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Exploration on the Reform of Integrated Teaching Mode of Electrical and Electronic Experiments Empowered by Digital Intelligence

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Abstract: Electrical and electronic experiments are essential practical courses for engineering students, supporting the development of experimental skills, engineering thinking, and innovation awareness. However, traditional teaching often remains verification-oriented and faces problems such as fragmented course arrangements, weak integration between online resources and offline practice, insufficient connection between virtual simulation and physical operation, and limited process-based assessment. To address these issues, this paper explores an integrated teaching mode for electrical and electronic experiments empowered by digital intelligence. Centered on students' experimental competence, the mode integrates online learning with offline practice, virtual simulation with physical operation, in-class teaching with out-of-class extension, and knowledge training with value guidance. It constructs a closed-loop process of pre-class guidance, simulation preparation, offline operation, data analysis, and feedback improvement. The implementation path includes developing digital experimental resources, reconstructing hierarchical experimental projects, applying virtual-physical and remote-open experiments, and establishing process-based assessment. This study provides a practical reference for optimizing experimental teaching organization and promoting the digital transformation and continuous improvement of electrical and electronic experiment courses.

Keywords: Digital Intelligence; Electrical and Electronic Experiments; Integrated Teaching; Virtual-Physical Integration; Process-Based Assessment

1. Introduction

Electrical and electronic experiments are fundamental practical courses in engineering education. They support theoretical verification, instrument operation training, and engineering practice. In laboratory teaching, students need to understand circuit principles and complete wiring, measurement, waveform observation, troubleshooting, and data analysis. With the development of emerging engineering education, engineering education accreditation, and educational digitalization, these courses should shift from step-by-step verification to the cultivation of practical ability, comprehensive design ability, and innovation awareness [1].

Several problems remain in current electrical and electronic experimental teaching. Some experiments are still verification-oriented, and students mainly follow fixed procedures in laboratory manuals, with limited training in independent analysis and scheme design. Modules such as circuit theory, analog electronics, digital electronics, and electronic technology practice are not closely connected, which may lead to gaps in competence development. In addition, online resources, virtual simulation, and offline practice are not fully integrated, while process tracking and assessment feedback still rely heavily on teachers' experience and laboratory reports [2,3]. Remote physical experiments and AI-supported platforms have extended experimental time and space, but they still need to be connected with physical operation, process assessment, and course objectives [4,5].

Recent studies have engineering education accreditation [1], experimental system reconstruction [2], explored online teaching [3], remote physical experiments [4], and "five-in-one" course construction [6], providing useful references for reform. Meanwhile, AI [7], knowledge graphs [8], IoT technology [9], and project-based learning have been introduced into experimental teaching [10], promoting more intelligent, personalized, and project-oriented resources, processes, and assessment methods. These studies show that the reform of electrical and electronic experiments has shifted from single resource construction to the coordinated improvement of platforms, content, processes, and assessment.

However, in course implementation, the connection among resources and classrooms, simulation and physical operation, process records and competence assessment still needs improvement. If micro-lectures, simulation platforms, report systems, and assessment tools remain separated, digitalization may only change the teaching form rather than improve students' experimental competence. Based on this consideration, this paper explores an integrated teaching mode for electrical and electronic experiments empowered by digital intelligence. Centered on students' experimental competence, the mode integrates online learning with offline practice, virtual simulation with physical operation, in-class teaching with out-of-class extension, and knowledge training with value guidance, forming a closed-loop process of pre-class guidance, simulation preparation, offline operation, data analysis, and feedback improvement.

2. Problems in Traditional Electrical and Electronic Experiment Teaching

2.1 Verification-Oriented Content and Weak Module Connection

Traditional electrical and electronic experiments are often arranged according to theoretical courses, such as circuit theory, analog electronics, digital electronics, electronic technology practice, and EDA. The progression among projects is not clear enough. After completing several experiments, students may master the measurement of individual circuits, but they still lack training in knowledge connection, comprehensive application, and engineering problem analysis [2].

In laboratory teaching, verification-oriented experiments still account for a large proportion. Experimental objectives, circuit diagrams, procedures, and data recording formats are usually provided in manuals. Students mainly complete wiring, measurement, and report writing by following fixed steps. This helps standardize basic operations, but it is insufficient for developing scheme design, parameter selection, fault judgment, and result optimization. Therefore, experimental content should shift from single verification to a hierarchical project system combining basic verification, comprehensive design, and innovative extension [8].

2.2 Insufficient Integration of Online Resources, Simulation, and Practice

Online platforms, virtual simulation, and remote physical experiments provide support for pre-class preparation, parameter analysis, fault prediction, and open experiments [4,5]. However, in some courses, online resources still mainly consist of courseware, videos, and electronic manuals. They are not closely connected with experimental tasks, simulation design, laboratory operation, and result analysis. As a result, students may finish online learning but still lack clear experimental schemes and judgment ability in the laboratory.

Virtual simulation can reduce trial-and-error costs, but it cannot replace real experiments. Component errors, contact resistance, instrument accuracy, and environmental interference in real circuits are important for developing engineering awareness and debugging ability. Therefore, students should be guided to compare simulation results with measured data and understand the relationship between theoretical models and engineering implementation through difference analysis [9].

2.3 Insufficient Process Tracking and Assessment Feedback

Experimental teaching should not only focus on whether the final data are correct, but also on students' performance in preparation, design, wiring, debugging, data processing, and reflection. Traditional teaching mainly relies on teachers' on-site inspection and report review, making it difficult to record the full experimental process. When the number of students is large, teachers usually have to deal with obvious operational errors first and cannot continuously track each student's thinking process.

Traditional assessment focuses more on attendance, experimental data, and report format, while insufficient attention is paid to troubleshooting, data analysis, teamwork, and reflective improvement. AI platforms, knowledge graphs, and learning data analysis provide new tools for process assessment. However, they can be effective only when preparation tests, simulation submissions, operation records, report reflection, and teacher feedback are integrated into a unified teaching loop [10].

3. Construction of the Integrated Teaching Mode Empowered by Digital Intelligence

To address verification-oriented content, weak module connection, insufficient virtual-physical integration, and limited process assessment, this paper constructs an integrated teaching mode for electrical and electronic experiments empowered by digital intelligence. Centered on students' experimental competence, the mode is supported by digital resources, virtual simulation, offline laboratories, remote and open experiments, and process-based assessment. Its framework can be summarized as "one core, four integrations, and five links," as shown in Figure 1.

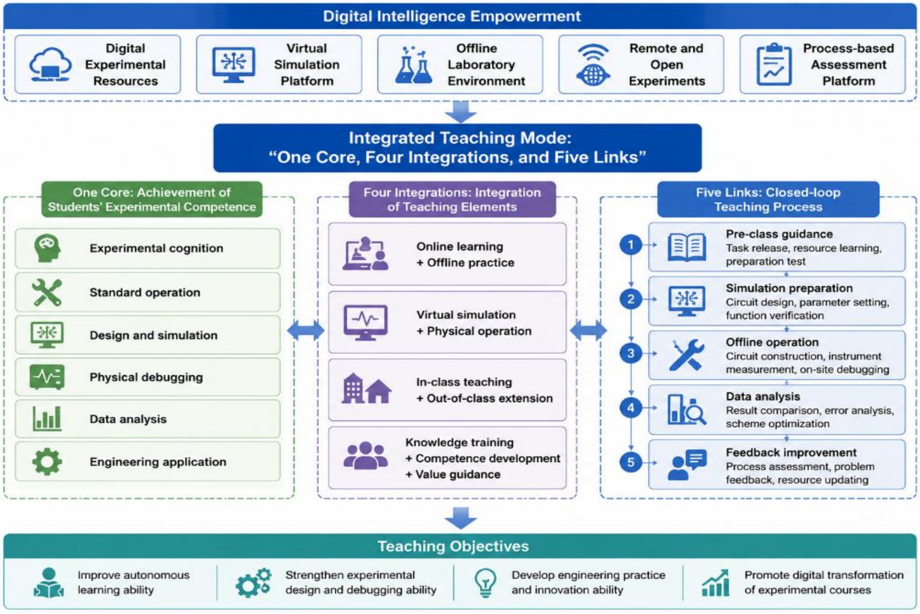

Figure 1. Framework of the Integrated Teaching Mode Empowered by Digital Intelligence

As shown in Figure 1, the mode uses digital intelligence to connect experimental objectives, teaching resources, experimental processes, and assessment feedback, avoiding the separation of online resources, simulation platforms, and offline laboratory practice.

3.1 Core objective: Achievement of Students' Experimental Competence

The integrated teaching mode should first clarify competence objectives. Electrical and electronic experiments require students not only to understand circuit principles, use instruments, and follow operational standards, but also to design schemes, conduct simulation analysis, debug physical circuits, process data, and present results. Therefore, the focus should shift from "completing procedures" to "achieving competence".

In this paper, students' experimental competence includes experimental cognition, standard operation, design and simulation, physical debugging, data analysis, and engineering application. Basic experiments train cognition and standard operation, such as instrument use, component identification, and basic circuit measurement. Comprehensive experiments train design, simulation, and physical debugging, such as amplifier, logic, and power supply circuit design. Extended experiments train data analysis and engineering application, and may involve IoT applications, intelligent detection, remote control, and engineering cases. Through this hierarchy, experimental projects shift from single verification to progressive competence training.

3.2 Four Integrations in the Teaching Process

The key to digital intelligence-empowered teaching is to connect the main links of experimental teaching. First, online learning is integrated with offline practice. Online platforms are used for task release, resource learning, preparation tests, and problem collection, while offline classes focus on real wiring, instrument measurement, on-site debugging, and fault diagnosis.

Second, virtual simulation is integrated with physical operation. Simulation supports scheme design, parameter optimization, and risk prediction before class, while physical experiments support real error analysis, troubleshooting, and engineering experience. Students should be guided to compare simulation results with measured data and analyze component errors, contact resistance, instrument accuracy, and environmental interference, so as to understand the gap between theoretical models and engineering implementation.

Third, in-class teaching is integrated with out-of-class extension. In-class experiments ensure basic training, while open laboratories, remote experiments, innovation projects, and competitions extend practice space. Students with weak foundations can use out-of-class platforms for supplementary practice, while stronger students can complete advanced design and project optimization.

Fourth, knowledge training is integrated with competence development and value guidance. Safety rules, teamwork, troubleshooting, and engineering cases all contain educational value. Teachers can strengthen standard awareness through instrument use, cultivate rigor through error analysis, and guide students to understand the relationship between technology application and social needs through engineering cases.

3.3 Five-link Closed-Loop Teaching Process

Based on the above integrations, this paper builds a five-link closed-loop process: pre-class guidance, simulation preparation, offline operation, data analysis, and feedback improvement. In pre-class guidance, teachers release tasks, resources, and preparation requirements, while students complete principle learning, instrument cognition, and preliminary scheme design. In simulation preparation, students use tools such as Multisim and Proteus to complete circuit design, parameter setting, and function verification.

In offline operation, students build circuits, use instruments, observe waveforms, and debug functions, while teachers focus on wiring standards, range selection, abnormal data, and troubleshooting. In data analysis, students compare simulation results with measured data, analyze error sources, and revise experimental conclusions. In feedback improvement, teachers evaluate preparation, simulation, operation, reports, and reflections, and transform typical errors and good schemes into later teaching resources.

Through these five links, experimental teaching shifts from the traditional linear process of “preparation-operation-report” to a closed loop of “task introduction-simulation design-physical verification-data analysis-feedback improvement”. This mode clarifies objectives, makes the process more traceable, improves feedback, and supports students’ autonomous learning, engineering practice, and innovation ability development.

4. Implementation Path of the Integrated Teaching Mode Empowered by Digital Intelligence

The implementation of the integrated teaching mode should focus on resource support, project-driven learning, and assessment improvement, so that digital resources, virtual simulation, offline practice, and process assessment serve the same competence objectives.

4.1 Developing Digital Resources and Reconstructing Hierarchical Projects

Digital resources should cover the whole experimental process rather than remain as uploaded courseware and videos. They may include task sheets, micro-lectures, instrument operation videos, simulation cases, preparation tests, typical fault libraries, and excellent experimental cases. Each project should include task requirements, principle guidance, simulation files, operation points, common problems, and assessment criteria, reducing the gap among preparation, simulation design, and physical operation.

Experimental projects should shift from single verification to a progressive structure of basic verification, comprehensive design, and innovative extension. Basic projects train component identification, instrument use, and basic measurement. Comprehensive projects train circuit schemes, parameter selection, simulation verification, and physical debugging. Extended projects may involve IoT applications, intelligent detection, remote control, engineering cases, or competitions, aiming to develop system integration and engineering application ability. Project design should not simply increase difficulty, but should guide students through scheme proposal, simulation verification, physical construction, fault correction, and result presentation.

4.2 Applying Virtual-Physical and Remote-Open Experiments

Virtual simulation, remote physical experiments, and offline practice should work together with clear functions. Simulation is used for pre-class scheme design, parameter adjustment, and risk prediction. Remote physical experiments support supplementary verification and scheme optimization after class. Offline practice focuses on real wiring, instrument measurement, on-site debugging, and troubleshooting. Through this combination, students can form schemes before experiments, complete verification during experiments, and continue improvement after experiments.

Teaching should emphasize the difference between simulation results and measured results. Teachers can guide students to explain data differences from component errors, contact resistance, instrument accuracy, measurement methods, and environmental interference. In this way, virtual-physical integration does not replace real experiments, but provides better preparation and extension for them.

4.3 Establishing Process-Based and Diversified Assessment

Assessment should cover before-class, in-class, and after-class learning. Before class, it focuses on preparation tests, simulation schemes, and safety rules. During class, it focuses on wiring standards, instrument use, troubleshooting, and teamwork. After class, it focuses on data analysis, reports, error explanation, and reflective improvement. The indicators may include knowledge mastery, operational skills, design ability, analytical ability, and engineering literacy, instead of relying only on results and report format.

Digital platforms can record preparation, simulation submissions, experimental data, report revisions, and teacher feedback, providing evidence for process assessment. AI tools and knowledge graphs can support learning diagnosis, resource recommendation, and personalized feedback, but teachers should still control assessment standards. The value of process data is not the amount of records, but its support for identifying common problems, adjusting projects, and improving the course continuously.

5. Conclusion and Reflection

This paper constructs an integrated teaching mode for electrical and electronic experiments empowered by digital intelligence to address the problems of verification-oriented content, insufficient curriculum connection, weak virtual-physical integration, and limited process-based assessment. Centered on students’ experimental competence, the mode is supported by digital resources, offline practice, remote and open experiments, and process-based assessment, forming a whole-process teaching loop before, during, and after class.

The proposed mode helps optimize experimental teaching organization. Students can complete knowledge preparation and scheme design before class, strengthen real operation, troubleshooting, and data analysis during experiments, and improve their understanding through feedback after class. Compared with traditional teaching based mainly on teacher explanation and result assessment, this mode gives more attention to autonomous learning, experimental design, physical debugging, and engineering practice. It can support the transformation of electrical and electronic experiments from verification-based training to comprehensive, design-oriented, and innovative practice. Future work may further use course operation data and learning process data to improve resource updating, virtual-physical difference analysis, and intelligent assessment.

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