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Research and Practice on an Intelligent Teaching Model for Control System Simulation Courses Empowered by Artificial Intelligence

Chonglin Gu, Xiaoyue Cao*

Liaoning Institute of Science and Technology, Benxi, Liaoning 117004, China

*Corresponding author: Xiaoyue Cao (Email: 18331593558@163.com)

Abstract

Amidst the rapid advancement of artificial intelligence technology, the education sector is undergoing profound digital transformation. As a core discipline within automation studies, the traditional teaching approach for control system simulation courses has become inadequate in meeting the demands of the intelligent era for versatile, innovative talent. This research endeavors to explore the deep integration of artificial intelligence technology with control system simulation courses. It constructs a novel smart teaching PBL (Project-Based Learning) model centered on 'AI-driven + intelligent algorithms + simulation collaboration'. This aims to enhance students' practical capabilities and innovative thinking, thereby forging new pathways for the high-quality development of engineering education.

Keywords

Artificial Intelligence; Simulation; Project-Based Learning; Control Systems.

1. Introduction

The theoretical underpinnings of artificial intelligence serve as the foundational framework for this research. Through core concepts such as deep learning algorithms and big data analytics, AI technologies drive educational innovation. Its enabling mechanisms manifest in personalized learning pathway planning, intelligent assessment feedback, and the construction of virtual simulation environments. For instance, AI can dynamically adjust teaching strategies based on student simulation experiment data, thereby achieving adaptive learning support.[1-3]

Control System Simulation stands as a core module within automation programmers, focusing on mathematical modelling, MATLAB/Simulink tool application, and system performance analysis. Its pedagogical objectives encompass cultivating abstract thinking, enhancing practical problem-solving capabilities, and broadening perspectives on cutting-edge technologies. The teaching framework typically comprises three key stages: model establishment, algorithm conversion, and simulation experimentation. Among practical project-based teaching innovations, Project-Based Learning (PBL) serves as a typical model.[4-6] Utilizing real-world engineering cases (such as temperature control system design), it drives students through the entire process from modelling to debugging, emphasizing teamwork and engineering thinking training. The innovation lies in integrating virtual simulation technology with actual control problems, such as constructing intelligent traffic light systems through three-dimensional simulation environments.

Within and beyond Liaoning Province, research on AI-empowered control system simulation is advancing rapidly. Through policy guidance and industrial collaboration, Liaoning is actively cultivating an AI innovation ecosystem, prioritizing the deep integration of AI technologies in industrial control and intelligent manufacturing. As the regional hub, Shenyang has explicitly designated intelligent robotics and smart equipment as key development directions, planning breakthroughs in critical technologies like intelligent perception in complex scenarios. This provides essential technical support for dynamic modelling and real-time optimization in control system simulation. Within the education sector, provincial universities are exploring AI-driven pedagogical reforms. Examples include systematically constructing theoretical frameworks through knowledge graphs and employing intelligent learning companions to deliver personalized guidance for simulation experiments. Such practices offer replicable paradigms for virtual simulation teaching in control systems. Nationally, Liaoning's computational infrastructure deployment and vertical industry large-model cultivation initiatives lay the groundwork for cloud-based simulation and collaborative R&D of complex control systems. Current research still faces challenges such as insufficient technology transfer efficiency and a shortage of interdisciplinary talent. However, through industry-academia collaboration in developing integrated resources (e.g., virtual automotive testing modules), a closed-loop verification system linking 'theory-simulation-industry' is gradually taking shape.[7] This demonstrates that provincial governments and universities at all levels place significant emphasis on research into industry-education integration and collaborative talent development within the AI context. Control system simulation courses constitute a vital component within artificial intelligence curricula, being mandatory for electrical engineering, electronic information, and mechatronics disciplines.[8]

A search on CKNI using the keyword 'control system simulation courses research' yielded 33 results, indicating this topic's relative novelty. Current Chinese research in AI-empowered control system simulation exhibits multidimensional convergence, with technological application and policy support forming a dual-drive dynamic. In education, Tsinghua University leverages its GLM4 large model to develop course-specific AI teaching assistants, enabling automated question generation and query resolution.[9] Meanwhile, Zhejiang University's 'Zhihai Platform' enhances simulation teaching efficiency through structured knowledge resource integration.[10] On the policy front, the Ministry of Industry and Information Technology's 2025 initiatives-the Measures for Identifying AI-Generated Synthetic Content and the Special Action Plan for Digital Empowerment of SMEs-provide standardized frameworks for technological implementation, emphasizing the supporting role of vertical industry large models in industrial simulation.[11] However, research still faces core challenges, including poor model transferability due to insufficient industrial data openness, discrepancies between simulation environments and reality, and energy consumption bottlenecks under high computational demands.[12] Looking ahead, with the construction of the 'East Data, West Computing' project's computational network and the refinement of the domestic large model ecosystem, China is poised to transition from technological catch-up to localized leadership in this field.[13]

2. Course Objectives and Student Profile Analysis

2.1. Course Objectives

Computer Simulation Technology is a compulsory specialized course within the Automation programmer. Grounded in the theoretical foundations of discrete-time signals and systems, it primarily addresses signal processing and its associated practical applications. The course employs theory, experimentation, and practical development as its core approaches to cultivate students' scientific thinking and innovative capabilities, equipping them to resolve complex engineering challenges. Aligned with the fundamental mission of moral cultivation and the university's educational positioning of nurturing applied professionals at Liaoning University of Science and Technology, and considering the basic learning circumstances of its students, this course focuses on four learning objectives, with their interrelationship illustrated in Figure 1.

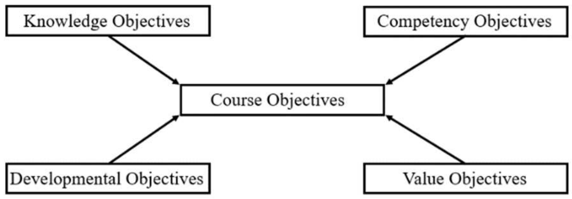

Figure 1. Course Objective Relationships

Knowledge Objectives: Master mathematical modelling techniques for control systems; comprehend the principles of continuous-to-discrete system conversion; conduct simulation verification of core system performance metrics-including stability, dynamic quality, and steady-state error-through time-domain analysis, frequency-domain analysis, and root locus analysis. Master simulation principles and procedures, grasp the fundamental concepts of control system simulation, and understand the complete workflow from 'modelling → algorithm selection → simulation execution → result analysis'. Recognize the role of simulation in control system design, analysis, and optimization.

Competency Objectives: Apply core knowledge to model, analyses, and process control systems in automation and related fields; design approaches for acquiring and enhancing performance parameters of automatic control systems; address specific application requirements within automation system installations by conducting practical engineering problem analysis, system design, and implementation. Cultivate students' ability to investigate automation engineering problems based on control system principles and techniques, encompassing model establishment, system design and implementation, experimental validation, data analysis, and deriving sound conclusions through information synthesis.

Developmental Objectives: Through classroom discussions, group assignments, and practical exploration, students will experience the application of control system simulation in technology, fostering a spirit of excellence and cultivating a diligent, pragmatic, and proactive character.

Value Objectives: Grounded in the discipline, innovative teaching methods will ensure discourse is reasoned, substantive, impactful, and measured. This cultivates cultural confidence and national pride, deepening students' sense of patriotism and commitment to their homeland.

2.2. Student Profile Analysis

Learning Profile Analysis figure 2 is as follows:

(1) Knowledge Foundation Characteristics

Students born in the 2000s generally possess high levels of digital literacy, enabling them to rapidly adapt to the digital learning environment driven by the 'Internet Plus' initiative. However, when studying engineering courses such as control system simulation, their knowledge structure exhibits breadth over depth: they demonstrate strong proficiency in emerging technological tools (e.g., MATLAB/Simulink, Python programming) but lack a systematic understanding of the underlying logic of control theory. Significant gaps are particularly evident in advanced knowledge domains such as complex system modelling for engineering applications and multivariable coupling analysis.

(2) Cognitive Characteristics

This cohort exhibits pronounced 'fast-thinking' traits: they demonstrate acute perceptiveness and rapid proficiency with new technologies and methodologies, yet exhibit deficiencies in

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higher-order cognitive abilities. This manifests as a tendency towards superficial learning, where tasks requiring deep logical reasoning-such as filter design or system stability analysis-often result in understanding the "what" without grasping the 'why'. Weak engineering thinking: When faced with simulation verification of complex control systems, they struggle to establish a complete 'theory-model-practice' thought chain. Team collaboration requirements: Group project-based learning (e.g., PID controller parameter tuning competitions) can effectively stimulate their curiosity, but an initial tendency towards free-riding and reluctance to tackle difficult tasks is common.

(3) Current State of Learning Motivation

As a core compulsory subject, students exhibit pronounced dual-drive characteristics: interest-driven, maintaining keen curiosity towards cutting-edge applications like intelligent control and robotics; utilitarian-oriented, with learning behavior markedly score-driven, overly focused on superficial formalities like experimental report formatting. In innovation experiments, they tend towards 'safe options,' demonstrating insufficient recognition of deeper values such as engineering ethics and system optimization. Based on these characteristics, the intelligent teaching model must priorities: - Constructing a cognitive scaffolding system that visualizes complex theoretical connections via knowledge graphs, utilizing AI teaching assistants to provide progressive problem guidance. - Implementing blended virtual-physical practice environments using digital twin technology to create 'low-risk, high-feedback' simulation settings, lowering engineering practice barriers. - Introducing real-world enterprise project cases into motivation conversion mechanisms, establishing an 'innovation points-to-competency certification' pathway for outcome transformation.

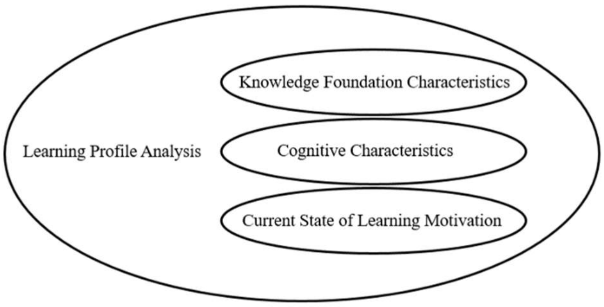

Figure 2. Learning Profile Analysis

3. Establishing an Intelligent Teaching Model for Control System Simulation Courses through Artificial Intelligence Empowerment

(1) Knowledge graph-driven curriculum restructuring involves constructing a knowledge graph for control system simulation courses, systematically organizing the logical relationships between knowledge points to form a structured, visualized knowledge network. This knowledge graph not only optimizes the organization of teaching content but also lays the foundation for designing personalized learning pathways. For instance, within the 'Control System Analysis and Design' course, the knowledge graph automatically identifies students' knowledge gaps and recommends targeted learning resources, enabling precise 'teaching tailored to individual needs'.

(2) A practice-oriented teaching system integrating virtual and physical elements, combining virtual simulation platforms with real control systems to establish a comprehensive competency development framework spanning 'theoretical understanding – computational analysis – applied practice'. For instance, digital twin technology simulates industrial control scenarios, enabling students to design and debug systems in virtual environments before

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validating solutions through physical equipment, forming a closed-loop ‘virtual-physical symbiosis’ practice. Practical data indicates this model elevates students' system debugging success rate from 60% in traditional approaches to 90%.

(3) AI-empowered personalized learning support incorporates AI teaching assistant systems. These provide real-time feedback and resource recommendations based on student learning behavior data (e.g., experimental operation records, simulation result analyses). AI technology also automatically generates simulation experiment reports and evaluates design proposal rationality, significantly enhancing teaching efficiency. For instance, AI analyses student design parameters and generates optimization suggestions, reducing average experimental design time.

The construction of an AI-empowered intelligent teaching model for control system simulation courses is illustrated in Figure 3.

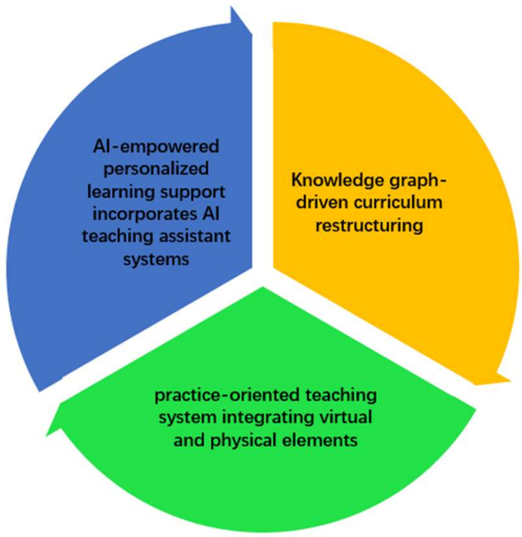

Figure 3. Construction of Intelligent Teaching Models

4. Practical Case Studies and Outcomes of AI-Empowered Control System Simulation Courses

Taking the course ‘Computer Simulation Technology’ as an example, the implementation of the smart teaching model has yielded remarkable results. Firstly, teaching efficiency has been enhanced, with AI teaching assistants handling 30% of repetitive tasks (such as marking experiment reports and answering basic queries), enabling lecturers to focus on cultivating higher-order skills. For instance, by analyzing student experimental data through AI, lecturers can swiftly identify common issues, thereby doubling the precision of classroom explanations.

Secondly, learning outcomes have been optimized. Through personalized recommendations powered by knowledge graphs, students' average experimental design time has been reduced by 50%, while system debugging success rates have increased by 50%. For instance, one student mastered a complex control algorithm within two weeks via an AI-recommended learning path – a feat that would have taken a month under traditional teaching methods. Finally, innovation capabilities have strengthened, with student awards in provincial-level and above intelligent control competitions rising by 50% year-on-year, demonstrating a marked enhancement in interdisciplinary application skills.

AI-Empowered Innovative Methods for Control System Simulation Courses:

(1) AI-Empowered Course: The ‘Control System Simulation’ course exemplifies a discipline where theory and practice are closely intertwined, emphasizing qualitative analysis and design.

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This presents heightened demands and challenges for developing AI teaching assistant systems. Currently, by enhancing the AI DeepSeek model's capabilities and code proficiency, the system has attained fundamental intelligent empowerment functions.

(2) Project-Based Learning in Groups: Prior to lectures, student learning profiles are analyzed. Group leaders are identified based on two weeks of classroom performance, forming study groups of approximately six members. Project-based learning is implemented for each knowledge point. Post-lecture, students are assigned project design tasks. Selected projects must relate to the knowledge point and possess practical significance. Groups present reports before each lecture. Following each group presentation, students vote to select the best design of the session, enhancing motivation for innovative learning.

(3) Aligning teaching objectives with industry demands to stimulate positive engagement and achieve deep learning: Through instructional redesign, cultivate students' positive affect to foster proactive learning and attain profound comprehension.

(4) Prioritizing social competence development: Conventional teaching models and assessment methods struggle to cultivate competencies effectively. Implement progressive guidance throughout the teaching cycle (establishing tiered advancement projects) to direct and incentivize learning investment;

(5) Goal-oriented, emotion-driven construction of a multi-dimensional evaluation system integrating internal and external synergies. With innovation capability as the cultivation objective, learning scenarios are created to stimulate interest. Teams are formed through AI-enhanced Project-Based Learning (PBL) initiatives, establishing cross-disciplinary teaching communities. Within this teaching community, establish virtual teaching and research rooms to hold regular seminars on curriculum content, course-based ideological education, and teaching case design. Subsequently, identify enterprises suitable for control system simulation teaching from collaborative education projects published by the Ministry of Education to foster industry-academia partnerships. This collaboration will assist enterprises in developing experimental kits tailored for cultivating innovative capabilities in control system simulation courses at higher education institutions, while enterprises can provide the requisite software.

5. Challenges and Future Directions

Despite demonstrating significant potential, the smart teaching model faces challenges. Teachers' AI literacy remains inadequate, with some encountering technical barriers in applying AI tools, necessitating enhanced specialized training. Data security and ethical concerns require stringent protection of student behavioral data within virtual simulation experiments to prevent privacy breaches. One platform employs blockchain technology to achieve encrypted data storage and access control, effectively safeguarding student privacy. Research will further explore the deep application of AIGC (Artificial Intelligence Generated Content) in simulation experiments, such as automatically generating complex control scenarios and intelligently optimizing algorithm parameters, driving the evolution of teaching models towards ‘intelligent adaptation’. For instance, one laboratory utilized AIGC technology to generate 100 distinct control scenarios, increasing student practical opportunities by 50%.

Future efforts should strengthen AI competency training for educators: universities are advised to introduce specialized courses on ‘AI+ Education Empowerment’ to enhance teachers' proficiency in AI tools. Data security frameworks require refinement, with recommendations to establish virtual simulation experiment data security standards to regulate data collection, storage, and usage protocols. Interdisciplinary collaboration should be promoted, suggesting enhanced integration between control engineering, computer science, and pedagogy to jointly develop novel intelligent teaching paradigms.

6. Conclusion

The future will see further deepening of personalized learning, with AI technology precisely predicting students' learning needs and providing more tailored learning pathways. The AI-empowered intelligent teaching model for control system simulation courses represents a crucial direction in the digital transformation of engineering education. By continuously deepening the integration of AI technology with teaching and learning, and constructing a more inclusive and forward-looking educational ecosystem, we can cultivate more versatile innovative talents suited to the demands of the intelligent era, injecting new impetus into the high-quality development of engineering education.

The AI-empowered intelligent teaching model for control system simulation courses achieves a strategic shift from 'knowledge transmission' to 'intelligent empowerment' through knowledge graph reconstruction, virtual-physical collaborative practice, and AI-driven personalized support. Practice demonstrates that this model effectively enhances students' engineering practical abilities and innovative literacy, providing replicable experience for engineering education reform in the intelligent era. Future efforts should focus on deepening the integration of AI technology with education and teaching to build a more inclusive and forward-looking educational ecosystem.

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