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AI-Empowered Reform and Practice of the Graduate Course "Automotive Reliability Theory and Applications"

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Abstract: ***Amid the rapid development of intelligent vehicles and digital engineering, the conventional graduate course Automotive Reliability Theory and Applications faces new challenges in connecting theoretical instruction with engineering applications, integrating modern computational tools, and diversifying instructional evaluation. To enhance graduate students' ability to solve complex vehicle-engineering problems using reliability theory, data-analysis methods, and engineering-simulation techniques, this study takes AI-empowered curriculum reform as its central theme. It develops an integrated curriculum system comprising theoretical foundations, data intelligence, and engineering practice and uses outcome-based education (OBE) as its methodological foundation to systematically reconstruct course content, innovate teaching methods, embed engineering cases, and optimize evaluation mechanisms. Based on the practical needs of course development, the study proposes an overall roadmap for AI-empowered curriculum reform, designs a machine-learning case for predicting the service life of automotive components and a finite-element case for assessing the reliability of vehicle-body structures, and establishes a competency-attainment analysis framework and reform-outcome evaluation system that do not depend on fabricated score improvements. The proposed model can facilitate students' transition from acquiring theoretical knowledge to developing the competence required to solve complex engineering problems and has strong potential for wider application in the cultivation of advanced vehicle-engineering talent under the emerging engineering education initiative.***

Keywords: Artificial intelligence, Graduate education, Automotive reliability, Curriculum reform, OBE, Competency attainment, Engineering practice.

1. Introduction

Automotive reliability is a core concern in vehicle engineering and a central requirement throughout product design, validation, and service [1]. Its purpose is to ensure that products deliver their intended functions, stable performance, and operational safety under specified operating conditions and throughout their service lives. Probability, reliability, and statistical methods provide the analytical foundation for engineering design under uncertainty [2]. Structural-reliability methods extend this foundation to safety assessment under variable loads, material properties, and boundary conditions [3]. With the rapid development of new-energy vehicles, intelligent driving, and the Internet of Vehicles, automobiles are evolving from conventional mechanical systems into complex systems that deeply integrate mechanics, electronics, control, software, and data. Accordingly, automotive reliability research has expanded from individual components to multisource information fusion, modeling of complex service conditions, intelligent failure prediction, and life-cycle reliability management. Condition-based maintenance integrates machinery diagnostics and prognostics into maintenance decision-making [4]. Modern prognostics further connects data acquisition and health-indicator construction with remaining-useful-life prediction [5]. Deep-learning approaches have also become important tools for machine-health monitoring and intelligent fault analysis [6].

Against this background, the graduate course Automotive Reliability Theory and Applications should not only teach the fundamentals of reliability but also develop students' ability to analyze complex engineering problems, integrate multidisciplinary knowledge, and conduct innovative research. Although the existing curriculum systematically covers conventional topics such as probability and statistics, failure analysis, life prediction, and reliability assessment, further improvement is needed in the introduction of modern computational tools for intelligent manufacturing and digital engineering, training in data-driven methods, and the design of engineering-practice activities.

In line with the curriculum-reform project on which this study is based, the central objective of course development is to strengthen graduate students' integrated competence in reliability analysis, numerical computation, engineering problem solving, and research communication. Building on previous reform efforts and the realities of course delivery, this study combines AI empowerment, OBE, and the development of competence for solving complex engineering problems to formulate a reform framework and implementation plan for the graduate course Automotive Reliability Theory and Applications.

2. Current Teaching Conditions and the Need for Reform

2.1 Insufficient Integration of Theory and Engineering Applications

Conventional courses focus on mathematical reliability models and theoretical derivations. Although students can master basic concepts such as failure rate, reliability, and life distributions, they often find it difficult to transfer these concepts to practical vehicle-engineering scenarios, including crash safety, structural durability analysis, failure prediction, and maintenance decision-making. An inadequate range of course cases weakens students' appreciation of the

engineering value of reliability theory and hinders the development of their subsequent research topics and engineering-application competence.

2.2 Insufficient Integration of Modern Computational Tools

As MATLAB, Python, finite element simulation software, and machine-learning tools become widely used in engineering, graduate students should acquire the basic ability to use modern computational tools for data processing, model development, and simulation analysis. Existing course content, however, remains relatively weak in digital resources, programming assignments, and intelligent-analysis training, and students often remain limited to formula-based calculations.

2.3 Relatively Undiversified Evaluation

A single closed-book examination is well suited to assessing knowledge acquisition but cannot fully capture the engineering, innovation, teamwork, and scholarly communication competencies that graduate courses should emphasize. Process evaluation, project evaluation, and competency-attainment evaluation should therefore be introduced to align course assessment more closely with the training objectives.

3. Overall Design of AI-Empowered Curriculum Reform

The reform follows an overall approach driven by needs, centered on competence development, supported by digital technologies, and sustained through continuous improvement. AI is integrated throughout course development not as an independent add-on, but as an important methodological tool that supports graduate students in analyzing complex engineering problems. The overall design comprises four levels: identifying course needs and pain points; reconstructing course content and teaching resources; developing an implementation pathway that integrates AI with teaching methods; and establishing diversified evaluation and continuous-improvement mechanisms. The resulting four-stage reform roadmap is shown in Figure 1.

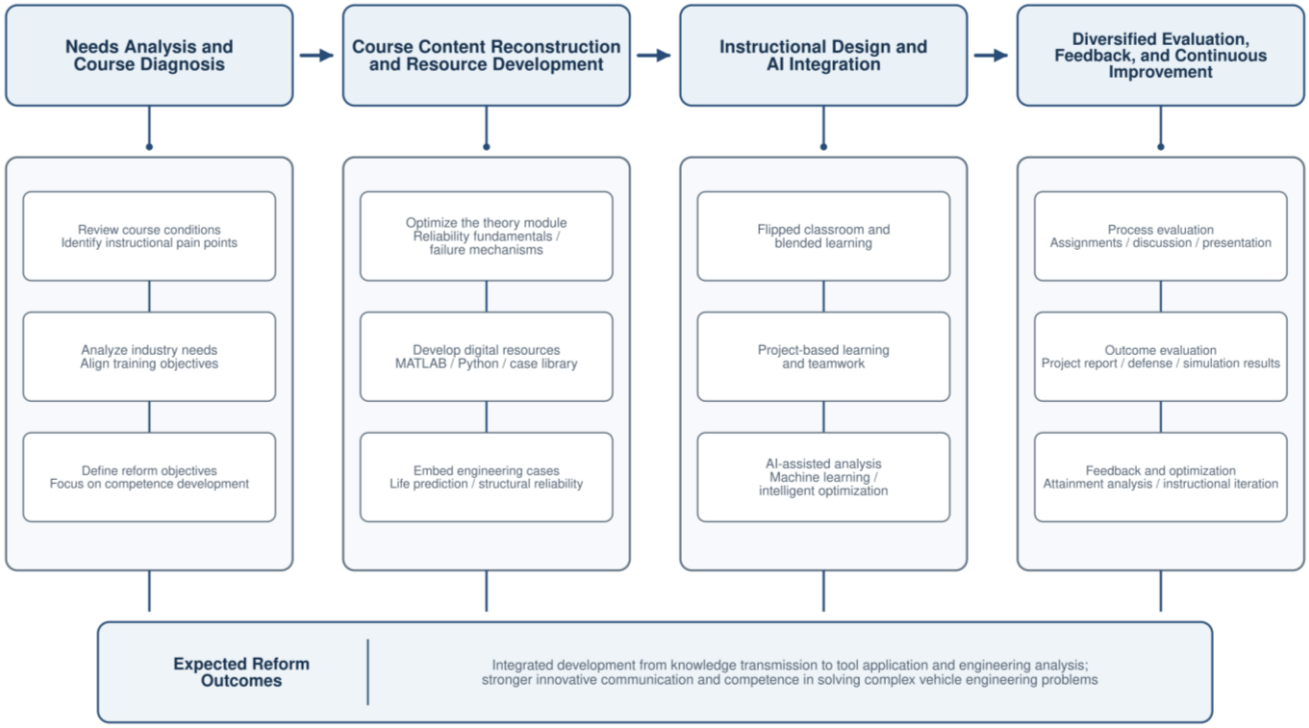


Figure 1: Overall roadmap for AI-empowered curriculum reform

4. OBE-Based Curriculum Reform Design

Constructive alignment requires learning outcomes, instructional activities, and assessment to operate as a coherent system [7]. Outcome-based education (OBE) uses expected learning outcomes as the starting point for backward instructional design and focuses on the competence ultimately developed by students rather than the mere coverage of course content [8]. For the graduate course Automotive Reliability Theory and Applications, this logic supports criteria-aligned engineering instruction and provides a clear methodological framework for addressing what should be taught, why it should be taught, and how attainment should be evaluated [9].

Considering the characteristics of graduate education in mechanical and vehicle engineering, this course specifies five expected learning outcomes: mastery of the theoretical foundations of automotive reliability; the ability to process reliability data and perform statistical analysis; the ability to use AI methods for life prediction and failure analysis; the ability to assess structural reliability in conjunction with finite element simulation; and competence in engineering communication, teamwork, and research innovation. On this basis, a closed-loop design is established that connects training objectives, course objectives, teaching content, practical tasks, evaluation feedback, and continuous improvement. The alignment and continuous-improvement cycle is illustrated in Figure 2.



Figure 2: OBE closed-loop model

5. Reconstruction of the Course Content System

5.1 Optimization of the Reliability-Theory Module

The course retains and strengthens conventional core content, including fundamental reliability concepts, fault-tree analysis, life distributions, and reliability assessment, while giving it a stronger engineering orientation. For example, instruction on life distributions goes beyond parameter estimation by using component fatigue-life cases to explain the relationship between distribution models and actual failure processes.

5.2 Integration of a Data-Driven Analysis Module

To address the large volumes of operational data generated by intelligent vehicles, the course adds data cleaning, feature extraction, statistical modeling, and visualization. Students can therefore use tools such as Python for basic data analysis and establish a foundation for subsequent machine-learning-based life prediction and fault diagnosis.

5.3 Development of Engineering Cases and Digital Resources

A case library is developed around representative tasks such as automotive-component life prediction and vehicle-body structural reliability analysis. MATLAB scripts, Python examples, simulation instructions, and report templates are provided to establish integrated digital resources comprising lecture notes, cases, programs, and reports.

6. An Integrated Theory-Data-Engineering Practice Framework

The integrated framework connects three categories of elements: reliability theory as the knowledge foundation; data analysis and AI as technical support; and engineering-practice tasks as the setting in which competence is developed. Through this framework, graduate students learn not only what reliability theory is, but also how data and tools can be used to solve practical engineering problems. The resulting theory-data-engineering practice pathway is summarized in Figure 3.

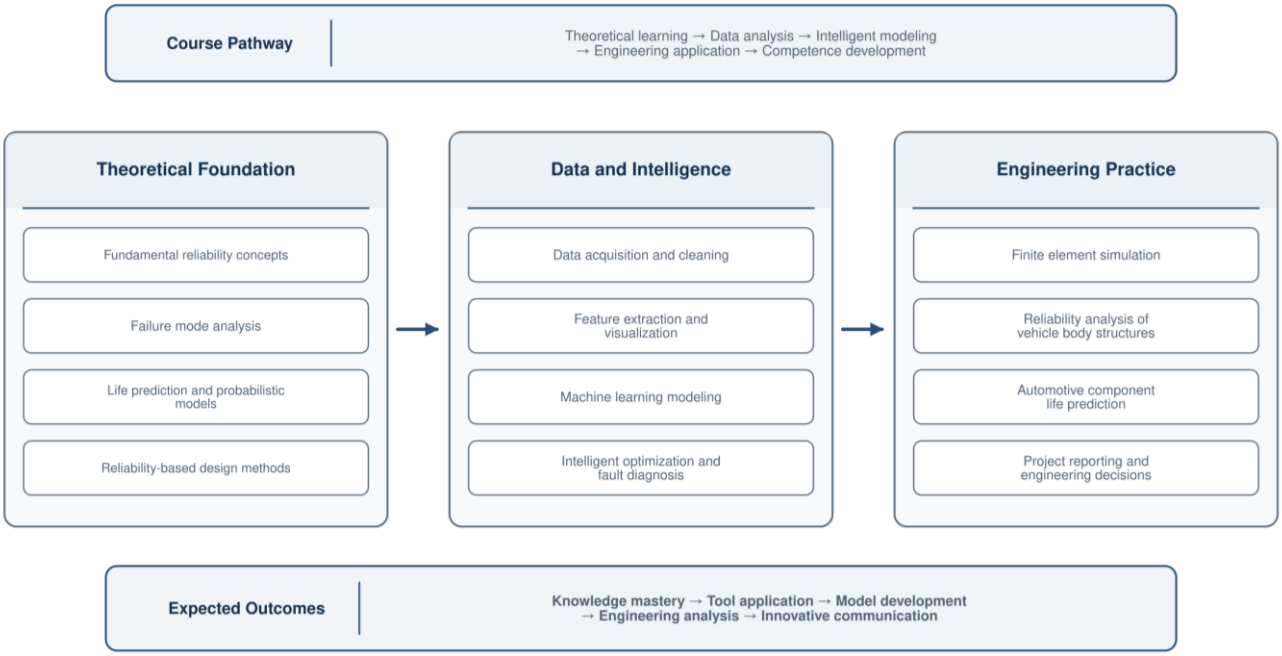


Figure 3: Integrated theory-data-engineering practice framework

7. Design of Engineering Case-Based Teaching

7.1 Machine-Learning-Based Life Prediction for Automotive Components

This case addresses the analysis of the service life of critical automotive components and is intended to help students understand how conventional reliability theory can be integrated with machine-learning prediction. Students first identify the object of life analysis and its failure modes and define key indicators such as failure time, remaining useful life, and the reliability function. They then clean the provided experimental and operational data, remove outliers, extract features, and normalize the data. Finally, they build support vector machine, random forest, or neural network models for life prediction and evaluate these models using mean squared error, mean absolute error, and the coefficient of determination.

The case has three primary instructional benefits. It helps students understand the complementary relationship between AI methods and conventional reliability theory, develops their ability to analyze problems using authentic data, and trains them to communicate a complete research process from model development to result interpretation.

7.2 Finite-Element-Based Reliability Analysis of Vehicle-Body Structures

This case focuses on evaluating the reliability of critical load-bearing vehicle-body structures. Under the instructor's guidance, students complete geometric modeling, material-parameter definition, application of boundary conditions, and load specification. They then use finite element software to perform static, modal, and fatigue analyses and further investigate the effects of parameter variations, load randomness, and material variability on structural reliability.

Through this case, students develop a cognitive chain that extends from theoretical analysis and numerical simulation to engineering decisions. They learn both the physical meaning of reliability-assessment results and the assumptions, computational boundaries, and engineering limitations of finite element models. After completing the case, students submit an analysis report and participate in a group defense to strengthen scholarly communication and engineering communication.

8. Innovation in Teaching Modes

8.1 Flipped Classroom and Blended Learning

Fundamental theory is studied in advance through online videos, lecture notes, and self-assessment questions, while classroom time focuses on case discussion, programming instruction, and simulation analysis. This arrangement emphasizes active learning, whose effectiveness in engineering education has been systematically reviewed [10]. Large-scale evidence across science, engineering, and mathematics courses also associates active learning with improved student performance [11]. The integration of online and in-person learning promotes students' capacity for independent learning and allows classroom activities to place greater emphasis on higher-order competence.

8.2 Project-Based Learning and Teamwork

Students work in groups on an integrative course project and divide responsibilities for information retrieval, model development, program implementation, and presentation of results. This approach strengthens teamwork and simulates authentic research and engineering-project environments. Such project-based designs are consistent with the broader evidence base on project-based learning [12].

8.3 AI-Assisted Learning Support

Systematic reviews of AI in higher education show that educators and pedagogical design must remain central to technology integration [13]. Instructors can provide code templates, data-processing examples, and problem-diagnosis prompts to help students understand the logic, opportunities, and limitations of using AI tools [14]. International guidance further requires human oversight, output verification, transparency, and academic responsibility when GenAI is used in education and research [15]. At the same time, students are guided to uphold academic norms and engineering judgment and not treat AI as a shortcut that replaces thinking.

9. Course Implementation and Analysis of Instructional Outcomes

To align this curriculum-reform study with the conventions of educational research without fabricating specific improvements in student scores, a competency-attainment analysis framework is used to evaluate course implementation and instructional outcomes. Beginning with the course objectives, the framework examines student performance in knowledge acquisition, tool use, engineering analysis, and innovative communication and combines process-based and outcome-based evidence to judge the actual effects of the reform.

Course implementation comprises four stages. During pre-class preparation, the instructor releases the learning objectives, resources, self-assessment tasks, and project instructions, and students preview the foundational knowledge. Classroom learning then combines theoretical instruction, case seminars, programming exercises, and simulation practice. During project implementation, students work in groups to complete either a machine-learning life-prediction task or a vehicle-body structural reliability analysis. Finally, during summary and feedback, the instructor organizes presentations, defense discussions, and course reflection and collects learning logs, project reports, and classroom feedback.

Instructional outcomes are analyzed across four dimensions. Knowledge is assessed through tests, short papers, and classroom discussions that reveal students' understanding of reliability theory and methodological systems. Tool use is assessed through programming assignments, data-processing results, and simulation operations involving MATLAB, Python, and finite element software. Engineering analysis is evaluated according to the completeness of problem modeling,

method selection, result interpretation, and engineering judgment in project reports. Innovative communication is evaluated comprehensively through defense performance, report structure, figures and tables, and teamwork.

Competency-attainment analysis does not seek a single absolute score; instead, it emphasizes consistency among objectives, evidence, and judgment. Specifically, the teaching team can assign evidence sources to each course objective, including test questions, program files, simulation models, project reports, and classroom presentations, and then use evaluation rubrics to judge the level of attainment for each competence. This framework captures the authentic implementation outcomes of graduate curriculum reform while avoiding artificially inflated achievement data in curriculum-reform studies.

The expected outcome of combining AI empowerment with OBE is that students' understanding of theoretical knowledge will become more closely connected to engineering contexts, while their tool-use and interdisciplinary integration competencies will also improve substantially. More importantly, when addressing complex engineering problems, students can develop a complete competency chain comprising problem identification, data analysis, model development, result judgment, and engineering communication. Such development is more consistent with graduate-training quality requirements than a single examination score.

10. Indicator System for Evaluating Reform Outcomes

Evaluation of the curriculum reform follows the principles of multidimensionality, evidence orientation, and sustainability. Rather than fabricating student-achievement data, it establishes an indicator system aligned with the course objectives. The system encompasses theoretical knowledge, engineering practice, innovation competence, and general professional qualities and supports both the evaluation of student learning outcomes and continuous course improvement. The dimensions, evidence sources, and evaluation methods are detailed in Table 1.

Table 1: Indicator system for evaluating curriculum reform outcomes

Evaluation dimension	Core indicators	Evidence sources	Evaluation method
Theoretical knowledge	Mastery of reliability theory, models, and methods	Tests, course reports, classroom discussions	Outcome evaluation
Tool application	Data processing, programming, and simulation-modeling competence	Code files, calculation results, simulation models	Process + outcome evaluation
Engineering analysis	Problem modeling, result interpretation, and engineering judgment	Project reports, case-analysis records	Project evaluation
Innovative communication	Solution design, presentation and defense, and teamwork	Defense performance, presentation materials, peer-assessment records	Comprehensive evaluation

11. Foundations and Safeguards for Reform Implementation

This curriculum reform has a solid foundation for implementation. The course leader has an interdisciplinary background in mechanical engineering, computational mechanics, and experimental mechanics and extensive experience in graduate teaching. Substantial research experience has also been accumulated in data-driven modeling, prediction of the mechanical properties of materials, and engineering simulation. This experience can be directly transferred to the development of course cases and the design of practical activities.

The reform is further supported by team and resource conditions, including experience from previous educational-reform projects, an existing reserve of course cases, access to commonly used engineering software, and a foundation in digital teaching resources. These conditions support course reconstruction, project-based practice, and the establishment of a continuous-improvement mechanism.

12. Conclusions

To address the reform needs of the graduate course Automotive Reliability Theory and Applications, this study develops a curriculum-reform plan that combines AI empowerment, OBE, and engineering case-based learning. The resulting framework systematically integrates a reform roadmap, an instructional framework, embedded engineering cases, and an optimized evaluation system.

Compared with conventional teaching models that emphasize the transmission of theory, the proposed approach focuses on developing graduate students' competence in solving complex engineering problems. It replaces purely score-oriented evaluation of instructional outcomes with a competency-attainment analysis framework, thereby enhancing the authenticity and operational feasibility of curriculum-reform research. The study can inform the development of graduate courses in vehicle engineering and related disciplines.

Acknowledgments

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