Frontiers in Public Management
ISSN Print: 3104-4441
ISSN Online: 3104-445X
CD ISSN: 3104-4468
https://doi.org/10.63313/FPM.2005

Teaching Reform and Research of Automotive Sensor Course Experiments Based on Project-Based Learning

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How to cite this paper: Zang, H. (2026). Teaching reform and research of automotive sensor course experiments based on project-based learning. Frontiers in Public Management, 2(1), 1–7. ISSN Print: 3104-4441, ISSN Online: 3104-445X. https://doi.org/10.63313/FPM.2005
Published: 2026-10-20

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Abstract

Address prominent issues in traditional experimental teaching of "Automotive Sensors" —such as the overabundance of verification-based experiments, the scarcity of comprehensive design-oriented projects, and students 'passive adherence to experimental instruction manuals—this study integrates the Project-Based Learning (PBL) framework into experimental courses. Utilizing authentic automotive engineering tasks as the foundation, this study restructures the experimental project system, the instructional organizational workflow, and the assessment and evaluation mechanisms. Practical implementation results demonstrate that PBL-based teaching effectively enhances students' engineering practical capabilities, teamwork skills, and problem-solving abilities, thereby offering significant potential for promoting applied talent cultivation in automotive-related disciplines within the context of New Engineering Education.

Keywords

Automotive sensors; Experimental teaching; Project-Based Learning (PBL);Teaching reform; New Engineering Education

Introduction

Automotive sensors serve as the "sensory organs" of modern automotive electronic control systems; their performance directly determines the control precision and reliability of systems such as engine management, chassis control, and autonomous driving assistance. As a core course for majors including Vehicle Engineering, Automotive Service Engineering, and Intelligent Connected Vehicle Engineering, *Automotive Sensors* combines theoretical and practical dimensions, and its experimental teaching component plays a pivotal role in cultivating students' professional competencies. With the rapid advancement of the "New Four Modernizations" in automotive technology—electrification, intelligence, connectivity, and sharing—employers are placing higher demands on automotive

engineering graduates regarding their practical engineering capabilities, system integration skills, and innovative capacities. The traditional verification-based experimental teaching model—characterized by instructor demonstrations and students replicating procedures step-by-step—no longer adequately supports the objectives of cultivating application-oriented and interdisciplinary talent. Building upon the current state of experimental teaching in this course, this study introduces Project-Based Learning (PBL) into the classroom to explore a novel experimental teaching approach characterized by "learning by doing and gaining insights through research."

1. Key Challenges in Traditional Experimental Teaching of Automotive Sensors

Based on a systematic review of teaching archives from the past three rounds of course instruction, student laboratory reports, and feedback from graduates—combined with publicly available teaching reform literature from peer institutions—it has been determined that the shortcomings of traditional laboratory teaching models are primarily manifested in the following four aspects:

Problem Dimensions	Typical manifestations	Impact on the development of students' capabilities
Experiment content	The focus is primarily on performance testing of single-point sensors, with confirmatory experiments accounting for over 70% of the tests; however, there is a lack of comprehensive tests spanning multiple sensors and systems.	Students often "understand only one aspect of the issue" and struggle to establish a systemic perspective encompassing sensors—signals—control—actuation.
Teaching methods, teaching approach, modes of instruction, way of teaching, education method, mode of teaching	The instructor explains the underlying principles and demonstrates the wiring process; students then follow the experimental guidebook step-by-step, with data processing conducted using standardized templates.	Students tend to follow passively, lacking practical training in solution design and fault diagnosis.
Evaluation mode	The weight assigned to the experimental report score is disproportionately high, and data completeness serves as the primary criterion for scoring.	An overemphasis on outcomes at the expense of the process makes plagiarism and the practice of padding results difficult to avoid, while process capabilities remain unrecognizable.
Engineering Handover	The test rig is decoupled from the production vehicle and the ECU diagnostic interface, resulting in a lack of real-world operating conditions and failure scenarios.	Graduates require an extended adaptation period; companies have reported that they "take time to get up to speed and are unable to troubleshoot faults."

2. Theoretical Foundations and Design Approaches of Project-Based Learning

2.1. Theoretical basis

Project-Based Learning (PBL) is grounded in constructivist learning theory, Dewey's "learning by doing" philosophy, and humanistic educational theory. It emphasizes

the use of real-world problems as a driving force, enabling students to actively construct knowledge and acquire skills through project completion. Compared to traditional lecture-based teaching, PBL is characterized by four distinct features—"real-world contexts, student-centeredness, outcome orientation, and process-based assessment" —which precisely address the pain point in automotive sensor laboratory courses: an overemphasis on verification at the expense of design.

2.2. Overall Design Approach

This reform adheres to the overarching principle of "using competency-based objectives to reverse-engineer experimental projects, leveraging authentic engineering tasks to integrate key knowledge points, and employing diversified evaluation methods to encompass the entire learning process." Accordingly, the course experiments have been restructured into a three-tier project system-"Basic Verification Layer, Comprehensive Design Layer, and Innovative Exploration Layer"-progressing step-by-step to enable students at varying foundational levels to achieve growth within their zone of proximal development.

Top class	Corresponding competency objectives	Examples of typical projects	Type of organization
Basic Validation Layer	Capable of recognizing, measuring, and reading waveforms	Testing of Typical Sensor Characteristics and Signal Calibration for Temperature, Pressure, Position, and Flow Rate	Completed independently by the individual; 2 class hours per assignment
Integrated Design Layer	Capable of selecting appropriate equipment, configuring systems, and troubleshooting.	Detection of the engine intake system sensor set, ABS wheel speed signal acquisition, and fault injection	Group session hours
Innovative Exploration Layer	Capable of proposing solutions to new requirements and building prototypes.	Multi-sensor fusion-based following distance warning and intelligent seat posture perception module	Group topic selection + university-enterprise co-designed topics; extracurricular extension activities2-4 week

3. Implementation Plan for Project-Based Teaching Reform

3.1. Implementation Process for Project-Based Learning

Each comprehensive design project is advanced through a closed-loop process consisting of five phases: "project launch-conceptual design-setup, testing, and commissioning-system integration -acceptance review and defense." Process documentation is maintained at three key milestones-conceptual design review, mid-term inspection, and final acceptance-ensuring that every step of the student's work is traceable and evaluable.

3.2. Project Topic Selection and Task Specification Design

The selection of project topics adheres to the "Three Proximity" principle: proximity

to authentic automotive failure scenarios, proximity to the knowledge chain of subsequent specialized courses, and proximity to students' zone of proximal development. Before the course begins, instructors distribute a task assignment that clarifies the project background, deliverables list, technical specifications, and key milestones—for example, the "Engine Idle Instability Fault Diagnosis" project requires students to complete signal measurement and fault localization for the crankshaft position sensor, throttle position sensor, and oxygen sensor within 8 class hours, and to submit a fault tree analysis report.

3.3. Teaching Organization and the Transformation of Roles for Teachers and Students

Teacher's Role: Transition from "expositor and demonstrator" to "project director, coach, and resource provider," posing guiding questions at critical junctures without providing direct answers. Student's Role: Working in small groups of 3–4 students, each group is assigned roles as a systems engineer, hardware engineer, data engineer, and report engineer; these roles are rotated across different projects to ensure that every student undergoes comprehensive competency training. Class Format: Experimental sessions will shift from a "uniform scheduling and uniform progression" model to a "project milestone-driven" model, where students reserve workstations and equipment at specific milestones, and instructors provide on-site guidance and Q&A support.

3.4. Teaching Resources and Platform Support

To facilitate the implementation of project-based teaching, the course development team is simultaneously developing three types of resources: first, hardware resources—adding an OBD diagnostic interface, an oscilloscope, and a reconfigurable wiring panel to the existing sensor experimental bench, while introducing 1–2 sets of real engine test rigs; second, digital resources—developing virtual simulation experimental modules for sensors, covering hazardous operating conditions and rare vehicle models; third, industry-academia collaborative resources—each semester, in partnership with automotive enterprises, the team releases 1–2 real-world industry challenges, with enterprise engineers providing online guidance and participating in the final defense sessions.

3.5. Multi-dimensional Process-Based Assessment and Evaluation System

We are breaking away from the outdated practice of "evaluating performance solely based on a single report," and instead establishing a three-dimensional assessment framework comprising "process, outcomes, and competencies." The weighting and assessment criteria for each dimension are detailed in the table below. All assessment indicators are disclosed to students at the outset of each project,

ensuring that "assessments are grounded in clear criteria, and feedback is targeted accordingly."

4. Typical Project Case: Comprehensive Testing of Sensors in an Engine Electronic Control System

Taing the representative project "Comprehensive Testing of Sensors in an Engine Electronic Control System" from the integrated design phase as an example, this section illustrates concrete implementation approaches for project-based teaching. Project Background: A training vehicle exhibited symptoms of idle vibration and weak acceleration; the diagnostic report from the 4S dealership indicated "signal anomalies; further localization required." Students were tasked with completing the fault diagnosis within a prescribed number of class hours. Task Decomposition: Each student group first breaks down the task and sequentially completes signal acquisition and waveform comparison for the air flow sensor, throttle position sensor, crankshaft position sensor, and oxygen sensor; subsequently, they read the fault codes and data streams via the OBD interface; finally, they identify the faulty sensor and provide recommendations for replacement or recalibration. Key Competency Development: This project naturally integrates five key knowledge areas—sensor principles, signal conditioning, CAN/OBD communication, data analysis, and fault tree methodology—allowing students to connect knowledge from different chapters within a single real-world task. This approach avoids the pitfall of traditional chapter-based experiments, where students "see the trees but miss the forest." Differentiated Requirements: The foundational group is required only to complete fault localization and report generation; the advanced group must additionally perform fault reproduction injection and plot calibration curves; the innovative group is tasked with developing a simplified waveform interpretation tool using an oscilloscope and a host computer. These three tiers of requirements ensure that students at all proficiency levels can "reach just beyond their current capabilities."

5. Outcomes of Reform, Reflections, and Prospects

5.1. Preliminary Results

The reforms have undergone continuous iteration across two rounds of teaching pilots, yielding marked improvements across three key dimensions: student participation in classroom questioning and discussion, the quality of student assignments, and feedback from subsequent courses. Specifically, the frequency of proactive student inquiries and discussions in class has increased significantly; the average length and depth of the "Fault Analysis and Improvement Suggestions" section in experimental reports have also risen substantially compared to the pre-reform period; furthermore, students who completed this course demonstrated greater proficiency in sensor selection and signal debugging during subsequent

course design projects and academic competitions in "Automotive Electronic Control Technology." Detailed quantitative data should be systematically collected at the conclusion of the full teaching cycle—by comparing results with those of a control group—and subsequently published in follow-up research papers. Issues and Reflections

5.2. Issues and Reflections

Class Time Allocation: Project-based teaching consumes significantly more class hours than confirmatory experiments; therefore, it is necessary to strategically adjust the ratio of theoretical and experimental courses at the curriculum syllabus level. Faculty Resources: This approach imposes higher requirements on instructors' engineering backgrounds and on-site guidance capabilities; these gaps should be addressed through mechanisms such as faculty-industry mutual appointments and providing opportunities for teachers to gain practical experience in enterprises. Workstations and Equipment: The concurrent execution of multiple comprehensive projects increases the demand for the number of test benches, oscilloscopes, and OBD devices; this pressure can be mitigated through scheduled class scheduling, the use of virtual simulation tools, and the provision of nighttime workstations. Fairness: To address the phenomenon of "free-riding" in group projects, three mechanisms—role rotation, peer evaluation within groups, and individual defense presentations—should be implemented in tandem to ensure equitable participation.

5.3. Future expectations, vision of the future, future tendency, future prospects

In the next phase, the course development team plans to deepen its efforts in three key areas: first, integrate more novel sensors for intelligent connected vehicles (mmWave radar, LiDAR, and camera-based visual fusion) into the innovative exploration module; second, leverage the virtual simulation platform to build "digital twin workstations," enabling students to repeatedly practice fault injection and recovery in a low-risk environment; third, consolidate outstanding student projects into a repository of exemplary cases for the next teaching cycle, thereby establishing a virtuous cycle where student work informs and enhances teaching practices.

6. Conclusion

In this study, we have integrated project-based learning into the experimental course "Automotive Sensors." By employing a three-tier project framework, a five-stage closed-loop implementation process, and diversified formative assessments, we have systematically addressed the shortcomings of traditional experimental teaching—namely its overemphasis on verification, insufficient focus

on design, and limited integration with engineering practice. Practical implementation of this reform has demonstrated that project-based teaching not only enhances students' depth of understanding of sensor-related knowledge but also generates positive spillover effects in terms of engineering thinking, teamwork, and professional competence. These findings provide valuable references for the reform of experimental teaching in automotive and related disciplines within the context of New Engineering Education.

Fund Project: 2021 Teaching Innovation Team of Suzhou Vocational Institute of Industrial Technology (No. 2021JXTD004)

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