Journal of Contemporary Educational Research, 2025, Volume 9, Issue 10
http://ojs.bbwpublisher.com/index.php/JCER
ISSN Online: 2208-8474
ISSN Print: 2208-8466

Research and Practice of Practical Teaching System Based on Virtual Simulation Platform: A Case Study of the Course "Electric Machine and Drive" at Liaoning Technical University

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Abstract: This paper introduces the experience and practice in constructing the practical teaching system for the course "Electric Machine and Drive." In response to the current status of cultivating innovative practical abilities among electrical engineering majors, based on the independently developed virtual simulation experimental teaching platform for Electric Machine and Drive, a stepped practical teaching process consisting of "classroom teaching–experimental teaching–comprehensive training–scientific inquiry" has been elaborately designed. A hierarchical practical teaching model for the second classroom has also been established. With teaching objectives as the optimization index, the teaching content, methods and means have been optimized; the teaching process has been organized and implemented in the form of team collaboration, thus constructing a comprehensive, stepped, hierarchical, and closed-loop innovative practical teaching system. This achievement provides references and assistance for the practical teaching of the same or similar majors in other colleges and universities.

Keywords: Virtual simulation; Practical teaching system; Hierarchical teaching method; Stepped teaching model

Online publication: November 10, 2025

1. Introduction

Following the call initiated by the Ministry of Education for the construction of national demonstration virtual simulation projects [1,2], an increasing number of colleges and universities have participated in the development of virtual simulation experimental projects, and many have initially established their own virtual experimental platforms [3]. However, some institutions fail to effectively align the construction of virtual simulation teaching platforms with their own teaching conditions and student characteristics. Most of the practical projects on these platforms are purchased from the market, resulting in low originality. This makes it difficult for teachers to fully integrate the virtual simulation platform into the professional teaching content and development during practical teaching [4]. Problems exist in virtual simulation practical projects, such as oversimplified operations and over-idealized results. The process flows and operation steps are relatively simple, which are far from the actual production site and real operations. This disconnect between practical training and theory fails to cultivate students' abilities to analyze and solve problems, and is not conducive to fostering their engineering literacy [5]. In addition, most virtual simulation experimental projects suffer from the issue of "face engineering": they have attractive external packaging but low-quality practical content, lacking in-depth development. This not only causes resource waste but also significantly undermines the quality of virtual simulation experimental teaching.

The traditional practical teaching system offers limited operational flexibility, which severely restricts the multi-level development of students and can no longer adapt to the teaching laws of education in the information age. The practical teaching system has attracted extensive attention and research. According to Wanfang data, there are 21,416 papers on practical teaching system research, with over 1,000 published annually in recent years; among core journals alone, there are 2,592 such papers, with more than 100 published each year in recent years. For virtual simulation experimental teaching systems, there are 49 papers, including 8 in core journals. Most of the teaching reform achievements focus on the practical teaching systems of universities, colleges or specific majors [6–8], and no research results targeting the practical teaching system of a specific course have been found. Although existing research achievements provide certain guidance for the practical teaching of a specific course, it is difficult to achieve the optimal teaching effect in the process of implementation. In order to form a practical teaching system that meets the training requirements of "Emerging Engineering" and the professional certification standards of engineering education, it is necessary to conduct research on the practical teaching system for specific courses.

2. Overall architecture

For the course Electric Machine and Drive, relying on the self-developed virtual simulation experiment platform, we ingeniously design a stepped practical teaching process that integrates classroom theoretical teaching, experimental teaching, comprehensive course training, and scientific inquiry. With the goal of cultivating innovative talents, we adopt the ideology of optimal control theory to optimize teaching content and methods. During the teaching implementation, we break through the concepts of "course-based" and "discipline-based" thinking, and actively carry out second-class practical teaching activities. Under the guidance of instructors with the best matching expertise, a hierarchical strategy is adopted to enable better development and improvement of different student groups. Student feedback is obtained through questionnaires, based on which the virtual simulation experiment platform is upgraded and transformed. Eventually, an all-round + stepped + hierarchical + double-closed-loop practical teaching system is formed.

3. Independently developed virtual simulation platform

Liaoning Technical University is a higher education institution with distinct features in the coal and mining industries. In coal mine production, underground drainage, ventilation, and air supply are crucial links for the safe production of coal mines. According to surveys, the energy consumption of water pumps, fans, and air compressors accounts for more than 40% of the total electricity consumption in raw coal production in mines. As AC motor-driven loads, water pumps, fans, and air compressors share similar mechanical characteristics and are collectively referred to as pump-type loads. Therefore, the teaching team has conducted in-depth research on mine drainage engineering and, combined with the teaching content of Electric Machine and Drive, built an original and distinctive virtual simulation teaching platform. The virtual simulation scenario and experimental operation interface of this platform are shown in **Figure 1**.

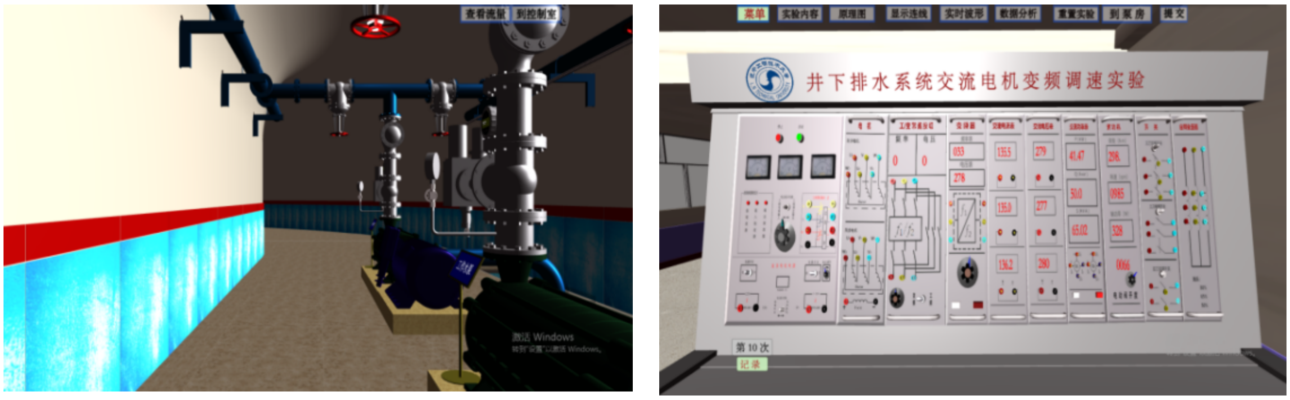

Figure 1. The virtual simulation scenario and experimental operation interface. Left: Virtual simulation scene of underground drainage system in coal mines; Right: Experimental operation interface of underground drainage system in coal mines

4. Stepwise practical teaching model

Relying on the virtual simulation experiment platform, we skillfully design practical links including "classroom theoretical teaching, experimental teaching, comprehensive training and scientific inquiry," and construct a stepwise practical teaching model to achieve the appropriate integration of theory, experiment, training, scientific inquiry and simulation practice [9].

4.1. Classroom theoretical teaching + simulation practice

Traditional experiments cannot be carried out on destructive operation issues such as the "runaway" and "stalling" accidents of separately excited DC motors, overvoltage and overload operation of AC motors, and motor locked-rotor operation due to safety concerns. With the help of the self-developed virtual simulation platform, students' understanding of the causes, processes and hazards of motor safety accidents is strengthened, achieving a shocking educational effect on motor safety warning.

For some abstract and tedious teaching contents, such as winding arrangement, rotating magnetic field of AC motors, and armature reaction, virtual simulation-assisted teaching is used for vivid and intuitive demonstrations. The proper integration of practical links into the classroom theoretical teaching process is conducive to students' understanding and mastery of basic theoretical knowledge, enlivens the classroom atmosphere, broadens students' horizons, stimulates their interest in learning, and greatly improves the efficiency of classroom teaching.

4.2. Traditional experimental teaching + simulation practice

Relying on the virtual simulation experimental teaching platform, simulation training on experimental principles, wiring, operation procedures, and other aspects is carried out before traditional experiments. This enables the optimal integration of virtual simulation and physical experimental teaching resources, achieving the combination of virtual and real elements and greatly improving experimental efficiency [10].

In the first semester of the 2019–2020 academic year, the electrical drive experimental equipment was out of repair due to years of use, making it impossible to conduct normal experimental teaching. Against this background, virtual simulation experimental teaching was carried out based on the virtual simulation experimental platform, which ensured the normal teaching order. At the same time, it greatly improved the efficiency of experimental teaching—the original eight experimental topics were expanded to 16. Since March 2021, small-scale virtual simulation experimental teaching activities have been carried out at Liaoning Technical University. In the first semester of the 2021–2022 academic year, three distinctive virtual simulation experimental projects were launched in the experimental teaching of Electric Machine and Drive for Class 13, Grade 2019 of the Electrical Automation major, serving as a valuable supplement to traditional experiments.

4.3. Course comprehensive training + simulation practice

Comprehensive training sessions are conducted based on the virtual simulation experimental teaching platform. According to the training requirements, students independently complete experimental scheme design, experimental testing, data analysis and processing, and summary. This approach is conducive to improving students' abilities to analyze and solve problems, as well as enhancing their professional literacy. As a crucial part of comprehensive training, virtual simulation practice can provide all-round support for the demonstration of experimental schemes, implementation of experiments, and data collection in the course's comprehensive training [11].

4.4. Scientific inquiry + simulation practice

Scientific inquiry activities are carried out relying on the virtual simulation experimental teaching platform, following a series of steps starting from raising questions, then going through making conjectures and assumptions, designing and conducting experiments, analyzing and demonstrating, and finally drawing conclusions. In combination with the course Electric Machine and Drive, students independently complete scientific inquiry activities. This not only helps students master scientific research methods, but also is beneficial for cultivating their scientific interests and practical abilities. It is of great significance for the improvement of students' scientific literacy and the development of their innovative capabilities [12].

5. Second classroom: Hierarchical practical teaching

With the teaching objective of "taking competence development as the core, expanding the knowledge foundation, and fostering comprehensive literacy," we have broken through the "curriculum-oriented" and "discipline-oriented" mindsets, and actively carried out the second classroom practical teaching activities of Electric Machine and Drive. The hierarchical teaching method was adopted in the practical teaching process. According to students' different interests and strengths as well as teachers' different expertise, students were divided into hardware interest groups, software interest groups, theoretical interest groups, and science and technology competition groups. Under the guidance of tutors with the best matching expertise, the hierarchical strategy was applied to enable these groups to achieve better development and improvement [13].

In the implementation process, the teaching principle of "teaching students in accordance with their aptitude" was reflected. Students at different levels were assigned the most suitable teachers, and the hierarchical strategy was used to conduct teaching and guidance on software programming, hardware development, theoretical studies, and discipline competitions.

6. Practice of the double closed-loop optimization mechanism

Students have the most say in the quality of practical teaching, and student evaluation of teaching should be the basis of curriculum evaluation. Therefore, the traditional teacher-centered teaching evaluation mechanism is not suitable for evaluating the practical teaching effect of this project. This project has developed a student evaluation mechanism based on questionnaires, which shows that the virtual simulation practical teaching activities of the Electric Machine and Drive course are beneficial to the development of students' competence. By detecting indicators and reconstructing teaching indicators, integrating the optimal control link with the expected teaching objectives, and adopting the ideological guidance of optimal control theory, we continuously innovate and expand the content of practical teaching, optimize practical teaching methods, and match them with the best implementation plans to form a closed-loop practical teaching system, aiming to achieve the best teaching effect. This practical teaching system meets the three basic characteristics of engineering education accreditation, namely "outcome-based, student-centered, and continuous improvement," and is also in line with the outcome-based education concept [14,15].

7. Practical significance and promotion value

7.1. Remarkable achievements in cultivating innovative talents

Since the implementation of this teaching achievement, a group of innovative talents with the characteristics of "solid basic theories, rich scientific knowledge, rigorous research methods, and courage to explore unknown fields" have been cultivated, winning wide praise from universities and enterprises.

7.2. Outstanding performance in disciplinary competitions

The Hardware Interest Group has carried out scientific research activities such as "power quality analysis of AC motors," "discrete Fourier transform algorithm," and "frequency characteristic-related test algorithm" through the virtual simulation experiment teaching platform, laying a solid foundation for the high-quality completion of works in electronic design competitions. The Software Interest Group has directly participated in the development of virtual simulation experiment projects, accumulated rich experience in software programming and project development, and achieved outstanding results in disciplinary competitions.

7.3. Significant improvement in the teaching and research strength of our college

Through the exploration and practice of the practical teaching system, a faculty team with a reasonable structure of teaching and research has been established, forming a teaching and research team with advanced educational concepts, high academic level, strong teaching and research capabilities, rich practical experience, and the courage to innovate.

7.4. Profound influences of achievement promotion and demonstration

This teaching achievement has become an important way to promote the reform of modern education and the progress of experimental teaching in our college. Leaders at all levels of the university and the college highly recognize this achievement and have given strong support. The successful experience of this teaching achievement has played a certain guiding and reference role in the teaching reform of other courses in this major or other majors. In addition, there are many institutions of higher learning that offer motor-related courses, so the promotion and demonstration of this achievement will have a profound impact and is bound to bring great social value.

8. Conclusion

Taking the course Electric Machine and Drive of the School of Electrical and Control Engineering at Liaoning Technical University as an example, the research team has conducted valuable exploration and practice on the course's practical teaching system relying on the independently developed virtual simulation platform. This effort has cultivated batches of outstanding undergraduate students with the courage to explore and built a teaching team committed to innovation. Although the practical teaching system has undergone five years of development, practical verification, and optimization, gradually becoming mature and improved, our teaching reform efforts will never stop.

Funding

Project of the 14th Five-Year Plan for Educational Science in Liaoning Province (JG24DB234); Project of Graduate Education and Teaching Reform Research in Liaoning Province (LNYJG2023115)

Disclosure statement

The authors declare no conflict of interest.

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