

Research on the Reconstruction of New Energy Vehicle Maintenance Courses Based on Modular Maintenance Approaches

Deliang Wei

Noncommissioned Officers Academy of PAP, Hangzhou 310000, Zhejiang, China

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Abstract: The new energy vehicle industry is growing quickly, bringing new opportunities and challenges to automotive maintenance professional education. This paper checks vocational schools' current new energy vehicle maintenance curriculum to see if the curriculum fits real maintenance work and industry needs. Industry and education are not linked well right now. This project takes "modular maintenance" as a starting point and rebuilds the traditional curricula. A vehicle is split into five main parts. It gets rid of gaps between different subjects and rearranges teaching content. A content system consisting of "modules-projects-tasks" is built and corresponding multimedia materials are added as a supplement. Teaching activities are designed, focusing on the "teach, learn, do, evaluate" way of learning. A diverse assessment method based on professional abilities is used. The results show that this approach is effective in developing students' systematic thinking, boosting their overall maintenance skills, cultivating their professional qualities, and helping vocational education combine with real social needs.

Keywords: Modular maintenance; Curriculum restructuring; New energy vehicles; Work process; Vocational education

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1. Introduction

1.1. Industrial transformation compels the transformation of maintenance talent training

China's automotive industry is undergoing significant changes at present. The change has the traits of "electrification, intelligence, connectivity, and sharing." The China Association of Automobile Manufacturers has released related data that in 2023, China made 9.587 million new energy vehicles and sold 9.495 million new energy vehicles. Production and sales rose by 35.8% and 37.9%, respectively, compared with last year. The market share went over 30%^[1]. This has a big effect on aftermarket maintenance. New energy vehicle maintenance has changed a lot. Traditional mechanical repairs are no longer the main work. Modular testing and assembly replacement are the main tasks. They are related to the "three-electric system."

New energy vehicles have unique technical features, different from traditional fuel vehicles. The high-voltage system runs at 300 to 800 volts. Maintenance work needs very high safety rules. The electronic control

system is highly integrated. Fault diagnosis needs special tools and data analysis work. Intelligent networking technologies are used widely. Software upgrades and system calibration become regular maintenance jobs [2]. These bring new challenges to maintenance personnel. Their knowledge structure and skill level need to be better.

Vocational schools' current curricula are far behind. Most schools still use a discipline-centered curriculum design. "Automotive Structure" and "Automotive Electrical Systems" are such course examples [3]. These curricula cannot meet the modular maintenance needs of new energy vehicles. Talent cultivation and industrial development are disconnected.

1.2. Teaching dilemmas faced by traditional curricula

Disciplinary barriers make students' knowledge scattered. Students may take the "Electrical and Electronics" course but they still cannot fix battery management system problems. Students may learn "Chassis Structure" content but they do not understand brake-by-wire principles. Diagnosing the "power battery cannot charge" problem needs much professional knowledge. It needs knowledge in high-voltage safety, battery management, charging protocols, CAN networks, and other fields [4]. Teaching is split into different disciplines, causing students to learn scattered knowledge points, and they cannot form a complete way to find and fix faults.

Scattered knowledge makes students' skills poor. Students may know some separate knowledge points but they still cannot solve a complete fault problem. Surveys show that over 60% of students say they "do not know what to do when encountering a fault." They need more than eight months of retraining in enterprises. Only then can they do basic repair work. Learning and real application are disconnected, which brings a heavy burden to enterprises and students.

1.3. Reform approaches

Following the logical thinking of industry experts, this paper puts forward a main solution using the "modular maintenance" method. This method is used widely in the industry. Students are trained according to job logic. Training starts when students first come to school. A vehicle is divided into several major functional modules. Teaching content and activities are arranged in specific steps: "fault diagnosis, module localization, assembly replacement or component repair" [5]. Students can develop the same work thinking as enterprise frontline technicians and also master similar work skills. This matches learning content to work tasks, updates the learning process with work activities, and makes assessment standards fit job requirements. **Table 1** shows the core differences between the traditional discipline-based curriculum system and the modular maintenance curriculum system.

Table 1. Comparison between the traditional discipline-based curriculum system and the modular maintenance curriculum system

Comparison dimension	Traditional subject system	Modular maintenance system
Curriculum structure	Organized by knowledge logic (e.g., Electrical and Electronic Engineering, Mechanical Principles)	Organized by work logic (e.g., Power Module, Chassis Module)

Content focus	Principle explanation, formula derivation, structural description	Fault diagnosis, maintenance decision-making, standardized operation, and safety points
Teaching sequence	From part to whole (learn components first, then systems)	From whole to part and back to whole (understand the system first, then master the modules)
Ability goal	Master knowledge points, pass theoretical exams	Develop a comprehensive ability to solve practical problems, be competent in job tasks

2. Theoretical basis and core concepts

2.1. Connotation and characteristics of modular maintenance

Modular maintenance is not just taking apart and fixing single parts. It regards the whole vehicle as a complete whole, which is made up of several relatively independent functional modules. It follows the process of “diagnosis–localization–replacement/repair.” New energy vehicles are highly integrated. They also have relatively clear interfaces. This is the main reason for this maintenance way. Tesla’s maintenance manual is an example. It divides the vehicle into many modules, including a battery pack, motor, body control, and thermal management system. Maintenance technicians check each module first and then decide to replace or repair the module ^[6].

Modular maintenance has three key characteristics. It pays attention to holistic diagnosis, finds faults from the whole vehicle’s perspective, and follows standardized operations. Each module has specific take-apart and put-together steps. It supports assembly interchangeability. Most modules are replaced as a whole, making the repair process faster. Traditional maintenance is “repairing where the problem occurs.” Modular maintenance is different, it has higher requirements for workers, requiring them to “analyze and resolve problems.”

2.2. Theory of systematized work processes

The theory of systematized work processes has a clear idea. Vocational education curricula should come from real work tasks, which need to be complete and specific. The German “dual system” has rich experience and proves the fact. Career-oriented curriculum design is more useful and is better than discipline-oriented design in training students’ comprehensive vocational abilities ^[7].

New energy vehicle maintenance has a complete work process. It includes vehicle reception and inquiry → fault diagnosis → data consultation → plan formulation → wiring connection → data stream reading → fault localization → decision-making → replacement or repair of relevant components → quality inspection → customer delivery ^[3]. Specific tasks can be picked out from this work process. “Diagnosing insulation faults in the power battery” is one such task. “Troubleshooting interactive faults in the intelligent cockpit system” is another. These tasks are highlighted in teaching. Students can learn to finish the whole work tasks.

2.3. Concept of competency-based education

Competency-based education has a clear goal. It trains students into comprehensive vocational and technical talents that can perform modular maintenance tasks. Course evaluation has new standards. It is not about whether students “completed the textbook content” or “passed exams.” It is about their ability to “independently complete typical modular maintenance tasks” ^[8]. For example, after students have learned the “power unit module,” they should do power battery detection correctly and safely, insulation testing, and assembly/disassembly well, not just have the related theoretical knowledge.

3. Restructuring design of the curriculum system

3.1. Division into five core learning modules

The course content is divided into five parts. It is based on new energy vehicles' technical characteristics and industry maintenance steps.

The Power Unit Module focuses on the “heart of the vehicle.” It includes safety inspection of power batteries, drive motors, and electronic control systems as well as their fault-finding and fixing work. It mainly teaches high-voltage safety knowledge. Students get familiar with battery pack insulation testing, learn performance testing and assembly disassembly, and solve common problems. The problems include large voltage differentials in power batteries and motor controller communication failures.

The Chassis Unit Module mainly focuses on the “limbs of the vehicle.” It includes the maintenance of electronically controlled braking systems and intelligent suspension and electric power steering systems. It stresses the combination of electronic control and mechanical systems. Students need to master wire-controlled braking, fault finding, and zero-point adjustment knowledge ^[9]. They also need to learn electronic control suspension height setting and sensor calibration.

The Electrical Unit Module centers on the “nerves and blood vessels of the vehicle.” It covers fault diagnosis of onboard charging systems. It also includes intelligent air conditioning, lighting, and body electrical systems. The charging part has key content, including AC and DC fast and slow charging knowledge. It also has communication protocols and high-voltage contactor control content. These need to be stressed in teaching.

The Control Unit Module focuses on the “brain of the vehicle.” It includes the diagnosis of vehicle controllers, gateway controllers, and domain controllers. It also includes their software flashing work. Students need to understand hardware connections and network topology, be familiar with controller operation modes, be able to read fault codes and view data streams, and master online flashing skills.

The Intelligent Driving Unit Module specializes in the “eyes of the vehicle.” It covers the calibration of sensing elements. It also includes their fault detection. The elements include millimeter-wave radar, ultrasonic sensors, and cameras. L2 and higher-level intelligent driving are used more and more. Sensor calibration becomes a new chance in the aftermarket.

3.2. Reorganization of teaching content

The five modules have been decided. The teaching content is reorganized in a systematic way. Disciplinary boundaries are broken down. The knowledge structure is rebuilt. The original content of some courses is taken apart. The courses include “Electrical and Electronic Engineering,” “Engine Principles,” “Chassis Construction,” and “Automotive Electrical Systems.” The content is distributed again into the five modules based on real work needs. For instance, relays, contactors, and IGBTs are put into the high-voltage circuits of the “Power Unit Module,” communication protocols and data frames are included in the CAN bus diagnosis of the “Control Unit Module,” and radar ranging and camera imaging principles are combined into the sensor calibration of the “Intelligent Driving Unit Module.”

A three-tier structure is built: “Module-Project-Task” structure. Each module has a set of representative projects. Each project is made up of several tasks. The “Power Unit Module” is a specific example.

Module: Power Unit Maintenance (72 class hours)

Project 1: Fault Diagnosis for Unchargeable Power Battery (16 class hours)

Task 1: High-Voltage Interlock Circuit Detection (4 class hours)

Task 2: BMS Data Stream Analysis and Fault Code Reading (6 class hours)

Task 3: Charging Communication Protocol Diagnosis (6 class hours)

Project 2: Drive Motor Abnormal Noise Troubleshooting (12 class hours)

Task 1: Rotary Transformer Sensor Signal Detection (4 class hours)

Task 2: Motor Controller IGBT Module Testing (4 class hours)

Task 3: Motor Three-Phase Resistance and Insulation Testing (4 class hours)

This three-tier structure makes learning content match work content. Students finish each task and master one practical skill. Students take on each project and learn a method to solve a type of problem. Students complete one module and have comprehensive maintenance knowledge in that field.

3.3. Development of supporting learning resources

A complete set of related materials is provided for students, meeting the needs of the new curriculum. Students can refer to these materials when learning. It ensures students have “standards to follow, examples to emulate, and precedents to refer to.” **Table 2** lists the core skills of the five modules and summarizes their main learning resources.

Table 2. Core skills of the five modules and their main learning resources

Module name	Core skills	Main learning resources
Power Unit	High-voltage safety operation, battery diagnosis, motor testing	High-voltage operation work orders, battery disassembly micro-course, Three-Electric (Battery, Motor, Control) case library
Chassis Unit	Brake-by-wire calibration, electronically controlled suspension debugging	Braking system debugging work order, air conditioning system micro-course
Electrical Unit	Charging system diagnosis, intelligent air conditioning repair	Charging pile communication work order, air conditioning system micro-course
Control Unit	Network diagnostics, software refreshing, controller programming	CAN bus diagnostics work order, refresh process micro-course
Intelligent Driving	Sensor calibration, data diagnostics, system testing	Radar calibration work order, point cloud analysis micro-course

The maintenance work order is a practical work guide made according to the enterprise’s specific situation. It lists work content and operation steps, also including precautions, quality requirements, and assessment standards. “Diagnosing insulation faults in power batteries” work order is an example. It describes how to use the insulation tester in detail. It has specific measurement methods and pass/fail standards, and explains how to deal with failures.

Micro-teaching videos are made for key and hard skills. Each video lasts 3–5 minutes. “Calibration of Intelligent Driving Sensors” is an example. Animations are used in the video to explain the working principles of radar. Real scene videos are also used, showing equipment installation and software usage. Students can understand the related knowledge more easily.

The fault case library collects about 200 enterprise cases. Each case has detailed information, including fault symptoms, analysis processes, and handling methods. It also has technical key points. Students can learn

and refer to these cases. The library is updated every three months.

4. Teaching implementation and evaluation reform

4.1. Action-oriented teaching model integrating “teaching, learning, doing, and evaluating”

The action-oriented teaching method is promoted a lot. The classroom is regarded as a workshop, and the teacher is regarded as a mentor. Students are divided into groups to carry out learning activities in real or simulated workplaces. They use maintenance work orders in the process. The four parts of “teaching, learning, doing, and evaluating” are combined. Each part is closely connected and helps the others.

“Diagnosing insulation faults in power batteries” is a teaching example. The teacher shows a specific case and asks questions for students to think about. Students collect related data in groups, analyze fault causes and design solutions, and finish work order tasks under the teacher’s guidance. They do detection work and record related data, analyze the data, and find where the fault is. Each group reports its work results, while the teacher gives feedback and comments.

This teaching method has a core point. It makes the learning process match the work process. Students finishing work tasks not only master professional knowledge, but they also develop systematic diagnostic abilities and cultivate good safety awareness. Real teaching experience has proved that “learning by doing” works well, as it greatly raises students’ learning enthusiasm and improves their learning effect.

4.2. Construction of a virtual-real integrated training base

Practical training has many challenges. It has the features of “high risk, high cost, and difficulty in replication.” A “virtual-real integrated” training room is built to solve these problems. It has special workstations in five areas. Virtual simulation software is mainly used for practicing high-risk operations in advance. Students can practice some tasks many times in a virtual environment. The tasks include taking apart high-voltage components and maintaining batteries. Wrong operations get immediate feedback, helping students develop good operating habits. This way is “simulation training followed by actual vehicle inspection,” which greatly reduces training costs and improves training safety.

The physical training area simulates a real enterprise environment. It is equipped with corresponding tools and diagnostic equipment. It also has enough spare parts. The power unit module area has specific equipment. It includes battery lifters, insulation testers, equalizers, and high-voltage harnesses. The intelligent driving module area also has special equipment. It has radar calibration plates, camera calibration instruments, and diagnostic computers. This is the “virtual first, real verification” way. It ensures the training effect and also controls training cost and risks well.

4.3. Diversified evaluation system centered on competency

The traditional single written examination system is reformed. A diverse evaluation method is put into use^[10]. It combines process evaluation and summative evaluation.

Process evaluation focuses on the whole process of doing tasks. It checks if operations are standardized, if diagnostic thinking is clear, if team members work well together, and verifies if students follow safety rules. “Battery pack disassembly and assembly” is an evaluation example. Evaluation is not just about finishing the task. It also checks if each step meets high-voltage safety requirements.

Summative evaluation tests students’ practical abilities. It checks if students can finish maintenance tasks

by themselves, and verifies if they can finish the work skillfully and quickly for a specific module. Students finish the power unit module learning. They are required to solve comprehensive fault diagnosis problems within a certain time. They get scores based on three aspects: task completion, diagnostic accuracy, and operation speed.

Certification evaluation combines multiple standards. It includes the “1+X” certificate standards. It also has the certification requirements of original equipment manufacturers^[8]. Students finish each module learning and get corresponding “micro-certificates.” They can exchange the micro-certificates for industry certificates when they have enough. It improves students’ personal value and enhances their employment advantages.

5. Practical outcomes and reflections

5.1. Presentation of practical cases

“Diagnosing Insulation Faults in Power Batteries” teaching content is taken as an example. The practical operation process is as follows. This case comes from a partner enterprise’s real situation. A new energy vehicle has run 80,000 kilometers. It showed an “insulation fault” after driving in the rain. The teacher asks questions. It lets students think about the possible fault causes.

Students first use VR simulation to practice. They do high-voltage operations and insulation testing. The system records their operation paths. It gives specific evaluations for their performance. Students pass the virtual test and then go to the real operation site for physical testing. They measure the resistance between the positive and negative terminals of the battery and the ground. They compare the measured value with the required value. They read the BMS fault codes and data streams. They check the changes in insulation conditions. They finally find the fault cause. It is the poor sealing of the battery pack, and water got into the pack because of this. The insulation value is 200Ω/V. The required value is more than 500Ω/V. Students put forward a solution: to replace the sealing ring and do tests after drying. The battery can return to normal after this.

Enterprise mentors give guidance during the work process. Students have this comprehensive work experience. They not only learn diagnostic methods but also develop a systematic way of thinking and cultivate strong safety awareness.

5.2. Comparative analysis of reform outcomes

An observation on the experimental class (62 students) and the control class (60 students) was conducted for one year. Clear changes were found through observation.

Students’ skill levels improved a lot. The excellent rate in the comprehensive skill assessment at the end of the semester was counted. It was 48.2% for the experimental class and only 33.3% for the control class. Students in the experimental class did better in fault diagnosis. They had more organized ways to do the work.

Students’ learning attitudes made great progress. A survey was done on students’ learning experience. Ninety percent of students think their “learning purpose was clearer.” Eighty percent of students feel their “hands-on abilities and problem-solving skills had improved.” The percentage of students finishing homework by themselves increased by 12.4%. Classroom learning enthusiasm has also risen by 13.3%.

Students’ employment competitiveness improved. Partner enterprises gave feedback on students’ performance. The professional qualification rate of students in the experimental class was 90.3%. The time for students to become skilled at work was shortened from six months to three months. Many students were pre-hired by enterprises during their internships and directly assigned to technical positions in the enterprises.

5.3. Implementation challenges and countermeasures

Faculty strength is a big problem. Modular teaching has high requirements for teachers. Teachers need a strong ability to combine different disciplines^[8]. They also need rich modular maintenance experience. A “dual-instructor collaboration” way is put into use to solve this. School teachers and enterprise mentors work together to prepare teaching content and give lessons together. Teachers are also sent to enterprises for practical training. They need to take part in the training for at least one month every year.

Curriculum updates are a dynamic challenge. New energy vehicle technology develops very fast. A “school-enterprise technology synchronization mechanism” is put into use to overcome this. 5 to 10 real cases are added to the teaching every month. Teachers visit enterprises to learn once every semester. The whole curriculum is updated every year.

6. Conclusion and outlook

6.1. Core conclusions

Curriculum reform is done based on modular maintenance. It is a good way for vocational education to combine with the industry. This reform has many advantages.

It makes learning content and work tasks the same. Students can turn the knowledge they learn into practical work abilities. It solves the disconnection between learning and application.

It helps train students’ comprehensive vocational abilities. Modular teaching not only teaches technical skills. It also teaches students to analyze problems from the whole. It fosters students’ safety awareness and teamwork spirit.

It builds a curriculum system that can be improved all the time. Modularization makes content updates in time. The curriculum can keep up with new technological developments. Vocational education can adapt to industry development effectively.

6.2. Future outlook

Deepening industry-education integration: Enlarge the range of partner enterprises. Cooperate in module development, base construction, and standard making. Make classrooms and workshops match. Make teachers and mentors match. Make students and apprentices connect well.

Exploring smart teaching methods: Use VR/AR, digital twins, AI, and other technologies. Improve teaching effect in high-risk modules. Develop intelligent guided learning virtual simulation software. Make personalized exercises based on students’ learning progress. Achieve the goal of “ability-based teaching.”

Promoting successful practices: Extend the modular curriculum idea to other automotive maintenance education content. Initial applications are done in industrial robot maintenance courses. It becomes a basic curriculum model for related professional clusters in the future.

New energy vehicle technology develops very fast. Corresponding maintenance talent training must keep up. Redesigning the curriculum system based on modular maintenance is not just a change in teaching content, but also a change in educational ideas. It changes from teaching knowledge to training abilities and from a discipline-centered to a work-centered way. This is very important for vocational education development to meet the country’s expectations for the automotive industry’s growth.

Disclosure statement

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