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A Brief Discussion on the Reform and Practice of the Integrated Undergraduate and Postgraduate Collaborative Teaching of the "Principles of Automatic Control" Course under the Background of Intelligent Operation and Maintenance

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Abstract: The Notice of The State Council on Printing and Distributing the Development Plan for a New Generation of Artificial Intelligence has put forward development goals i.e., accelerating the intelligent upgrading of industries, promoting new manufacturing models such as remote diagnosis and operation and maintenance services, and promoting the integrated innovation of artificial intelligence with various industries. It clearly pointed out that Artificial Intelligence for IT Operations (AIOps), as an innovative application of big data and artificial intelligence technologies in the upgrade of traditional management and automation models, aims to address the challenges of efficiency and stability in the digital transformation of enterprises. Under the background of this plan, the core courses in the undergraduate and postgraduate stages of the electrical major, i.e., Principles of Automatic Control (PAC) and Status Identification and Fault Prediction of Electrical Equipment (SIFPEE), both have the defect of chain reinforcement and optimization as well as the problem of deep disconnection in terms of theoretical foundation supporting practical application and technical progressive complementary influence. Therefore, how to form a collaborative path of basic theory to advanced application for the electrical major based on two courses (PAC+SIFPEE) and promote the comprehensive development of students in the fields of intelligent control and predictive maintenance is the main content of this study.

1. Introduction

Under the guiding ideology i.e., Action Plan for Deepening the Reform of Basic Education Curriculum and Teaching issued by the Ministry of Education, which sets the macro goal of forming a regular and long-term working mechanism by 2027, and requires localities to formulate transformation paths of "one plan for one place" and "one policy for one school", systematic arrangements should be made in terms of goal setting, resource allocation, stage division, risk

assessment and progress control. In order to form a long-term teaching update and feedback, a comprehensive guidance and overall strategic planning implementation plan are needed to clarify the direction and responsible entity for the connection of undergraduate and postgraduate courses [1].

The development of the discipline of electrical engineering requires a seamless connection between the knowledge systems of undergraduate and postgraduate studies. Currently, 'Principles of Automatic Control' as a core basic course for undergraduates and 'Status Identification and Fault Prediction of Electrical Equipment' at the master's level have problems of content repetition but depth gap. Through the construction of comprehensive courses, this article summarizes the realization of the following contents:

• The understanding of the application of control theory should be strengthen in electrical equipment during the undergraduate stage.

• At the master's level, intelligent diagnosis research is directly conducted based on control theory.

2. Problems and Reform Significance Existing in the Integrated Collaboration of Undergraduate and Postgraduate Studies

2.1. Analysis of the Problems Existing in the Integrated Collaboration of Undergraduate and Postgraduate studies

2.1.1. Connection Gap of Knowledge

The undergraduate course PAC focuses on classical control theories (such as PID regulation and frequency domain analysis), while the postgraduate course SIFPEE aims to cultivate high-level talents who can transfer basic theories to advanced application scenarios in the era of artificial intelligence. Therefore, postgraduate courses need to integrate modern control theory i.e., state space method and data-driven methods i.e., deep learning, but the two types of courses lack transitional content design.

2.1.2. Disconnection in Ability Cultivation

In the process of comprehensively launching innovative applications in key areas and gathering and cultivating high-level talent teams and innovation teams, there exist:

• The phenomenon of a thinking gap between analysis and prediction– Undergraduate courses emphasize the stability analysis of linear simplified systems and simple controller design, while postgraduate courses require comprehensive fault feature extraction and life prediction. Students are prone to fall into the predicament of being able to analyze but not make decisions, lacking the training to transform from control thinking to predictive maintenance thinking.

• Toolchain disconnection: During the undergraduate stage– The main tools used are MATLAB/Simulink [2]. At the postgraduate stage, one needs to master frameworks such as Python, TensorFlow, and PyTorch. However, in terms of the current curriculum design, cross-platform collaborative case teaching is insufficient, and the defect in the curriculum design affects the ability to integrate the technology stack.

2.1.3. Uneven Allocation of Teaching Resources

Although various institutions have been actively developing virtual integrated experimental platforms and making full use of teaching resources, there are still many problems in the reconstruction of teaching models and the optimization of curriculum systems. For instance, the

undergraduate educational and teaching resources that focus on traditional control theory and the postgraduate teaching mechanism that emphasizes intelligent algorithm research has led to the lack of faculty collaboration and the absence of a teaching and research mechanism. Moreover, the issue of separating experimental platforms such as the configuration of undergraduate laboratory equipment that focuses on basic control objects and the configuration of postgraduate teaching and research equipment that relies heavily on industrial-grade equipment is another one needs to be solved.

2.2. The Significance of the Reform and the key Scientific Issues to be Addressed

In order to achieve innovative results and transformation in the discipline of intelligent automation, it is necessary to shift the traditional theoretical research content towards practical engineering applications. Moreover, in the teaching process, emphasis should be placed on guiding postgraduate students to integrate this course. Therefore, the following issues need to be urgently addressed in the integrated teaching process of undergraduate and postgraduate studies involved in this article, including:

a) During the online operation of complex equipment, the historical and real-time data output by sensors are applied to drive and obtain the model mathematical description of the system in both healthy and different fault states. Combined with the undergraduate course 'Principles of Automatic Control', the transfer function description of the system is completed, as well as the time response analysis, stability analysis and steady-state error calculation of the system. It is one of the key scientific issues that need to be urgently addressed to achieve integrated undergraduate and postgraduate teaching.

b) By using the Fault-Pattern Library (FPL), the observed state (i.e., the Fault characteristic vector) is mapped to the fault category. Combined with the content of Chapter 5 of this course, that is, the frequency domain analysis method of linear systems, the frequency characteristic analysis of the system is completed. Using the Nynikov criterion and the logarithmic frequency stability criterion, the stability of the system, and the phase angle margin as well as amplitude margin of the system, and identifying the stability of complex systems under different fault conditions are also the key scientific issues in achieving integrated undergraduate and postgraduate teaching.

c) Under the ideal framework of maximizing the service life of equipment and minimizing maintenance and operation costs, in combination with the content of Key scientific Question Two and the content of Chapter 6 of the undergraduate course PAC, design correction methods such as series leading correction, lagging correction, feedforward correction, and compound correction that meet the frequency domain performance based on the characteristics of the complex system under study. In fact, in order to realize theories and methods such as brain-like complex systems and brain-like control, designing PID fault-tolerant control, fuzzy PID fault-tolerant control, adaptive fault-tolerant control, adaptive fault-tolerant control based on neural network compensation, and adaptive fault-tolerant control strategies based on expert systems, so that the system can complete the task realization under the influence of a certain degree of fault under the disturbance of the complex external environment of the somatic intelligence is another key scientific issue in the integrated teaching of undergraduate.

3. Plan and Features in the Entire Implementation

In line with the spirit of the Ministry of Education's 'Opinions on Accelerating the Reform and Development of Postgraduate Education in the New Era', and in combination with the 'Action Plan for Deepening the Reform of Basic Education Curriculum Teaching' of Ministry of Education, the implementation plan is deeply planned through the reconstruction of course knowledge, ability

connection, resource sharing, and the development of practical case libraries at the undergraduate and postgraduate stages based on the background of 'new engineering' construction. Moreover, considering that the innovative teaching reform points such as the joint guidance of undergraduate and postgraduate supervisors, we aim to cultivate compound talents with both academic depth and industrial vision [3].

3.1. Specific Implementation Plan

3.1.1. Reconstruction of Course Content (shown as Table 1)

Table 1 Reconstruction of the content of collaborative integrated course based on PAC and SIFPEE

Stage	Original course content	Key points of renovation	Bridging achievements
Undergraduate course (PAC)	Classical control theory: Time/frequency domain analysis method	Add special topics on electrical equipment modeling (i.e., derivation of motor transfer functions)	Master the methods for describing the dynamic characteristics of equipment
Postgraduate course (SIFPEE)	Teaching of fault diagnosis and prediction algorithms	Review Module of Pre-Control Theory (i.e., application of Root Trajectories in Stability Criteria	Realize the traceability of the algorithm principle

3.1.2. Construction of Teaching Resources

a) Sharing of experimental platform

• Renovate the existing control training room and add equipment condition monitoring terminals.

• Develop a coherent experimental project and completed cases under the theoretical framework of "control parameter debugging → fault feature extraction".

b) Development of case library (shown as Table 2)

Table 2 Display of electrical engineering students' case database

Type of equipment type	Teaching case of undergraduate	Extension directions of postgraduate
Fault diagnosis of wifi chip	Construction of simplify model	Wavelet transform of output signal
Flaw detection of wind turbine blades	Transfer function deter-mined via digital twin model	Fault category diagnosis based on residual fuzzy logic method

3.1.3. Faculty Collaboration Program

a) A joint teaching and research group, i.e., undergraduate control theory teachers + master's diagnosis direction teachers should be established.

b) Teaching model of "1+1", i.e., master's program within the first four weeks, and intensive module of control theory implemented by educational reform practitioners should be developed.

3.2. Expected Features

Based on the current cutting-edge trends and typical practical cases of higher education reform, the expected features and innovations of this educational reform content can be elaborated in two sub-modules: undergraduate and postgraduate.

3.2.1. Innovative Points in the Teaching Reform of the Undergraduate Course - (PAC)

a) Reconstruction of teaching models

• Teaching method of ‘scene-driven’ is realized, i.e., unmanned aerial vehicles, unmanned boats, robot control, and DC motor control should be integrated into teaching cases throughout the theoretical teaching process.

• Experimental platform combined virtual ones and in-silico testbed is developed using teaching resources, i.e., automatic control theory and computer control technology test chamber (ACCT-IV) under MATLAB/Simulink environment to conduct computational simulation and hardware-in-the-loop (HIL) real-time control experiments, in order to verify the system characteristics of the physical experimental device.

b) Optimization of the curriculum system

• Based on the application of data structures and pattern recognition required by the data-driven model method in control systems, a new chapter on the integration of undergraduate and postgraduate studies has been added.

• Flexible exploration structure, i.e., core theory (24 hours) + industry topics (12 hours) is reconstructed by splitting the original 36-hour course.

c) Reform of the evaluation mechanism

• Three-stage ability assessment is implemented under a novel teaching structure i.e., classroom + after-class, which can be designed as basic concept test (40%) + system analysis and design defense (40%) + artificial intelligence innovation strategy project design (20%).

3.2.2. The Innovative Features of the Postgraduate Course - (SIFPEE)

a) Integration of cutting-edge artificial intelligence algorithms

• By integrating intelligent fault diagnosis methods such as neural networks, fuzzy neural networks, radial basis neural networks, and wavelet neural networks, equipment fault category discrimination and early warning are achieved, and a multi-source fusion intelligent diagnosis system is constructed.

• Digital twins technology is introduced to achieve a virtual simulation platform for real-time monitoring and predictive maintenance of equipment status.

• Energy data analysis projects is developed with power enterprises jointly, moreover, completed projects as engineering case transformation teaching resources is utilized to cultivate engineering practice abilities of students.

b) Collaboration among industry, academia and research

• For cultivating engineering practice abilities of students in reading, energy data analysis projects should be developed with power enterprises jointly, moreover, teaching resources is also needed to transform as completed as engineering case utilizing completed projects [4][5].

4. Forms of Achievements and Expected Promotion

4.1. Forms of Achievements

This project integrates the undergraduate course with the postgraduate course (SIFPEE) to build a bridging integrated curriculum system that focuses on the cultivation of social practice abilities. Specifically, it includes:

a) Integrated curriculum outline and training Program

Construct a teaching system covering the entire process of the undergraduate course through a practical teaching system. In order to achieve a coherent and stepwise course content for advanced

postgraduate courses and strengthen the course positioning and logical connection, optimization strategy using optimization is developed from both the horizontal and vertical directions of undergraduate and postgraduate courses. On the basis of mastering the core content and achieving basic cognition, while breaking through key technologies to complete professional strengthening, we also look forward to cutting-edge topics to solve innovative applications and complete a step-by-step content design.

b) Shared teaching resource library

Cross-stage digital textbooks, experimental cases and online courses have been developed, and the mutual selection of undergraduate and postgraduate courses has also received significant support. The above strategies can reduce the transition time for some students who have already set clear goals for postgraduate studies.

c) Integration of scientific research practice platforms

To cultivate students' innovative and management capabilities, in the reform of integrated undergraduate and postgraduate collaborative teaching, it is necessary to combine the discipline direction of electrical engineering and provide scientific research training positions. The cooperation between schools and enterprises needs to be completed in depth, and the establishment of specific measures such as joint laboratories or project bases also provides in-depth support for it.

4.2. Expected Promotion Plan

The achievements of this project can be extended to all high-efficiency electrical automation majors across the country.

a) Phased discipline coverage

The collaborative integrated reform will be prioritized for pilot practice in disciplines such as Control Science and Engineering, Electrical Engineering, and Intelligent Science and Engineering. After verification, it will be promoted to other majors both inside and outside the school, and gradually expanded to related interdisciplinary fields.

b) Promotion mechanism

The project reform is implemented through the Ministry of Education's shared course resources such as the Outstanding Engineers Program and the Engineering Education Professional Accreditation Platform. Meanwhile, during the promotion process, it is necessary to draw on and replicate relatively successful promotion models i.e., One Body, Two Precisions, Three Comprehensives, and Four Elements.

5. Conclusions

Over all, it can be seen that this project takes the educational practice system as its core, and is carried out in stages (from undergraduate to postgraduate) to connect, promote and extend to the beneficiary groups including students, enterprises and regional development, forming a closed loop of the education chain - industrial chain - innovation chain. The reform measures of the project can be used as feedback information to specifically regulate the educational mechanism and make the course objectives clearer.

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