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Design and Application of the VAC Teaching Method Oriented Towards the Transformation of the Automotive Industry

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Abstract: The automotive industry is currently undergoing a rapid transformation, particularly in the areas of electrification, intelligence, networking, and sharing, all of which require the support of advanced computational methods. In alignment with national strategy and the trends of contemporary science and technology, Wuhan Huaxia Institute of Technology introduced a course titled "Computational Methods and Engineering Application." In its initial phase, the course was structured using a traditional teaching mode, which limited students' ability to recognize the knowledge demands aligned with automotive transformation trends. They faced challenges in addressing complex engineering problems and struggled to foster innovation. To address these issues, three step teaching method called Visible-Accessible-Creative (VAC) is applied in the course. First, the course implemented an "Automotive + Multidisciplinary" knowledge system, encouraging students to engage in transfer thinking. Additionally, a three-stage progressive project system, based on career role processes, was established to guide students in solving engineering problems. This system deeply integrates classroom teaching with scientific innovation activities, refines evaluation criteria for both process and final assessments, and ultimately designs a three-dimensional curriculum evaluation system to ensure continuous improvement. Through these curriculum reforms and practices, a strong foundation has been established for cultivating high-quality, applied automotive engineering talents.

Keywords: VAC Teaching Method; "Automotive + Multidisciplinary" Knowledge System, Career Role Based Project System; Defect-Oriented Project Design

1. Introduction

With the release of national strategies such as the "Energy Saving and New Energy Automobile Industry Development Plan (2012-2020)", the "Smart Car Innovation Development Strategy", the "National Car Networking Industry Standard System Construction Guide (Intelligent Car) (2017)", and the "new four modernizations" have emerged as the primary direction of automotive industry development. In the ongoing transformation and upgrading of the automotive industry, automobiles are no longer merely mechanical modes of transportation; they are evolving into intelligent mobile spaces, energy storage units, and digital platforms. To adapt to these trends, automotive-related disciplines (such as vehicle engineering) at local application-oriented universities must urgently cultivate professionals who are knowledgeable in cutting-edge developments, excel in practical abilities, and exhibit strong innovative awareness.

Theoretical research, scientific experiments, and scientific computing constitute the three pillars of modern scientific inquiry [1]. Computational methods are central to scientific computing, and advancements in these methods drive both the innovation of scientific research and the development of the "new four modernizations" in the automotive industry. Engineering programs at various colleges and universities widely offer courses related to computational methods [2-7]. However, during the course construction process, several challenges arise, including an abundance of theoretical content coupled with limited class time [1,3,6,8], as well as textbooks that prioritize theoretical explanations while neglecting practical application [3,6,8-10]. Some universities have introduced application cases in their curriculum reforms to enhance student engagement in computation, programming, discussion, and demonstration, thereby increasing the proportion of process assessment. Nevertheless, variations among different types of universities and the diverse skill sets of students in various majors lead to discrepancies in the course objectives for computational methods, particularly in terms of knowledge systems and skill levels. Therefore, it is essential to conduct an in-depth analysis of course-related issues and implement targeted curriculum reforms tailored to the specific characteristics of each major and the associated talent training objectives.

The advancement of the “new four modernizations” in the automotive industry demands technological innovation and extensive application of computational methods in engineering. Today, computation is a crucial component in addressing automotive engineering challenges. Consequently, the university has introduced a foundational course titled “Computational Methods and Engineering Applications” for third-year undergraduate students majoring in vehicle engineering (termed “VE”). This course aims to equip students with the ability to apply computational methods and automotive technology comprehensively to solve practical engineering problems, thus laying the groundwork for the development of future professionals. The “Visible-Accessible-Creative” teaching method, which has undergone multiple rounds of refinement, has significantly enhanced student engagement and overall teaching effectiveness.

2. Problems Existing in the Course Construction of “Calculation Method and Engineering Application”

In the initial phase of the course, conventional teaching approaches were employed to provide a foundation for students in developing computational thinking. However, the traditional curriculum failed to align with the evolving knowledge demands of the transforming automotive industry. The conventional teaching paradigm struggled to foster students' proficiency in addressing complex engineering challenges. Furthermore, the lack of integration between daily teaching and innovation competitions hindered the stimulation of an innovative mindset among students.

2.1 Invisible: Traditional Teaching Leads to Students Being Unable to Perceive the Knowledge Demands under the Trend of Automotive Transformation

Traditional teaching, centered on textbooks, often overlooked the practical application of computational methods in automotive engineering. This led to students developing a limited understanding and struggling to apply these methods to complex problems. The one-directional teaching model, in which teachers delivered knowledge and students followed coding instructions, failed to foster independent learning and critical thinking, thereby hindering students' ability to effectively identify and apply appropriate computational methods.

For students majoring in vehicle engineering, the course should introduce real-world automotive engineering problems to help students establish a systematic knowledge framework that integrates engineering challenges with computational methods. However, automobiles, being systems composed of tens of thousands of independent components, encompass not only traditional technologies such as mechanical structure, electronics, aerodynamics, NVH, and optics, but also cutting-edge technologies such as electrification, intelligence, connectivity, and sharing. The traditional teaching model struggled to equip students with the “strong interdisciplinary and new technology-oriented” knowledge system required to solve contemporary automotive engineering problems.

2.2 Inaccessible: the Conventional Teaching Approach does not Equip Students with the Skills to Tackle Complex Engineering Problems

Actual automotive projects often require team communication and collaboration. However, traditional teaching primarily trained students to solve mathematical problems independently but lacked team collaboration exercises. As a result, students frequently encountered psychological barriers when faced with real-world issues, making it difficult for them to know where to begin.

Additionally, when designing teaching scenarios for problem-solving, it is necessary to incorporate engineering problems with a high level of complexity and challenge. Real automotive engineering problems are highly complex and advanced, making them ideal project material for the course. However, it is crucial to consider the alignment between students' abilities in application-oriented universities and the complexity of automotive engineering problems to ensure that students can "access" these challenges through active learning and exploration.

2.3 Uncreative: Traditional Classroom Types Struggle to Foster a Sense of Innovation in all Students

The evolution and advancement of the automotive industry are intrinsically linked to the ongoing evolution of technology. Therefore, the curriculum for VE majors should embody the innovative spirit of automotive technology. However, in the conventional case-teaching approach, due to the constraints of limited class time, instructors often prioritized guiding students through mathematical modeling and programming in a single session. This approach neglected the innovative phases of experimentation, refinement, and optimization, which are crucial for fostering a sense of innovation among students.

Competitions and industry-university-research (IUR) projects, termed the second class, play a pivotal role in nurturing innovation among early undergraduate students. Despite providing a platform for rapid skill development and an innovative mindset, these projects typically involved first- and second-year students who learned through a mentorship model, leading to fragmented knowledge and a lack of systematic approaches to tackling complex, interdisciplinary challenges. Meanwhile, regular classroom instruction (the first class) provided a structured knowledge base but was often introduced only in the third year, causing some students to miss out on earlier innovation experiences. Bridging the gap between theoretical and practical learning by incorporating a "trial-and-error phase" in the first class, complemented by the secondary class, is a promising approach to nurturing a culture of innovation among all students.

3. Teaching Design and Practice of the Course

The three-step teaching method has been designed to address the aforementioned issues (Figure 1). The core concept is to establish the advanced goals of "knowledge visible", "ability accessible", and "innovation reachable". Nine teaching activities were designed for students, and teaching practice has been implemented. This approach provides a paradigm for cultivating automotive engineering professionals who are up-to-date in knowledge, possess outstanding practical abilities, and exhibit innovative awareness. Through the reconstruction of the knowledge system and training in transfer thinking, the course exposes students to hot topics and cutting-edge engineering issues during the transformation of the automotive industry. It also enables students to identify computational methods for typical aspects of engineering problems through self-learning and transfer thinking. The course guides students to identify their roles within teams in project practice, using computational methods and program design thinking to solve key aspects of real engineering problems in a process-oriented manner. By tackling defect-based problems and being immersed in a "trial-and-error" classroom environment, students are encouraged to develop innovative awareness and the ability to identify and address new challenges.

3.1 Visible: "Automotive + Multidisciplinary" Knowledge System and the Transfer Thinking Method Linking old and new Knowledge

Amid the transformation of the automotive industry, automotive engineering problems have demonstrated strong characteristics of interdisciplinary integration. The course begins with automotive engineering challenges and integrates knowledge points from top to bottom, such as physical modeling, mathematical derivation, and program design, to form an "automobile + multidisciplinary" knowledge system. An online resource library that links engineering problems with computational methods has also been established for students' self-study before class and for further exploration after class. The specific approach is as follows: first, select computational processes from the entire vehicle development process (R&D, validation, manufacturing, and improvement) and choose seven typical stages from five major automotive engineering problems. Then, set up each typical stage as a separate chapter. The online resources for each chapter integrate content such as national strategies, automotive technology, relevant standards, mathematical knowledge, and programming methods. Additionally, the online resource library incorporates self-recorded popular science videos by students (e.g., the principles of guitar vibration and the imaging principles of LiDAR) to stimulate students' interest in learning.

The rapid transformation of the automobile industry accelerates the evolution of automotive engineering knowledge. The curriculum should not only build a knowledge system that is contemporary but also guide students in connecting new knowledge with prior knowledge, enabling them to quickly absorb new technology and apply it to project practice. Online discussions and classroom Q&A sessions are utilized to guide students in transfer thinking. The course facilitates online discussions, enabling students to compare the functionalities of traditional cars and autonomous vehicles, linking cutting-edge knowledge with traditional automotive knowledge to identify specific engineering problems. During classroom Q&A sessions, students explore the commonalities among life sciences, mathematics, and engineering problems to determine appropriate physical models and computational methods. These approaches help students abstract fundamental principles across various contexts and apply them to formulate suitable models and computational strategies for solving engineering problems.

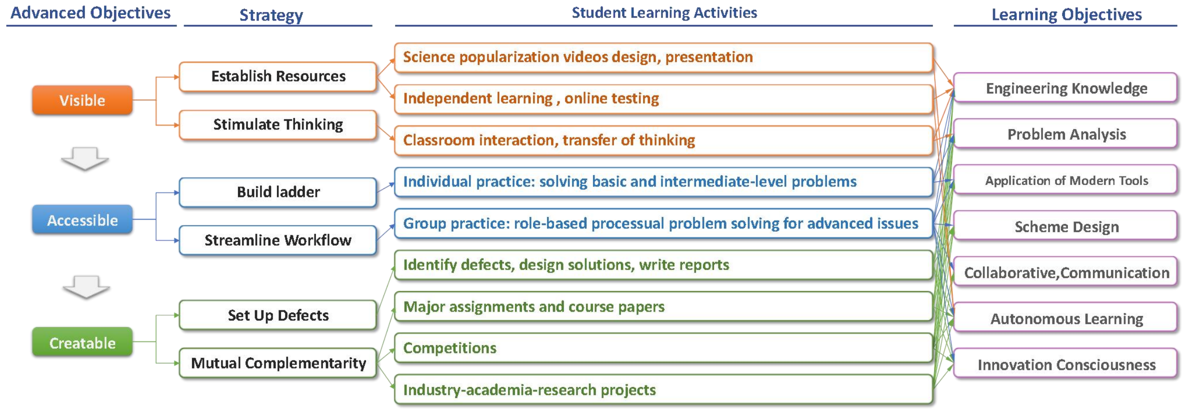


Figure 1. The Framework and Core Concepts of the Three-Step Teaching Method

3.2 Accessible: Process-Oriented Three-Stage Progressive Project System based on Career Roles

Nowadays, Project-Based Learning (PBL) has become a trend in teaching innovation, which creates immersive scenarios for collaborative problem-solving among multiple individuals. In the implementation process of PBL in this course, there are mainly two major challenges: one is matching the complexity of actual automotive engineering problems with the capability level of applied undergraduate students who are initially exposed to professional courses; the other is that not all students are motivated by uniform team activities.

In view of the matching degree mentioned before, the teaching team constructs a Three-Stage Progressive Projects via "simple-complex" and a "top-down" approach. At the macro level, focusing on traditional and frontier problems, typical engineering problems are screened, related mathematical issues from textbooks are analyzed, and life-related and simple professional problems are designed from mathematical concepts. Finally, a Three-Step Advancement Project is constructed based on the principle of starting from simple to complex. As shown in Figure 2, the basic project consists of simple mathematical problems, the intermediate project involves simple life and professional problems, and the advanced project comprises typical stages of comprehensive life and engineering problems. This advanced project teaching cultivates students a sense of responsibility and self-confidence, enabling them to complete tasks that progress from simple to complex and to bravely tackle complex engineering problems in the final assessment.

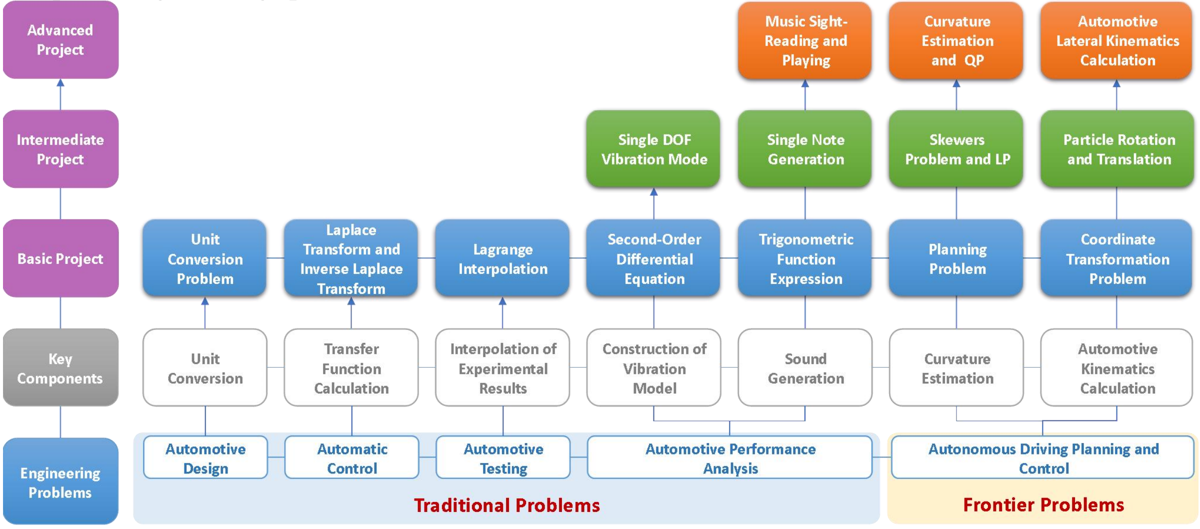


Figure 2. Three-Stage Progressive Projects

During the early implementation of advanced projects, it was observed that undifferentiated group PBL tasks often became the sole responsibility of only one or two students, failing to stimulate the interest and motivation of all students. From teaching reflections, it was discovered that the automotive technology chain related to computing often includes specification formulation, target distribution, physical modeling, mathematical modeling, programming, and testing, involving different roles of engineers such as automotive management engineers, automotive R&D engineers, and automotive testing engineers. Not all students will pursue careers as automotive R&D engineers related to computation in the future. Therefore, the course must design tasks for each team member based on the personalized career aspirations of students.

The teachers issued a career survey questionnaire before class, developed an eight-step standardized process for applying computational methods to solve practical engineering problems, and set personalized tasks for students according to the results of the career survey questionnaire. Students choose roles such as project management, R&D, technology, or testing based on their own strengths for practical project operations, and each role must complete the corresponding tasks within the eight-step process (Figure 3). The teaching team designed a task of online group presentations, where each student member must present upstream outputs, their individual tasks, and downstream inputs in the form of an online meeting. The meeting videos should then be uploaded to the PBL module within the online resource library. Teachers guide students to effectively communicate with upstream and downstream task roles during the process, ensuring that the group completes the project efficiently and with high quality. Role-based and process-oriented practical training helps students quickly find their positions within the team, master effective communication methods, leverage their own strengths to complete projects according to the eight-step process, and enhance their abilities in project design, application of modern tools, and team collaboration and communication.

Management Position

- Engineering Problem Analysis
- Target Plan Development

R&D Position

- Physical Model Establishment
- Mathematical Model Building

Technical Position

- Program Design and Debugging
- Result Comparison and Analysis

Other Position

- System Parameter Acquisition
- System Improvement and Optimization

Figure 3. Process-Flow Task Setting Based on Career Roles

3.3 Innovative: Defect-Oriented Project Design and the Integration of Two Types of Courses

Iterative processes and optimization are primary methods of automobile product innovation, and identifying new problems in the research and development process is the key driver of iteration and optimization. The teaching method of this course departs from the traditional model that relies solely on a single successful demonstration and constructs an "iterative and optimization" process through the design of parameter analysis and defect-oriented advanced projects, aiming to cultivate students' innovative mindset. For example, in basic and intermediate projects, such as "simple harmonic vibration" and "single degree of freedom vibration," teachers assign the task of "analyzing the influence of various parameters on the outcomes." Students observe the changes in results caused by parameter variations and apply theoretical knowledge to analyze the causes of these changes, thereby improving their observational and analytical skills. In intermediate and advanced projects, defective projects are implemented, which may include incomplete constraints or non-optimal results. For instance, the premise of the "cost issues of skewer barbecue and linear programming" project fails to account for students' personalized needs; the original method of the "sight-reading music" project fails to accommodate the varied rhythms and timbres of music. Teachers encourage students to observe, analyze, and evaluate the rationality of the results to identify new problems based on these outcomes, thereby continuously refining computational methods to meet personalized needs or yield improved results.

In addition, the course emphasizes interaction with extracurricular activities. The online resources of this course serve as learning resources for the formula racing team, intelligent car team, intelligent connected automobile algorithm team, and IUR studio, enhancing independent learning and enabling students to apply relevant knowledge in automobile-related competitions and real IUR projects. Simultaneously, the faculty team proactively explores competitions and research projects in these extracurricular settings, integrating emerging technologies and advanced computational methods into classroom instruction and transferable thinking. They decompose projects and design executable micro-projects to enhance students' practical experience while employing a team cooperation model with personalized professional roles in group PBL teaching. Students get to enhance their awareness of innovation through training in real projects.

3.4 Course Assessment Reform

The course assessment is structured into process assessments and final evaluations, which are subdivided into seven modules based on the concept of "Visible- Accessible-Creative" (Table 1). The teaching team relies on the online platform to assess the students' overall learning progress and analyze the attainment of course objectives. The process assessment consists of five modules: online learning, course interaction, individual projects, group projects, and attendance. Among them, the online learning module and course interaction module primarily assess the knowledge dimension, while individual projects and group projects evaluate the ability dimension. The final assessment assignments and course papers provide comprehensive evaluations across the three dimensions of knowledge, ability, and quality.

Table 1. Course Process Assessments and Final Evaluations

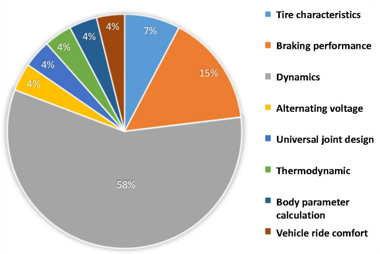
Type	Module	Scale	Assessment Form	Content of Assessment
Process assessment	Online learning	10%	Self-learning and testing online.	The mastery of engineering knowledge and independent learning ability.
	Course interaction	5%	Evaluation online and feedback offline by teachers.	The mastery of engineering knowledge and problem analysis ability.
	Individual projects	15%	Online evaluation and feedback by teachers.	Accuracy of computational method and programming in basic projects.
	Group projects	15%	Offline evaluation by students, online and offline	In intermediate and advanced projects, the rationality of computation and

Type	Module	Scale	Assessment Form	Content of Assessment
			evaluation and feedback by teachers.	programming, and the accuracy of process and result analysis report.
	attendance	5%	Online check-in.	Sense of responsibility.
Final assessment	Major assignment	15%	Online evaluation by teachers.	The rationality of the computational method and programming.
	Course paper	35%	Offline and online evaluation and feedback by teachers.	Innovative topic selection, the integrity of eight-step process. The logic clarity and the normative standardization of the course paper.

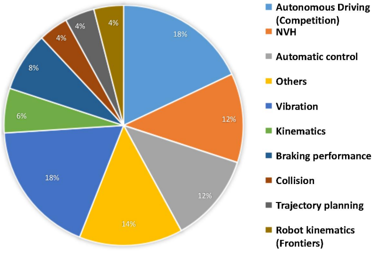
In the process assessment, the online learning module evaluates students' comprehension of national strategies, corporate standards, automotive knowledge, mathematics, and programming, as well as the results of online evaluations conducted before class. In the course interaction module, segments have been established, such as offline thematic discussions, online quick responses, and voting. This assessment evaluates students' participation in both online and offline interactions, analyzing their understanding of new technologies and their ability to transfer known engineering principles to unfamiliar contexts. In the individual project module, instructors evaluate the foundational projects completed by students on the online platform, primarily examining their ability to independently solve basic problems using computational methods and programming tools. In the group project module, instructors assess students' ability to collaboratively address real-world problems and typical engineering challenges via offline comments and online reviews of group project reports. Attendance module examines the student attendance rate.

In the final assessment, the major assignment provides students with the opportunity to independently explore a variety of automotive engineering issues while also enabling them to pursue more complex problems in alignment with their abilities. This combination of major assignments and course papers as the final assessment method comprehensively evaluates the knowledge, ability, and quality objectives of the course. The final assessment establishes three detailed evaluation criteria, including the innovation of topic selection, the accuracy of computational methods and program design, and the standardization of the thesis format. These indicators facilitate a comprehensive analysis of students' learning outcomes and are conducive to the continuous improvement of the course.

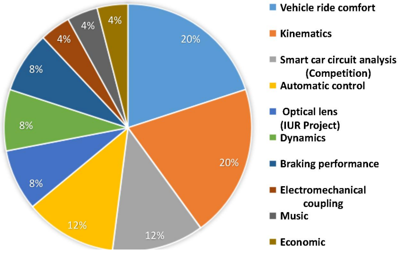
4. Teaching Efficiency



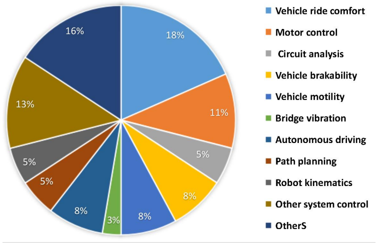
a VE 2018(Before the reform, in 2020)



b VE 2019(After the reform, in 2021)



c VE 2020(After the reform, in 2022)



d VE 2021(After the reform, in 2023)

Figure 4. Statistics of Topic Selection of Students in Recent Three Courses

To evaluate the effectiveness of the

reconstruction of the curriculum knowledge system and the application of the transfer teaching method on the extension of students' engineering knowledge, we compare the scope of course paper topics over the years, as illustrated in Figure 4, which shows a gradual enrichment following the reform. Before the reform, the scope was relatively narrow, with approximately 58% of course papers focusing on the analysis of automobile power performance. Other topics were similarly restricted to braking performance, ride comfort, and other subjects within the “Automobile Theory” course offered during the same period. After the reform, the scope of students' independent course paper topics not only encompasses traditional issues such as power performance and braking but also includes optics, intelligent vehicle competitions, and autonomous driving, which are IUR content and cutting-edge topics. Students demonstrate proficiency in identifying a variety of engineering problems within the automotive field and can effectively apply the engineering knowledge acquired in class, as well as independently, to address these challenges.

The dimension of “accessible” primarily evaluates whether the ability objectives have been achieved, assessed through the results of three-phase project evaluations conducted before and after the reform, as well as the sophistication of course paper topics and the completion of major assignments. This provides a reference for the optimization and reshaping of the PBL teaching model. The statistical analysis conducted by the teaching team indicates that, following the reform, there has been a significant increase in the proportion of students achieving excellent and good grades in assessments compared to the period before the reform (Figure 5). Furthermore, students have demonstrated the courage to address sophisticated engineering challenges in their final assessments. They have chosen thesis topics that encompass a variety of advanced areas, including electronic throttle system simulation, lens design for automotive reading lights, and the control algorithm for intelligent vehicles. Their work includes detailed explanations of calculation derivations, programming processes, and comparative analyses, demonstrating a profound engagement with the subject matter. This shows that the reform significantly improved students' ability for self-regulated learning and problem-solving in engineering.

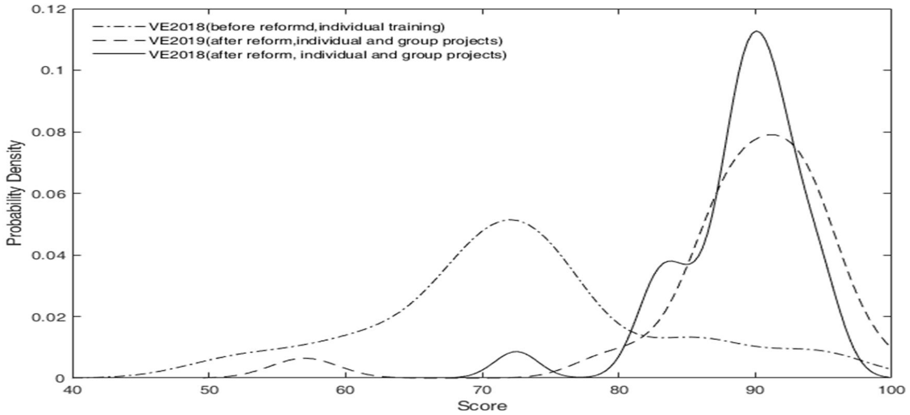


Figure 5. Comparison of the Excellent Rate of Students' Test Performance before and after the Reform

The dimension of “innovative” primarily assesses the extent to which the educational process fosters students' innovative consciousness and the course's role in promoting scientific and innovative activities. Since the reform of the course, participation in science and technology innovation teams has increased year by year. To date, the course has attracted over 200 students to engage in science and technology innovation activities, encouraging them to explore the automotive engineering applications of computational methods proactively. Based on the practices established in this course, students have won more than 20 national and provincial awards related to computational methods in various competitions over the past three years, including the National College Students Smart Car Competition and the China ICV Algorithm Challenge. Additionally, they have received approval for seven provincial projects focused on innovation and entrepreneurship training. Students have also actively applied the computational methods learned in the course to more than 10 IUR projects, with some products successfully entering the international market.

5. Conclusion

The advancement of intelligence in the automotive industry is inherently linked to the need for applied talents possessing solid computational methods and engineering experience. The course “Computational Methods and Engineering Applications” is designed with advanced teaching objectives and methods grounded in the “Visible-Accessible-Creative” framework, reflecting the requirements of the new engineering context. It reconstructs the knowledge system of “automobile + multidisciplinary” to enhance students' computational and engineering expertise. This course guides students in problem analysis by integrating new and existing knowledge through transfer thinking and employs sequential project designs to help students systematically approach engineering challenges. Furthermore, it encourages students to identify their professional roles and improve their problem-solving abilities. The “Visible-Accessible-Creative” teaching method has been implemented in over ten courses, including “Autonomous Vehicle Decision and Control” for vehicle engineering majors at Wuhan Huaxia Institute of Technology, and has been adopted by other universities such as Jianghan University and Wuhan University of Media and Communication. The course received the first prize in the 8th Xipu National University Teaching Innovation Competition. Statistical analyses indicate that the course has effectively constructed a systematic engineering knowledge base, enhanced self-learning, problem analysis, modern tool usage, collaboration, communication skills, as well as innovative consciousness of students, and helped to cultivate high-quality applied vehicle engineering talents essential for the development of intelligent automobiles.

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