Research on The Application of COMSOL Software in The Teaching Reform of a Certain Unmanned System Course

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Abstract: With the reform of the curriculum system in military academies, there is a greater emphasis on cultivating talents with broad knowledge, solid foundation, and comprehensive quality. Meanwhile, unmanned systems are increasingly applied in the military field, making it urgent to enhance the practical level of talent cultivation through teaching reform. Some parts of a certain unmanned system course involve the knowledge system of fluid mechanics, which is an important basic course in engineering. Its theoretical abstraction and engineering practicality pose high demands on teaching. Traditional teaching models have problems such as the disconnection between theory and practice and insufficient student participation. This paper explores the application path of COMSOL Multiphysics software in the teaching reform of a certain unmanned system course. By constructing an integrated teaching system of "theory–simulation–practice", optimizing course content and teaching methods, and designing course cases based on real engineering problems, it is shown that the introduction of COMSOL software can effectively enhance students understanding ability, innovative thinking, and engineering practice ability, providing a new paradigm for the curriculum reform in military academy education.

Keywords: Teaching Reform; COMSOL Software; Teaching Design

1. Introduction

Some parts of a certain unmanned system course involve the knowledge system of fluid mechanics, including a large number of differential equations, boundary layer theory, turbulence models, and other abstract concepts. Traditional teaching relies on blackboard derivations and limited experimental demonstrations. Students often have difficulty establishing intuitive cognition due to the "invisibility and intangibility" of these concepts. In addition, traditional experiments are limited by equipment costs and safety risks, making it difficult to cover the observation and analysis of complex flow fields such as unsteady flow, multiphase flow, and fluid-structure interaction, resulting in students lack of ability to solve engineering practical problems [1-2].

With the development of computational fluid dynamics (CFD) technology, simulation software such as COMSOL Multiphysics provides new tools for fluid mechanics teaching. COMSOL has functions such as multi-physics field coupling, parametric modeling, high-precision numerical calculation, and visualization post-processing. It can transform abstract flow field characteristics into intuitive velocity cloud diagrams, pressure streamlines, and vorticity distributions, helping students understand theoretical knowledge. At the same time, its open modeling environment supports the definition of custom physical fields and boundary conditions, facilitating personalized experiments and engineering case design, which meets the teaching needs of virtual-real integration and industry-education integration under the background of new engineering [3-5].

2. Analysis of the Pain Points of Traditional Teaching Models

2.1 Abstract Theoretical Teaching, Difficult for Students to Understand

The derivation of the N-S equations, boundary layer separation, and Karman vortex street in fluid mechanics rely on mathematical modeling and logical reasoning. Students need to construct a physical image of the flow field in two-dimensional or three-dimensional space. Traditional teaching only uses formula derivations and static diagrams for explanation, lacking dynamic visualization means. As a result, students remain at the level of memorization for questions such as "Why does flow separation cause a sudden increase in resistance?" and "How does turbulent pulsation affect heat transfer?" and are unable to form physical intuition.

2.2 Significant Limitations in Experimental Teaching

Traditional fluid mechanics experiments rely on wind tunnels, water channels, and other equipment, with three major bottlenecks:

(1) High cost: Large-scale experimental devices are expensive, and most universities can only offer basic experiments such as flat plate boundary layers and pipe flow resistance, unable to cover complex flows.

(2) Long cycle: Experimental preparation and data collection take a long time, making it difficult for students to complete multi-condition comparisons within a class.

(3) Low safety: Experiments involving high-speed flow and high-pressure environments pose safety risks, limiting the expansion of teaching content

2.3 Insufficient Cultivation of Engineering Practice Ability

In the design phase of the course, there is a significant deficiency in the cultivation of engineering practice ability. Specifically, the course design often focuses too much on theoretical calculations and neglects comprehensive and systematic modeling training for actual engineering problems. When students encounter complex flow problems in the real world, they often feel at a loss and lack effective ways to convert theoretical knowledge into practical operational skills. More importantly, due to a lack of in-depth understanding and practical experience of the engineering application process of CFD (Computational Fluid Dynamics) software, students often find it difficult to independently undertake the entire process from problem definition, model establishment, parameter setting to result analysis when facing engineering problems that require simulation technology to solve, thereby limiting their ability to solve complex flow problems.

3. Advantages of COMSOL Software in The Teaching of a Certain Unmanned System Course

3.1 Multi-physical Field Coupling, Breaking the Limitation of Single Flow

The Fluid Flow module of COMSOL software, with its powerful multi-physical field coupling capability, deeply integrates various complex physical phenomena such as laminar flow, turbulent flow, multiphase flow, and fluid-structure interaction. This feature enables it to accurately simulate and analyze complex flow problems widely existing in actual engineering, effectively compensating for the limitation of single flow scenarios in traditional teaching models. In traditional teaching, students often only come into contact with idealized laminar flow or simple turbulent flow models, making it difficult for them to fully understand complex flow phenomena such as the interaction between fluid and solid and the coexistence of multiphase media in the real world. However, COMSOL software, through its highly integrated physical field modules, provides students with a platform to comprehensively explore and understand these complex flow phenomena, greatly enriching teaching content and enhancing students' practical abilities and innovative thinking.

3.2 Visualization and Parameterization, Building Dynamic Learning Scenarios

COMSOL software not only offers powerful real-time simulation result visualization capabilities, presenting complex flow features such as velocity vectors, pressure contour lines, and streamline trajectories in an intuitive and vivid manner, but also supports parameterized scanning technology to flexibly adjust key parameters such as Reynolds number and attack angle, and real-time simulate and display the entire complex transition process from laminar to turbulent flow. This dynamic demonstration method greatly enhances the interactivity and interest of teaching, making abstract theoretical knowledge concrete and perceptible, effectively helping students deeply understand the profound impact of dimensionless numbers such as Reynolds number on flow characteristics. For example, when teaching the classic fluid mechanics problem of flow around a cylinder, teachers can use COMSOL software to vividly show the variation law of vortex shedding frequency under different Reynolds numbers (Re) through animation, enabling students to intuitively grasp the physical meaning of the Strouhal number (St) and its application in actual flow phenomena, thereby creating a dynamic learning scenario full of vitality and exploration [6].

3.3 Open Modeling, Supporting Inquiry-Based Learning

COMSOL software, with its unique open modeling environment, grants users the powerful ability to define control equations and boundary conditions, providing a unique advantage for conducting research-oriented teaching. In this environment, students can fully exert their initiative, independently design and implement a series of challenging experimental projects, such as "Comparison of Flow Resistance on Walls with Different Roughness" and "Study on the Impact of Porous Medium Permeability on Seepage Field". By flexibly adjusting model parameters and meticulously analyzing simulation results, students can not only deeply understand the basic principles of fluid mechanics but also exercise and enhance their scientific inquiry abilities in practice. Compared with the fixed process preset in traditional experiments, this open simulation experiment mode based on COMSOL, with its high flexibility and exploratory nature, can better stimulate students innovative thinking, encourage them to break away from the traditional framework, and be brave to try new ideas and methods, thereby constantly breaking through themselves in the process of solving problems and achieving the innovation and application of knowledge [7]

3.4 Close to Engineering Practice and Strengthen Application Orientation

COMSOL software has a rich and diverse library of engineering cases, covering multiple practical engineering fields from heat exchanger flow field optimization to water turbine cavitation simulation. These cases not only closely meet the real needs of the industrial sector but also strictly follow the standard process of CFD (Computational Fluid Dynamics) projects in the industrial sector, including key steps such as geometry processing, meshing, solution setup, and post-processing. By personally operating and completing these cases, students can experience the entire process of engineering simulation, thereby gradually familiarizing themselves with and mastering the standard process of engineering simulation in practice. More importantly, this process enables students to deeply understand and master the core skill chain of "model simplification, parameter setting, and result verification", that is, how to reasonably simplify complex engineering problems while ensuring calculation accuracy, how to accurately set simulation parameters to reflect actual working conditions, and how to verify the reliability of simulation results through scientific methods. The teaching mode oriented towards engineering practice not only greatly enhances students' practical operation ability but also lays a solid foundation for them to quickly adapt to and solve actual engineering problems in their future careers.

4. Conclusion

4.1 Reconstruction of Teaching Content: Deep Integration of Theory and Simulation

4.1.1 Embedding Real-time Simulation Demonstrations in Theory Classes

When explaining key knowledge points, real-time modeling and simulation demonstrations with COMSOL are used to achieve the connection of formula derivation–physical phenomenon–engineering example. For instance, when explaining the Bernoulli equation, a suitable model, such as a Venturi tube model, is selected based on the physical meaning of the Bernoulli equation to demonstrate the inverse relationship between flow velocity and pressure, and to compare the pressure distribution cloud diagrams under different contraction ratios. Through simulation demonstrations, students can combine the abstract Bernoulli equation with intuitive flow phenomena, deepening their understanding of the basic principles of the Bernoulli equation.

4.1.2 Transforming Laboratory Classes into "Virtual and Real Combined" Mode

Traditional experiments are divided into basic verification type and simulation expansion type. In basic verification type experiments, classic experiments such as the measurement of pipe flow resistance coefficients are retained, and students are required to compare the measured data with COMSOL simulation results and analyze the sources of errors (such as wall roughness modeling, turbulence model selection); meanwhile, in simulation expansion type experiments, complex flow experiments that cannot be achieved with traditional equipment are set up, such as "Study on Vortex Shedding Characteristics of Flow around a Cylinder" and "Analysis of Flow Field inside Centrifugal Pump Impeller", where students need to independently complete modeling, simulation, and result analysis, and write experimental reports.

4.1.3 Focusing on Real Engineering Problems in Course Design

With engineering projects as the orientation, comprehensive course design topics are designed, such as "Design of Flow Solid Coupling Drag Reduction Structure for Unmanned Underwater Vehicle", requiring students to establish three-dimensional geometric models, simulate pressure distribution and drag coefficients under different grid angles, and optimize structural parameters using the orthogonal test method.

4.2 Innovation in Teaching Methods: Student-centered Diversified Teaching

4.2.1 Case-driven Instruction (CDIO)

Select typical cases from the fields of aviation, energy, environment, etc., and break them down into four links: problem description–theoretical analysis–COMSOL modeling–result discussion.

4.2.2 Innovative Design of Teaching Mode

Before class, pre-study videos on COMSOL simulation (such as basic geometric modeling and meshing techniques) are released. Students learn software operation through the MOOC platform. During class, students complete the modeling task for given problems in groups, and the teacher provides targeted guidance on boundary condition setting and turbulence model selection. After class, students are required to submit simulation reports, including problem analysis, model settings, result visualization, and conclusions.

4.2.3 Virtual Simulation Competition and Innovative Practice

Organize school-level or regional "COMSOL Fluid Mechanics Simulation Competitions", with topics covering "drag reduction structure design", "flow field interference of multi-UUV cooperative operation", etc. Encourage students to propose innovative solutions based on professional knowledge. For example, a participating team reduced the simulation drag coefficient by 12% by optimizing the attached shape of the underwater unmanned vehicle. Their achievement can be transformed into an excellent case for course design.

4.3 Optimization of Assessment System: Process Evaluation and Competency-Oriented

The traditional assessment mainly relied on the final written exam (accounting for 70%). After the reform, a multi-dimensional evaluation system was adopted. Among them, theoretical exams accounted for 50%, including in-class tests and final written exams, mainly testing students' mastery of theoretical knowledge; practical ability accounted for 40%, including experimental reports and course design results. The assessment dimensions included modeling standardization, depth of result analysis, visualization effect, etc., mainly testing the connection between students' theoretical knowledge and practice; in addition, students innovative thinking was also part of the assessment form, accounting for 10%, including contribution to group discussions, performance in simulation competitions, and solutions to open-ended problems, focusing on testing students high-level thinking.

5. Conclusion and Outlook

Integrating COMSOL software into the teaching of a certain unmanned system course, through theorization of simulation, virtualization of experiments, and practicalization of course design, effectively solved the problems of abstraction and practicality in traditional teaching, and constructed a "knowledge transmission–ability cultivation–innovation training" three-in-one teaching system. Practice has proved that this model has enhanced students learning interest and engineering literacy, providing replicable experience for course reform under the background of new engineering.

In the future, the following directions can be further explored:

(1) Develop an online virtual simulation platform to achieve cross-campus sharing and remote experiments. Based on cloud computing and WebGL technology, develop a lightweight online platform integrating the COMSOL kernel. The platform builds a course resource pool, storing standardized simulation models, teaching videos, etc., supporting cross-campus collaborative modeling and resource sharing among teachers and students from multiple institutions; students can remotely access the computing cluster through a browser to complete the entire process of modeling and simulation online, and teachers can view the progress in real time and provide guidance; the

platform automatically records operation trajectories and generates student performance analysis reports to assist in precise teaching. This platform can break through physical space limitations, be suitable for synchronous teaching in joint training projects of military academies, and also meet students' needs for independent expansion after class, reducing experimental costs while improving resource utilization and teaching collaboration;

(2) Combine artificial intelligence technology to build an automatic assessment system, providing intelligent feedback on students modeling processes and results. Use deep learning algorithms to train a simulation process assessment model to automatically identify typical problems such as missing boundary conditions and insufficient mesh quality in students modeling, and provide real-time improvement suggestions through visual prompts. By leveraging natural language processing technology to analyze experimental reports, the depth of students physical understanding of simulation results can be evaluated, and structured comments can be generated. Based on historical data, personalized learning content can be dynamically pushed, such as advanced modeling tutorials or cutting-edge cases. For military scenarios, a federated learning evaluation system can be developed to optimize models while protecting data privacy, enhancing the accuracy of evaluations for complex flow field problems, and providing data-driven analytical ability training for the cultivation of intelligent combat talents.

(3) Deepen the integration of industry and education, introduce real projects as course design topics, and promote seamless connection from classroom to laboratory and then to workplace. Actively cooperate with military research institutes and defense enterprises, and transform real military demands such as noise reduction design for unmanned underwater vehicles and anti-wind field interference for unmanned aircraft swarms into course design topics. Require students to complete simulation and optimization according to the process of military projects, and invite industry experts to participate in the review. Establish a dual-teacher teaching mechanism of university teachers and military engineers, where the former focuses on theoretical foundations and the latter imparts engineering modeling skills and practical experience. Relying on military training bases, build a "virtual simulation–physical verification" platform, allowing students to convert simulation schemes into actual verification through 3D printing, wind tunnel testing, etc., shortening the ability transformation cycle from classroom to workplace, and promoting the in-depth connection between teaching achievements and the practical needs of equipment research and development. Through continuous optimization of teaching content and methods, COMSOL software will play a greater role in cultivating high-quality talents with innovation ability and competitiveness.

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