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An Engineering Case Study for Teaching in Optimal Control Courses

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Abstract

This paper discusses the application of engineering case teaching in optimal control courses and its teaching effect. Through the introduction of actual engineering cases, students were able to closely integrate theoretical knowledge with practice, which significantly improved their comprehensive application ability. The results show that the engineering case teaching method effectively improves students' learning interest and practical ability, and at the same time promotes the integration of interdisciplinary knowledge, which provides an important reference for the teaching reform of optimal control theory.

Keywords

Optimal control, engineering case study teaching, teaching reform, innovative thinking.

1. Introduction

In today's fast-developing technological era, the application of optimal control technology is becoming more and more widespread, playing a key role in promoting industrial automation and intelligent manufacturing, and at the same time putting forward higher requirements for the training of related professionals. As an important part of the automation field, the innovation and reform of the teaching method of optimal control courses is particularly urgent. Due to the strong theoretical nature of the course, abstract content, interdisciplinary integration, and other reasons, students usually have a lack of interest in the learning process, difficult to understand, and other problems. The traditional optimal control course emphasizes theoretical lectures, and the experimental link firstly considers starting from computer digital simulation, realizing typical optimal control algorithms through computer programming to achieve the purpose of preliminary application of theory and practice [1]. The focus of the final assessment is still the ability to answer the theoretical questions, there is a more serious problem of "science of engineering majors", and the ability of students to apply knowledge has not been fundamentally improved [2]. To enhance students' practical and problem-solving abilities, the teaching reform should place greater emphasis on integrating theory with practice by introducing real industrial cases and designing and implementing projects. This approach aims to improve students' overall competence and practical experience.

2. Analysis of Optimal Control Courses

The optimal control course is rich in content and is one of the most important courses in the field of control, representing the frontier of control theory and technology development. It also has a wide range of applications in many engineering and scientific fields. The course covers the basic theories, methods, and technical applications of optimal control, enabling students to understand the field's cutting-edge knowledge, application background, and development prospects. As a course designed for Ph.D. students, the optimal control course requires students to have a considerable knowledge base and model-building ability. Students usually have completed mathematics courses such as calculus, linear algebra, and matrix theory, as well as specialized knowledge such as modern control theory, before studying optimal control. These pre-requisite courses provide the necessary mathematical tools and theoretical foundations for optimal control, through which students can acquire the basic skills of system modeling, analysis, and optimization. This knowledge will help them cope with complex mathematical derivations, algorithm design, and problem-solving in practical application scenarios in optimal control courses.

The teaching contents of optimal control courses usually include the basic contents of deterministic optimal control, the variational method of optimal control, the principle of minimal value and its application, the shortest time control system, the least fuel control system, and the optimal control system with quadratic objective function, dynamic programming, etc. The optimal control course is highly theoretical, involves complex mathematical derivation and algorithm design, and focuses on practical applications. To enhance students' practical ability, the course emphasizes the combination of theory and practice. By combining engineering case-driven learning, simulation software application, and real systems' modeling and optimization, students can explore the design, optimization, and implementation of optimal control systems in real or near-real environments. This engineering case-driven teaching approach will consolidate students' theoretical knowledge while also helping to cultivate their innovative thinking, system design capability, and practical problem-solving ability.

3. Analysis of Traditional Teaching Methods in Optimal Control Courses

The importance of optimal control courses is becoming more and more prominent in the context of the era of rapid development of automation and intelligent technology. However, with the changes in educational needs and environment, the limitations of traditional teaching methods in this course have become increasingly apparent. These shortcomings weaken the teaching effect and limit the full realization of students' potential. Optimal control courses are characterized by their strong theoretical nature, involving abstract concepts such as generalized function analysis and closely practiced with mathematics. With the development of optimal control theory and the advancement of teaching methods, traditional teaching methods have gradually exposed some drawbacks [3]. It is mainly manifest in the following aspects:

3.1. Theory-Based Teaching, Lack of Practical Sessions

Traditional optimal control courses mainly focus on the teaching of theoretical knowledge, and the content concentrates on the mathematical models of control theory, control algorithms, and their basic principles. Teachers usually use courseware to explain textbook knowledge, derive formulas, and analyze classical cases to teach. However, this theory-based teaching method often ignores the importance of practice, resulting in students mastering a large amount of theoretical knowledge, but it is difficult to transform what they have learned into concrete skills in practical application. Only by concretizing abstract ideas into physical objects can we truly achieve a deep understanding of knowledge and skillful mastery. The optimal control course is highly theoretical and practical, and the disconnection between theory and practice directly affects the cultivation of students' comprehensive ability. In addition, the experimental teaching link is limited by the limited experimental equipment in the school, the experimental teaching time is short, and the content of experimental teaching is also relatively single. Students lack the opportunity for in-depth exploration and free practice, which leads to the accumulation of practical experience is insufficient.

3.2. Single Method of Teaching and Low Student Engagement

In the traditional teaching mode, teachers usually adopt a one-way way of imparting knowledge, and students passively accept knowledge. The teaching method relies too much on lectures and boards and lacks diversified forms of interaction and participation, and this teaching method neglects students' initiative and creativity in learning. Since teachers mainly focus on the conceptual derivation and formula calculation of control theory, students often lack the opportunity to participate in discussions, raise questions, and solve problems. Students can easily feel tedious, thus reducing their interest and motivation in learning. In addition, traditional teaching seldom uses methods such as heuristic teaching and case analysis, and students lack practical application scenarios and opportunities for multi-perspective thinking in understanding complex theories or interdisciplinary concepts, making it difficult for them to comprehensively master their knowledge and improve their problem-solving abilities.

3.3. Single Mode of Assessment makes it difficult to comprehensively assess students' abilities

In traditional teaching, the assessment method of optimal control courses is mainly based on written test scores supplemented by the usual homework scores, focusing on students' memorization and understanding of theoretical knowledge. This assessment method neglects the assessment of students in project practice, innovative thinking, and teamwork. The single form of examination leads to the tendency of students to learn for the sake of test-taking in the learning process, neglecting the cultivation of analyzing and solving ability of practical problems. For a field that emphasizes application and innovation, it is obvious that this assessment method cannot fully reflect the comprehensive quality of students.

4. Teaching Reform

To adapt to the requirements of scientific and technological development and innovative countries on the quality of talent cultivation in higher education institutions, all universities are exploring teaching management methods to cultivate high-quality and excellent talents to achieve the purpose of cultivation quality improvement, students' healthy growth, and innovative national service [4]. Therefore, to make up for the shortcomings of traditional teaching methods and improve students' practical ability, innovative thinking, and interdisciplinary integration ability, multifaceted reform measures must be taken. Teaching reform should not only enrich the content and form of teaching but also focus on the diversification of the evaluation system and the integration of interdisciplinary knowledge, to comprehensively improve students' comprehensive quality and ability to solve practical problems. The specific program of teaching reform will be elaborated in detail from the following aspects: introduction of engineering case teaching, enhancement of interactive and project-based learning, and diversification of assessment systems, etc.

4.1. Enhancing Interactive and Project-Based Learning to Increase Student Engagement

To enhance students' engagement and motivation, reforming the traditional teaching mode is necessary. Introducing interactive and project-based learning breaks the limitations of traditional one-way teaching and builds a classroom environment with two-way interaction between teachers and students. In actual teaching, teachers can organize students to conduct group discussions, classroom design, and other activities to stimulate students' creative thinking and desire for exploration.

In addition, project-based learning can effectively improve students' comprehensive ability and practical level. Teachers can introduce specific engineering cases in the course, so that students can complete the whole process, from project requirements analysis, and design solutions, to programming implementation and debugging optimization in groups. Students need to apply what they have learned and solve real-world problems in this process, which not only promotes their deep understanding of theories but also cultivates project management skills and teamwork spirit. The combination of interactive and project-based learning not only enhances the interest of the classroom and students' initiative but also improves students' practical operation and innovation ability.

4.2. Introducing Engineering Case Teaching to Enhance Practical Application Ability

The engineering case teaching method is one of the important means of teaching reform, which applies theoretical knowledge to the process of practical problem-solving by introducing real industrial cases. By combining the theoretical knowledge in the optimal control course with specific engineering cases, students can understand the practical application of the theory more intuitively and further consolidate and deepen their knowledge.

In the early stage of the course, common optimal control cases can be selected, and some classic cases that are easy to understand and representative can be chosen, such as battery management systems, thermostatic control systems, inverted pendulum control, etc. These cases involve simple control algorithms. These cases involve simple control algorithms and basic mathematical models, which are convenient for students to understand the basic concepts and applications of control theory. Combine these basic cases with real-life or simple industrial systems, such as smart home systems, so that students can initially master control theory in a familiar environment, use simulation or laboratory equipment to conduct simple experiments, and consolidate theoretical knowledge through practical hands-on operation.

Advanced cases select complex engineering cases with multi-objectification or real-time requirements, such as power system scheduling, aircraft trajectory optimization, robot path planning, and navigation. These cases are more challenging than the basic cases and involve more complex control strategies and algorithms. An in-depth understanding of these cases requires multidisciplinary knowledge reserves, through which multidisciplinary knowledge integration learning can be effectively promoted. Group work can be carried out to analyze the project, decompose the complex project into multiple sub-tasks, and discuss and analyze the correlation between them together.

This teaching method not only helps students master the core technology of optimal control but also enables them to learn how to select and apply appropriate control algorithms and strategies in complex real-world environments. Through organizing case discussions, group cooperation, and independent research, students can cultivate their teamwork and innovation abilities. At the same time, students can also be guided to participate in real projects or virtual simulations to deepen their understanding of the course content and the mastery of practical skills through engineering design, programming debugging, model optimization, and other practical operations. This case-driven teaching method helps to stimulate students' learning interest and hands-on ability and enhances their confidence in dealing with complex engineering problems.

4.3. Establish an industry-university-research cooperation mechanism to train industry talents in an all-round way

The establishment of an industry-university-research cooperation mechanism is an important means to make up for the insufficiency of traditional teaching. By introducing enterprise resources and practice opportunities, students' practical hands-on ability and professionalism can be effectively enhanced. By establishing close cooperation with industry-leading enterprises and developing engineering cases with practical applications as the background, real engineering problems of enterprises are introduced into the classroom. This initiative not only exposes students to the latest developments and challenges of optimal control technology in practical applications, but also enriches the teaching content by inviting enterprise experts to participate in teaching and organizing lectures, workshops, and joint projects, enabling students to understand the industry needs earlier, and enhancing their learning interest and career awareness. In addition, the establishment of off-campus apprenticeships and practice bases provides students with opportunities to learn and practice in real engineering environments, enabling them to accumulate valuable practical experience and exercise problem-solving and teamwork skills during their participation in actual engineering projects. This kind of practical experience not only enhances students' hands-on ability and professionalism but also lays a solid foundation for their future employment and cultivates high-quality talents with practical working ability.

4.4. Diversified assessment system to comprehensively assess students' abilities

To overcome the limitations of traditional assessment methods, the teaching reform should build a diversified assessment system to comprehensively assess students' performance in theoretical knowledge, practical skills, and innovation ability. In addition to the traditional written test, various forms of assessment such as process assessment, project review, case study report, and group cooperation evaluation should be introduced. Specifically, teachers can divide the assessment content of the course into multiple parts, integrating factors such as theoretical examination, project design and implementation accounted for, case analysis report, classroom performance, and teamwork into the evaluation of students' performance. This assessment system can more comprehensively reflect the actual learning level and comprehensive ability of students.

The diversified assessment system should also focus on process evaluation, that is, dynamic tracking and assessment of students' participation, creativity, and problem-solving ability in the process of project implementation. Through multi-angle assessment, students can gradually recognize the combination of knowledge and practice in the learning process, and promote their awareness of active learning and independent innovation. At the same time, teachers can also adjust the teaching strategies and contents in time according to the feedback and performance of students to further improve the teaching quality and effect.

5. Conclusion

Through the analysis of the traditional teaching methods of optimal control courses, it can be seen that there are deficiencies in adapting to the needs of modern science and technology and industrial development, and it is urgent to make improvements in various aspects. The reform measures proposed in this paper include the introduction of enhanced interactive and project-based learning, engineering case teaching, industry-university-research cooperation mechanisms, and a diversified assessment system. Through these multifaceted teaching reforms, the practical ability and innovative thinking of students will be more effectively enhanced, to comprehensively strengthen their comprehensive quality and professional ability, and cultivate high-quality talents that better meet the needs of society.

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