ISSN: 2424-8460(O)
2251-2608(P)

Original Research Article

Artificial intelligence empowering the teaching reform practice of the "Computational fluid dynamics and application" course

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Abstract: As a core course for graduate students in fields such as aerospace and energy power, Computational Fluid Dynamics (CFD) presents challenges for traditional teaching models due to its abstract theory, complex practice, and delayed feedback. These models struggle to meet the requirements of personalized parenting and industry demands. To address these issue, this paper systematically elaborates the implementation path of AI in theoretical teaching, practical training, and application expansion. It boosts students' efficiency in mastering core CFD knowledge, enhances programmatic and emulation practice competency, and provides a reference for teaching reform in graduate courses in science and engineering.
Keywords: artificial intelligence; computational fluid dynamics; postgraduate education

1. Introduction

Computational Fluid Dynamics (CFD) [1], based on computational mathematics, modern fluid mechanics, and computer science, utilizes computers as the primary tool to numerically simulate and visualize various flow phenomena in engineering applications. It is an essential research tool for graduate students in fields such as aerospace, energy and power, and environmental engineering. However, CFD course instruction has long faced multiple challenges. (1) Theoretical content in CFD is abstract. Core topics such as numerical discretization of the Navier-Stokes equations and turbulence models require a strong foundation in mathematics and physics, leading to significant differences in student comprehension. (2) Practical implementation is complex. From algorithm programming and Fluent simulation operations, the process involves detailed tasks such as mesh generation and boundary condition setup. Traditional classroom instruction struggles to meet the diverse guidance needs of students with varying backgrounds. (3) Feedback is lagging. Issues in student programming assignments, such as parameter selection and non-converging iterations, often require waiting for centralized grading by instructors before feedback is received affecting learning continuity. The development of artificial intelligence technologies offers a new approach to address these challenges: by intelligently analyzing student learning behaviors, dynamically delivering resources, and providing real-time feedback on practical outcomes, personalized instruction tailored to individual learners can be achieved. This is of significant importance for cultivating graduate students' capabilities in CFD applications and research-oriented innovative thinking [2].

This paper focuses on the teaching reform of graduate-level CFD courses empowered by AI, and consists of the following main sections. A comprehensive analysis is first conducted on the current teaching status. Based on the analysis of the current situation, a reform concept and framework for AI-empowered CFD course teaching are proposed. Then, the specific implementation path of AI in CFD course instruction is elaborated. Finally, a summary is provided.

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2. Analysis of current teaching situation

2.1. Course teaching objectives

The knowledge objectives are to master the basic concepts, equations, theorems, and methods of computational fluid dynamics, to be able to analyze the properties of numerical discretization methods and their application extent; to be proficient in applying the basic methods of computational fluid dynamics for programmatic calculation to solve typical applications and practical issues in the use of Weapons and equipment.

2.2. Issues faced in teaching

Theory and practice is separated. Although students learn the basic principles and numerical method of CFD in theoretical courses, in actual operation, it is often difficult to combine this theoretical knowledge with specific numerical simulation practice.

The teaching mode is single. Currently, the teaching mode of CFD courses is mainly based on educator lectures, and students passively receive knowledge. This teaching mode lacks interactivity and personalization, making it difficult to meet the learning requirement of different students.

Insufficient industry requirement adoption. With the continuous development of technology, CFD technology and its application in the industry are also constantly updating and expanding. However, the current teaching content and methods of CFD courses are relatively lagging, making it difficult to cover these cutting-edge application requirements.

2.3. Feasibility of AI-empowered CFD courses

In recent years, artificial intelligence technology has made considerable progress [3]. At the technical layer, natural language processing can support CFD-specific intelligent Q&A, and adaptive learning systems can push layered resources based on the differences in mathematical and physical foundations of graduate students, and phantom emulation enhancement technology can provide live feedback on flow field simulation results. These technologies have formed mature application paradigms in the education realm.

From the perspective of teaching requirements, the "theoretical knowledge - programming practice-scientific research connection" three-stage trait of CFD courses is highly consistent with AI's personalization push, dynamic evaluation, and case generation competency. It can accurately facilitate students in overcoming pain points such as finite volume method discretization and turbulence model choice.

3. AI-empowered teaching reform of CFD courses

3.1. Reform concept

The core reform concept of AI-empowered graduate-level CFD courses is a student-centered approach that fully leverages the advantages of AI technology to achieve the integrated teaching objective of "AI facilitation - competency boosts - industry alignment."The student-centered approach emphasizes respecting students' individual differences and learning requirements, using AI technology to provide personalized learning support and coaching for each student. AI-facilitated teaching aims to enhance teaching efficiency and quality by ingesting AI technologies such as intelligent teaching systems and data analysis tools, helping students better understand and master CFD knowledge and skills. In terms of competency enhancement, emphasis is placed on

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2251-2608(P)

developing students' innovation ability, practical skills, and problem-solving capabilities.

3.2. Overall teaching framework construction

At the theoretical teaching level, AI large model technology is leveraged to achieve visualization and intelligent explanation of abstract concepts. For example, through AI-generated animations, impersonation videos, and other means, complex physical phenomena in CFD—Such as the evolution of flow fields and vortex formation—Are intuitively presented to students, helping them better understand abstract theoretical knowledge. With the support of the intelligent teaching system, relevant knowledge point explanations and practice questions are automatically pushed based on students' learning conditions and issues, enabling personalized learning guidance. By leveraging AI technology to conduct analysis on students' learning data, educators can gain live insights into students' learning progress and pain points, allowing for timely adjustments to teaching policies.

At the practical teaching layer, AI technology is primarily used to implement personalized simulation training and live feedback. Through AI algorithms, personalized CFD simulation quests are generated for each student based on their previous practical grades and competency levels. The difficulty and content of the quests are matched to the students' actual abilities, which not only stimulates students' learning interests but also effectively boosts their practical competency.During the process of students conducting simulation operations, AI tools are leveraged to monitor students' action steps and simulation parameter settings in real time. Once an issue is discovered, timely hints and recommendations are provided to prevent students from wasting time in the wrong direction.

At the application expansion layer, the focus is on introducing cross-disciplinary case-based teaching of AI + CFD to parent students' interdisciplinary application competency. For example, by ingesting AI-based aerodynamic shape optimization design cases for aircraft, students learn how to apply AI algorithms to analyze and optimize CFD simulation outcomes, thereby boosting aircraft performance.Organize students to carry out group projects with the subject of AI-assisted CFD design, such as AI-based optimization design of engine air intakes. Through the implementation of real-world projects, cultivate students' teamwork skills and comprehensive application competency.

3.3. Construction of instructional resource library

To support AI-empowered CFD course instruction, it is necessary to build a comprehensive instructional resource library. The resource library includes AI-assisted instructional tools, such as intelligent Q&A systems, learning analysis platforms, etc.; a classic CFD case library covering CFD application cases of varying domains and difficulty levels, providing students with materials for practice and learning; and a frontier case library that promptly collects and collates the latest AI + CFD application cases in the industry, enabling students to engage with cutting-edge technologies and applications.It should also include relevant teaching videos, lesson slides, exercises, and other resources to facilitate students' self-directed learning.

4. Conclusion

To address issues currently present in graduate-level education, artificial intelligence technologies were leveraged to reform the teaching procedure of the Computational Fluid Dynamics and Applications course. First, through methods such as knowledge point visualization and intelligent Q&A, AI significantly boosts the efficiency of theoretical instruction, markedly shortening the cycle for students to grasp abstract concepts. Second, by utilizing features like personalized quest generation and intelligent assistance during procedures, the precision of practice training is enhanced, making smaller the competency gap among students with varying foundational levels. Third, through cross-disciplinary cases and project-based learning, students are guided to transition from merely being able to impersonate simulations to being capable of conducting optimizations. Through the three-level empowerment, AI technology effectively enlarges the educator's "coaching radius" while simultaneously unlocking students' potential for autonomous inquiry.

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Funding

This work is supported by National Aviation Power Supply Curriculum Education and Teaching Reform Project (2025FDJXN-12) and Shaanxi Key Project for Major Research on Teaching Reform in Undergraduate and Higher Continuing Education (23ZG020).

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