Teaching Model Innovation of "Fuzzy Control Theory and Applications" Driven by Science and Education Integration

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Abstract. In the era of innovation and development, the integration of science and education and the pursuit of innovative growth have become key characteristics of research-intensive university construction. In order to serve the national strategic plan for artificial intelligence, ignite the spirit of innovation among postgraduate students, and enhance the quality of teaching, it is necessary to reform the current teaching situation of the "Fuzzy Control Theory and Its Applications" course for postgraduates, which is characterized by outdated content, monotonous teaching methods, and traditional assessment approaches. The reform should focus on updating the teaching content, integrating various teaching methods, and fully utilizing online learning resources to establish a comprehensive course system with a distinct maritime university feature, centered around "basic theory + cutting-edge development + engineering application". This approach explores a new teaching model where professional courses participate in the establishment of a knowledge system, and contribute to the cultivation of research and innovative capabilities.

Keywords: Integration of Science and Education; Construction of Curriculum System; Postgraduate Education; Scientific Research and Innovation Capability

1 Introduction

Education, science and technology, and talents are the fundamental and strategic supports for the comprehensive construction of a modern socialist country [1] [2]. To enhance the overall effectiveness of the national innovation system, it is necessary to strengthen self-reliant cultivation and build a large-scale, well-structured, and high-quality innovative talent team. As an important component of the national strategic scientific and

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technological strength, universities are a key convergence point of education, science and technology, and talents. Accelerating the development of new quality productive forces, promoting the transformation of scientific and technological achievements, and cultivating top-notch high-quality innovative talents oriented towards the future are crucial focal points for universities to serve national strategies, and they are also an inevitable requirement for the high-quality and connotative development of universities.

The integration of science and education is an important means for universities to promote the coordinated development of education, science, and talent, and to cultivate outstanding innovative talents [3]. The issue of the relationship between teaching and research can be traced back to the early 19th century, when universities such as the University of Berlin emphasized the unity of teaching and research. This became the origin of the integration of science and education. In the mid-20th century, the United States began to pay attention to the development of the integration of science and education, promoting the development model of the integration of industry, academia, and research through collaborations with Silicon Valley enterprises. At the end of the 20th century, Japan emphasized the core position of scientific and technological innovation in economic and social development through the implementation of the "Science and Technology for the Country" strategy. Since the 21st century, the development of the integration of science and education has been further promoted globally, with countries implementing policies of integrating science and education to enhance the efficiency of scientific and technological innovation and talent cultivation. In China, the relationship between teaching and research has also undergone a process of continuous deepening of understanding, from the early days of the founding of the country when China imitated the Soviet Union's "separation of science and education" educational model, to the reform and opening-up period when Deng Xiaoping proposed that universities should become both the center of education and the center of scientific research, known as the important instructions of the "two centers," which emphasized the combination of research and teaching. Further, the report of the 20th National Congress of the Communist Party of China clearly proposed the concept of "three integrations" to promote the integration of vocational and general education, the integration of production and education, and the integration of science and education. After more than 70 years of development, China has gone through a process from focusing solely on teaching to giving equal importance to both education and science, and then from equal emphasis on education and science to the combination and integration of education and science, and finally to the integration of education and science. With the continuous improvement of the scientific research level of research-oriented universities, especially since the construction of the "Double First-Class" universities, universities have made significant progress in scientific research and the ability to innovate, focusing on national strategies and the forefront of academic research. They have charted a new path with Chinese characteristics for cultivating outstanding innovative talents. Strengthening the integration of education and science plays a crucial role in improving the quality of postgraduate education, reinforcing the construction of mentor teams, and enhancing the development of higher education. It has also provided a powerful impetus for building a strong education power [4].

The course "Fuzzy Control Theory and Applications" is one of the professional elective courses for master's students in the field of control science and engineering. The main content of the course includes the mathematical and logical foundations of fuzzy control, design of fuzzy controllers, development of fuzzy control systems, and the cutting-edge development trends of fuzzy control [5]. In recent years, with the rapid development of artificial intelligence (AI) technology, fuzzy control, as an important method of intelligent control, has been widely researched by scholars at home and abroad, and many cutting-edge theoretical achievements and advanced engineering applications have emerged. However, the content in textbooks is no longer sufficient to meet the requirements of the control and AI industry for the cultivation of high-quality innovative talents. There is an urgent need to reform the traditional teaching model [6]. The integration of science and education is introduced into the teaching of the "Fuzzy Control Theory and Applications" course, combining the latest scientific research achievements of the AI industry with classroom teaching, transforming research achievements into teaching examples. This approach can not only stimulate students' interest in learning, enhance their participation and autonomy, but also enable students to understand the current situation of industrial development, fundamentally promoting the cultivation of innovative talents in the field of control.

2 Problems and Analysis in the Teaching Process

2.1 In Terms of Teaching Content

The basic theoretical content in the teaching classroom of "Fuzzy Control Theory and Application" is too extensive, leading to the students finding it rather dull and having low listening efficiency. At the same time, the traditional content of fuzzy control teaching is outdated in its knowledge system, still focusing on traditional fuzzy look-up tables, Mamdani fuzzy inference, and fuzzy PID as the key teaching content, lacking an introduction to the cutting-edge scientific development in the field of fuzzy control.

2.2 In Terms of Teaching Methods

Traditional fuzzy control course teaching methods tend to be monotonous, primarily focusing on lengthy theoretical lectures by instructors in the classroom. This approach struggles to stimulate students' enthusiasm and autonomy in learning. The teaching process lacks diversity and interactivity, and there is insufficient connection to the cutting-edge developments within the discipline and real-world engineering applications. Moreover, there is a lack of introduction to advanced research directions in fuzzy control specific to marine-related fields. As a result, students find it challenging to integrate fuzzy control concepts with their own research topics.

2.3 In Terms of Assessment Methods

Effective assessment methods are a crucial component of the teaching of "Fuzzy Control Theory and Application", but they are also a challenging aspect to implement and monitor. Traditional assessment methods in fuzzy control usually involve end-of-term exams. However, the end-of-term exam format is limited by time, has a narrow scope of content, lacks practical application assessment, and is not capable of fully evaluating students' learning achievements and innovative practical abilities.

3 Reform Proposals under the Teaching Model of Integration of Science and Education

The article aims to improve the teaching of fuzzy control by incorporating the latest research in AI and fuzzy control into the learning process. This is done through changes in three main areas: course content, teaching techniques, and assessment methods. The result is a comprehensive "Fuzzy Control Theory and Applications" curriculum that merges "theoretical basics, latest research, and practical applications".

3.1 Teaching Content Reform

Establishing an integrated curriculum system for "Fuzzy Control Theory and Its Applications" with the structure of "basic theory + cutting-edge development + engineering application", this includes modular design of course content and the construction of a teaching case library based on the characteristics of the maritime university's control discipline. The design also incorporates the integration points of science and education in each module, ensuring that the teaching content is dynamically updated to track the latest scientific research achievements in the fuzzy field. This approach of using research to nourish teaching aims to achieve a deep integration of curriculum construction with scientific research outcomes.

1. Solid theoretical foundation, laying the mathematical groundwork. Fuzzy control is based on fuzzy mathematics. "Fuzzy mathematics" is a new branch of discipline, which is an important carrier for cultivating students' thinking and application abilities in fuzzy control[7]. Before studying fuzzy control, students must systematically learn the theories of fuzzy mathematics. Fuzzy theory is profound and its concepts are abstract. To improve the effectiveness of teaching, it is advisable to compare and teach related theories, such as the similarities and differences between ordinary sets and fuzzy sets; the differences between characteristic functions and membership functions, and so on.

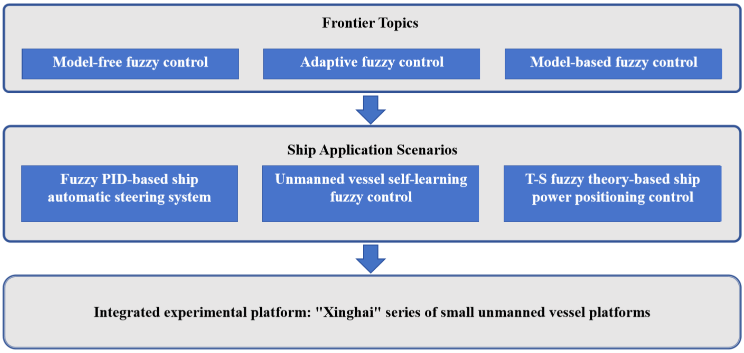

Fig. 1. The curriculum content reform plan integrates the concept of integration of science and education with the characteristics of maritime majors.

2. Keeping pace with the times and focusing on cutting-edge topics. The teaching content of this course has been reorganized and classified into three forefront subjects: "Model-Free Fuzzy Control", "Adaptive Fuzzy Control", and "Model-Based Fuzzy Control". Traditional methods such as fuzzy lookup tables, Mamdani fuzzy inference, and fuzzy PID are not taught comprehensively but are integrated, in line with the school's maritime specialty, from the perspective of cultivating research-oriented talents. The latest knowledge and technology in the field of fuzzy control are ingeniously integrated into the classroom teaching, enriching and updating the content continuously. This promotes a spiral advancement of teaching and research and fosters students' innovative thinking and spirit. For instance, in the subject of "Model-Based Fuzzy Control", the course focuses on introducing cutting-edge issues such as T-S fuzzy control, T-S fuzzy dynamic sliding mode control, interval Type-2 T-S fuzzy control, and finite frequency domain T-S fuzzy control. It also explores the integration of fuzzy control with AI learning methods, parallel control, and cyber-physical systems. The curriculum content reform plan, integrating the concept of integration of science and education with the characteristics of maritime majors, is illustrated in Figure 1.

3. Rooted in the vast blue, crafting maritime characteristics. Integrating the school's distinct maritime characteristics and transportation industry nature, this paper incorporates actual ship control cases into the fuzzy control curriculum. Originating from front-end topics and critical issues, three case studies are presented in each subject: "Ship Automatic Steering System Based on Fuzzy PID", "Unmanned Ship Self-Learning Fuzzy Control", and "Ship Dynamic Positioning Control Based on the T-S Fuzzy Theory". This approach enables students to understand the practical application scenarios of cutting-edge fuzzy control theories by analyzing real-world cases. Moreover, by relying on the "Xinghai" series of autonomous surface vessel platforms independently developed by the research team, it provides students with a physical platform for algorithm validation. This guidance leads students to discover new issues in experiments, allowing them to thoroughly grasp and flexibly apply the closed-loop research method of "Theory - Practice - Innovation - Theory".

3.2 Teaching Method Reform

We aim to explore a problem-based learning (PBL) approach[8] [9], which incorporates a research mindset into the classroom setting. Additionally, we are investigating a blended learning model that combines in-class and out-of-class activities, leveraging technological elements and online resources. This includes incorporating renowned online courses and lectures to deliver the latest research trends to students. Furthermore, through flipped classrooms and student-led group explorations, we aim to fully engage inactive knowledge acquisition, transforming them from passive recipients to active explorers of knowledge, thus fully harnessing the proactivity of students.

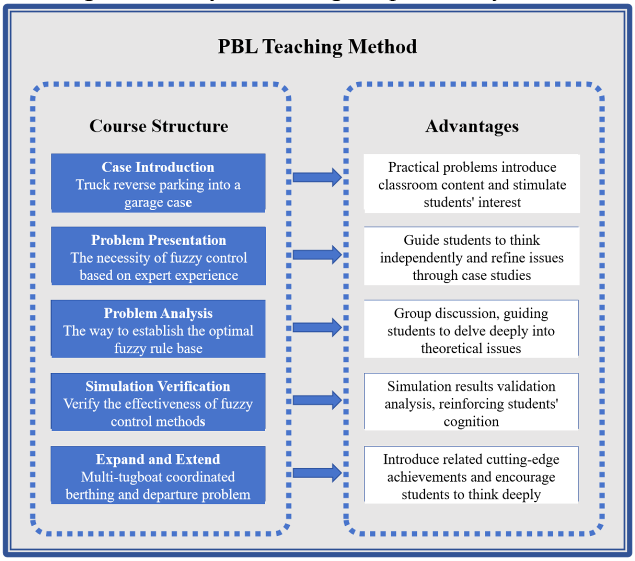

Fig. 2. Example of PBL Teaching Method.

1. Explore research-based teaching methods based on PBL. In the fundamental theory section of this course, such as fuzzy sets, the traditional teaching approach often involves teachers directly presenting the process of fuzzy inference and providing relevant proofs. This methodology lacks diversity and interactivity, keeping students in a passive state of knowledge acquisition. Moreover, the theoretical derivation in this part is relatively complex. This project attempts to adopt the PBL teaching model (as shown in Figure 2) and design a teaching approach of "posing problems - analyzing problems - solving problems". For example, when explaining the content of fuzzy systems, traditional teaching would directly explain and prove according to the three steps of fuzzification - fuzzy reasoning - defuzzification. Students find it difficult to understand the fuzzy system modeling. In this paper, we try to introduce practical engineering problems such as "truck backing into a parking space" and "multiple tugboat coordination for berthing and departure", guiding students to raise the question of "the necessity of fuzzy control based on expert experience". Then, we guide students to generalize several fuzzy logic rules by analogy to human expert experience, discuss the "way to establish the best fuzzy rule base", and finally, the teacher leads the students through

rigorous proof and Matlab simulation to verify the effectiveness of fuzzy control, encouraging students to engage in group discussions, and in-depth thinking, allowing students to gain a deeper understanding of the necessity, advancement, and effectiveness of fuzzy control.

On the other hand, the traditional teaching of fuzzy control courses, which primarily relies on long hours of teacher-led classroom lectures. Students also find it challenging to integrate the theory of fuzzy control with their own research topics. To address this issue, we divide the teaching content into three themed sections. Each group is assigned a general research theme by the teacher, who provides a specific scientific problem and a set of literature materials. Through a closed-loop process of "teacher's explanation, student group discussion, teacher's feedback, and student group discussion", students are gradually guided to delve into the research background, current status, and potential innovative areas of the relevant themes. Throughout the teaching process, the focus is squarely on actual scientific research questions in the field of fuzzy control, leading students to take initiative in their learning and strengthening their understanding of related issues and mastery of knowledge points. Taking the topic of " Self-learning Fuzzy Control" as an example, students with relevant research directions are grouped together. After the teacher has explained the basic research background, current status, fundamental theory, and simulation validation of self-learning fuzzy control, a question is posed: "Can self-learning fuzzy control be combined with advanced AI algorithms (such as meta-learning, concurrent learning, etc., which are data-based AI algorithms) to improve the control effect of fuzzy controllers?" The student group, through searching and studying the latest literature, pondering, and discussing, attempts to provide a solution.

2. Explore the "classroom + extracurricular" blended learning model. Classroom learning adopts methods such as teacher lectures, student group discussions, and teacher comments, implementing a topic-driven group comprehensive practical training approach to guide students to explore autonomously, discover problems, and solve them, allowing students to fully transform from passive recipients of knowledge to explorers of knowledge. Extracurricular learning integrates and utilizes diverse teaching resources, including NetEase Open Courses, MOOCs, famous teacher lectures, etc., to fully permeate scientific research and innovation elements and enrich teaching methods, improving teaching effectiveness. For example, invite experts to give online lectures on the cutting-edge field of fuzzy control, allowing students to understand the latest research progress of fuzzy control theory; at the same time, make use of online resources and the Rain Classroom platform to build a network learning and discussion area for fuzzy control theory, enabling students to learn and communicate anytime, anywhere.

3.3 Curriculum Assessment Reform

Adopting an outcome-based education (OBE) approach, the educational model is reformed in terms of assessment periods and organizational methods. There is an increased emphasis on process-based assessment, and a model of project-driven, group-based comprehensive practice and innovation is implemented. Students are encouraged to select topics from several cutting-edge directions in fuzzy control and engage in exploratory learning in conjunction with their own graduate research projects.

1. In terms of assessment period, the traditional end-of-term exam, which relies solely on a single exam to determine grades, fails to comprehensively encourage students to pay attention to the content of all teaching components in the course, thus cannot guarantee effective teaching outcomes. To address this issue, it is essential to explore a new approach to course assessment that emphasizes whole-process evaluation, increasing the proportion of assessment on student performance throughout the learning process. Firstly, diverse assessment methods should be integrated, which include but are not limited to: class participation, homework, oral presentations, course reports, and teamwork. This whole-process assessment approach focuses on evaluating students' learning achievements and abilities from multiple dimensions. Additionally, leverage the online platform, such as Yuketang, to combine both online and offline assessment methods, facilitating the submission of homework and course reports, as well as the establishment of an online discussion forum. Furthermore, course construction and feedback are crucial components. Throughout the teaching process, students' opinions and suggestions are continuously collected, thereby enhancing the overall quality of the course.

2. In terms of the mode of assessment organization, to adapt to the trend of cultivating postgraduate research and innovation capabilities under the new engineering education background, a practice-oriented comprehensive innovative teaching mode driven by project-based learning is implemented, encouraging students to be bold in their attempts and innovations. In addition to assessment methods such as class participation and homework, students are required to submit a course report in groups at the end of the course. The total score of the students' report is composed of four parts: research direction overview, group discussion, course report, and defense performance. Teachers need to evaluate each student's contribution to the group and their performance in the defense, while groups will also score each other in a manner similar to "peer review". During the practical phase of this semester, teachers allocated students according to their interests to explore around three cutting-edge topics. Each group followed the technical route of: propose a problem → review literature → design a general plan → establish fuzzy control algorithms → Matlab simulation and analysis of simulation results to conduct research and form course reports and PPTs. This has greatly improved students' application of fuzzy control theory, and also stimulates their innovative thinking, thereby improving their innovative capabilities.

4 Effectiveness of Educational Reform Implementation

The application of the new teaching model in the "Fuzzy Control Theory and Application" course during the second semester of the 2023-2024 academic year has shown the following effects:

1. In terms of teaching quality, a total of 13 students enrolled in the course this semester, with a passing rate of 100%, 10 students scored above 90 (accounting for 76.9%), and 3 students scored between 80 and 89 (accounting for 23.1%). Overall, the

students have a relatively comprehensive grasp of the key points of fuzzy control theory, and the majority of students have performed well in achieving the course objectives. However, there are still a few students who need to improve their comprehensive analysis skills and innovative thinking. Moreover, some students have insufficient participation in the course content, and there is room for improvement in the writing standards and logical coherence of their course reports.

2. In terms of research promotion, from the presentations and reports submitted, the majority of students' research content demonstrates a certain level of self-study and research capabilities. They are able to search for and analyze materials based on their chosen topics, apply basic knowledge and analytical methods to form their own knowledge systems, and gain a deeper understanding of the cutting-edge applications of fuzzy control. Through exploring three cutting-edge topics and key issues, the students have a more intuitive understanding of fuzzy control theory and research methods, which lays a certain foundation for their postgraduate research.

5 Conclusion

The "Fuzzy Control Theory and Applications" is an elective course for postgraduate students in control science and engineering. To meet the needs of building a new-era research university and to meet the talent demands of the AI industry, it's important to create a teaching practice system that fits the talent cultivation needs in the era of science and education integration. This includes reforming and practicing the "Fuzzy Control Theory and Applications" course. By reorganizing the knowledge structure, combining various teaching methods, and fully using online learning resources, we have proposed a curriculum construction plan, which is "Basic Theory + Frontier Development + Engineering Application". This plan combines the latest research achievements with classroom teaching and integrates cutting-edge theories with practical applications, using scientific research to support teaching. This approach has inspired students' interest in learning, increased their engagement and autonomy, and has positively contributed to exploring new innovative talent cultivation models in universities.

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