, the lack of connection with prerequisite courses and differences in learning and thinking methods further prevented students from effectively grasping the material.

3.2. Lack of authentic, high-level engineering project scenarios in course implementation leads to inadequate practical application ability

Despite the hands-on nature of the course and its adoption of project-based teaching, traditional project-based methods have been confined to low-level projects that differ significantly from actual enterprise requirements. Students lack awareness of real application scenarios and are not guided by targeted engineering project cases, resulting in limited engineering analysis and application abilities. Consequently, they are unable to apply what they have learned to solve complex real-world problems.

3.3. Course design lacks pathways and platforms for developing innovation ability, resulting in insufficient engineering innovation capacity

Traditional teaching focuses on the mastery of knowledge and skills through fixed knowledge points or project cases, typically progressing through the stages of listening, understanding, imitation, and application [1]. However, the cultivation of innovation ability is not made concrete and lacks clear pathways and platforms. This deficiency leaves students ill-equipped to meet the demands of engineering innovation in the context of industrial transformation and upgrading.

4. Theoretical foundations and innovation strategy

4.1. Theoretical basis

The theory of “meaningful learning” asserts that instruction should first build a “bridge” between prior knowledge and new knowledge, incorporating new content into the student’s cognitive structure so that it can be assimilated and internalized, while prior knowledge is reconstructed and refined [2].

4.2. Innovation strategy

At the top-level design stage, the course team integrated mechanical engineering curriculum content to establish strong interconnections between courses and between individual knowledge points. Through a three-tiered, progressive project-based teaching model, along with aligned teaching resources, instructional organization, and assessment strategies, the course facilitates the step-by-step assimilation of new and prior knowledge. This approach ensures that instruction is not only phased, hierarchical, and logical, but also inclusive, open, and systematic.

5. Measures and implementation pathways

5.1. Top-level design: building an intelligent manufacturing practice curriculum system centered on this course

Under the context of intelligent manufacturing, mechanical engineering mainly encompasses the design, manufacturing, and control of mechanical products. However, the corresponding courses for these three areas are often distinct and operate independently. Although each course has undergone its own reforms—such as Mechanical Drawing evolving from sketching basic household items to drafting shaft-sleeve components more relevant to the discipline—these components are rarely applied in subsequent courses.

To cultivate high-level application-oriented talent, relying on a single course is insufficient. Therefore, our top-level design aims to break down the barriers between traditional mechanical courses and control-oriented courses.

Accordingly, the practical content of the microcontroller course is organically linked with earlier traditional mechanical course projects, forming a curriculum cluster with the microcontroller at its core. This establishes a close connection between prerequisite courses and this course, and aligns the specific practice content of the entire cluster with each project in the current course.

Under this design framework, the course team began by researching industry demands through company visits, initiated cross-disciplinary projects, and allocated project components across different courses. Each course co-developed teaching resources in collaboration with enterprises, and engineers were invited into the classroom to participate in both instruction and evaluation. By incorporating industry cases and disciplinary frontiers, some traditional mechanical and control course projects were integrated. For instance, in the microcontroller-based robotic arm project, students are required to control a six-degree-of-freedom robotic arm. During their freshman year, students produce component and assembly drawings of this robotic arm in their Mechanical Drawing course. In the smart vehicle project, second-year students apply their knowledge from Mechanical Design and Mechanical Principles courses to design the chassis structure of the vehicle.

5.2. Mid-level alignment: focusing on instructional innovation in this course

5.2.1. *What to teach: constructing a “Four-Integration, Three-Progression” curriculum content system*

The curriculum content is structured into a progressive model consisting of “basic projects, industry projects, and expansion projects,” integrating core knowledge, industry cases, cutting-edge disciplinary topics, and ideological and political education cases.

While industry projects play a vital role in cultivating students’ higher-order abilities, the complexity of application scenarios and the difficulty of knowledge points in this course require students to first acquire a solid professional foundation. To this end, the course content has been restructured into a three-tier instructional model. The first-tier basic projects focus on mastering fundamental microcontroller knowledge and simple applications, addressing the common challenges students face in learning and comprehension [3]. The second-tier industry projects, which incorporate technologies from other disciplines and real-world cases, aim to improve students’ engineering practice abilities. The third-tier expansion projects are designed by students themselves based on inspiration from competitions, personal interests, real-life scenarios, and resources provided by the course team. These projects target students’ weak innovation capabilities and promote individualized development.

The first-tier basic projects (30 class hours) are low-level projects reconstructed from textbook core knowledge points and are intended to build foundational knowledge through four projects: Project 1 “Decorative Lights” (microcontroller minimum system, LED flashing, and development environment); Project 2 “I/O Interfaces” (digital traffic light, simple calculator, dot matrix

advertisement display); Project 3 “Interrupt System” (anti-theft alarm, digital clock, dual-computer communication); Project 4 “Standalone Systems” (lighting control, temperature sensing, motor control).

The second-tier industry projects (24 class hours) are based on interdisciplinary industry cases from cross-disciplinary horizontal research projects [4]. These projects aim to develop students’ ability to apply engineering skills in real-world industry scenarios, including: “Handling Robot” (servo motor-controlled robotic arm, robotic arm material handling, industrial robotic arm handling); “Smart Car” (basic driving, obstacle-avoiding line-following car, remote-controlled car).

The third-tier expansion projects (10 class hours) are independently designed by students, drawing from cutting-edge disciplinary developments, deep industry-education integration, innovation and entrepreneurship insights, and real-life inspiration. These projects aim to foster students’ engineering innovation capacity to adapt to industrial transformation and upgrading [5].

5.2.2. *How to teach: developing instructional resources through a digital platform*

Teaching resources are developed across the entire instructional process, including teaching aids, lab platforms, online resources, and ideological-political cases. Teaching aids are flexibly aligned with enterprise production practices while ensuring that the knowledge points remain grounded in the curriculum and the implementation is not dependent on textbooks.

The foundational projects adopt a combination of “traditional textbooks + school-based handouts” (developed by the course team), while the industrial and extended projects use “traditional textbooks + technical manuals” (jointly compiled with industry partners). In collaboration with partner enterprises, a four-tier experimental platform has been established: “verification laboratory – pocket experiment board – smart classroom mobile experiment board – real-world scenario laboratory,” designed to progressively enhance students’ practical skills. Before class, students can preview and independently verify key concepts in the verification laboratory, which consists of two components: a microcontroller basics lab and a student competition studio. The first-tier foundational projects are completed using our self-designed pocket experiment boards, which are portable and convenient for completing after-class assignments. Due to the complexity and increased difficulty of the industrial and extended projects, tasks at the lower level are completed in smart classrooms using mobile experiment boards, while advanced tasks are carried out in real-world scenario laboratories co-established with industry partners.

A wealth of online resources supports the entire teaching process, including a “course preview resource library, assignment and test bank, frontier case expansion library, and industry application discussion bank” [6]. To help students build a solid knowledge base and support repeated and sustained learning, over 100 instructional videos have been developed to explain fundamental concepts. Additionally, verification lab manuals and demonstration videos have been published to guide students’ pre-class learning. An Ideological and Political Education (IPE) case library has also been curated to address issues such as repeated use of the same cases across multiple courses within the same major, uniform IPE elements across different teaching periods, and identical IPE content regardless of class or student background. The industry application and innovative case libraries enable students to understand real-world applications of each concept and help them identify innovation opportunities that align with industry transformation and upgrading needs.

5.2.3. *Implementing a “Three-Level, Three-Pivot, Multi-Process” classroom teaching structure*

The three pivots of the course organization—pre-class peer support by student assistants, in-class guided instruction by lead teachers, and post-class supervision by teaching assistants—support three progressive levels of instructional content, each employing a distinct organizational approach. The multi-process instructional phase during class is closely aligned with the characteristics of the project. Overall, the classroom teaching structure for the second- and third-tier projects mirrors the development process of real-world application scenarios.

5.2.4. *Establishing a “Multi-Dimensional and Comprehensive” course assessment system*

The assessment system is anchored on three core evaluators: “primary assessment by instructors, peer assessment within and between student groups, and supplementary evaluation by industry mentors.” The three-tier projects are assessed using eight different methods: knowledge point testing, post-class assignments, project implementation, thematic discussions, presentations, project reports, project outcomes, and advanced applications. These assessments evaluate students’ mastery of knowledge points, engineering application skills, engineering innovation capabilities, and the industry value of their outcomes. In doing so, they measure students’ achievement of the nine course objectives across knowledge, skills, and competencies, while also incorporating value-added evaluations to assess their high-level application capabilities.

5.3. Bottom-level execution: focusing on instructional innovation in a single class session

Taking the course “Smart Manufacturing (Industrial Project II) — Robotic Arm Control (Task I)” as an example, the in-class instructional process is based on the real-world product development workflow for microcontroller-controlled devices and includes the following stages:

Case Introduction: The instructor introduces an engineering problem through a horizontal research project involving an airport logistics production line, incorporating a technological innovation case from a real airport as the Ideological and Political Education (IPE) element.

Goal Clarification: Students are informed of the specific tasks to be completed during the class to quickly grasp the project's core requirements and avoid deviation in the subsequent design phase.

Knowledge Review: Key and difficult points from prior learning are reviewed to reinforce foundational knowledge relevant to the lesson.

Guided Instruction:

- **Requirement Analysis:** Under the instructor's guidance, students identify specific tasks and performance indicators based on a real project, followed by requirement analysis.
- **Design Planning:** Students engage in intra-group discussions to formulate their design plans, followed by group presentations and peer evaluations, after which instructors guide revisions and refinements.
- **Application Exploration:**
- **Hardware Design:** Students are guided to explore problems during circuit design and progressively engage in deeper analysis and development.
- **Programming:** Building on pre-class preparation, the instructor teaches advanced control methods for a single servo motor. Students then write code through hands-on practice to achieve functional goals.
- **Debugging and Operation:** With instructor guidance, students discuss how to extend control from a single servo motor to multiple motors and ultimately to a robotic arm composed of six servos.

In-Depth Expansion: Practice-based validation, adjustment, and optimization strategies are used to simulate the object handling process.

Class Summary: The instructor summarizes and evaluates the strengths and weaknesses of each group's implementation process, highlights challenges encountered, and guides students toward problem-solving strategies.

6. Conclusion

Through teaching reform and innovation, students have shown notable improvements in professional skills and ideological quality, with significantly enhanced employability and job readiness. The course team uses the curriculum as a vehicle to clarify objectives, break the silence of traditional classrooms, and cultivate students' comprehensive ability to solve complex problems. Practice has shown that these innovative methods effectively address key teaching challenges, significantly improve instructional outcomes and teaching proficiency, and enhance societal recognition. These strategies provide valuable insights for talent cultivation in application-oriented undergraduate education.

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