

Research on Smart Teaching Methods for High-Frequency Electronic Circuits Course Empowered by Artificial Intelligence

Yongxin Li*, Jian Yang

Jinjiang College of Sichuan University, Meishan 620000, China

Abstract

High-Frequency Electronic Circuits is a core course for electronic information majors. It has long faced three teaching challenges: difficulty in intuitively understanding nonlinear theories, the "black-box" nature of hardware experiments, and delayed learning assessment feedback. Based on the Outcome-Based Education (OBE) philosophy, this study explores AI-empowered smart teaching methods. First, a "micro-project"-driven parameter visualization teaching model is proposed. AI-assisted interactive models transform abstract nonlinear circuit analysis into dynamic visual curves, helping students develop physical intuition. Second, an "AI Teaching Assistant + Hardware Practice" experimental paradigm is designed. AI identifies circuit topology and analyzes component functions, guiding students from passive wiring to active principle exploration. Third, a data-driven diagnostic mechanism is established. AI performs semantic analysis on high-frequency errors and generates learning diagnostic reports, supporting dynamic adjustment of teaching strategies. Two rounds of teaching practice show promising results. The average accuracy on objective questions in difficult chapters exceeded 70%. Effective operating time in laboratory sessions increased significantly. Classroom interaction also improved notably. This study provides a scalable paradigm for digital teaching transformation in application-oriented universities.

Keywords

Artificial intelligence; High-frequency electronic circuits; Smart teaching; Virtual-real mutual verification; OBE.

1. Introduction

Artificial intelligence (AI) has been increasingly applied in education. Yang [1] noted that AI can customize learning content and paths based on students' characteristics, abilities, and interests. This significantly improves learning efficiency. Smart teaching, as a product of integrating information technology with educational theory, enhances active participation and deep learning through personalized environments. How to effectively integrate AI into professional course teaching has become an important topic in higher education reform.

High-Frequency Electronic Circuits is a core course for electronic information majors. It combines theoretical abstraction with engineering practice [2]. The course covers frequency-selective networks, high-frequency small-signal amplifiers, resonant power amplifiers, oscillators, modulation, and demodulation. Its knowledge system is extensive and highly interconnected. Tian et al. [3] pointed out that traditional teaching of such courses faces several challenges, including abstract theories, high comprehension difficulty, limited practical training, and a simplistic evaluation system. Zhang et al. [4] also identified issues such as outdated content, insufficient practice, and disconnection between theory and industry.

Recent breakthroughs in generative AI offer new solutions to these challenges. AI can assist in building visualization resources, serve as an intelligent teaching assistant in experiments, and

enable precise learning profiling through data analysis [1]. Li et al. [5] analyzed AI-empowered teaching evaluation from a "technology-education" co-construction perspective. They argued that AI can shift evaluation from experience-based to data-driven and from outcome-oriented to process-oriented. Zheng et al. [6] further proposed that the core value of AI in educational evaluation lies in creating a "diagnosis-feedback" closed loop for evidence-based teaching adjustment.

Based on the OBE philosophy, this study addresses three pain points in teaching High-Frequency Electronic Circuits. A three-pronged smart teaching innovation system is proposed: "micro-project-driven parameter visualization," "AI teaching assistant-empowered virtual-real verification experiments," and "data-driven precise diagnosis and improvement." The goal is to shift from knowledge transmission to competency achievement.

Figure 1 illustrates the overall research framework linking teaching challenges, smart teaching methods, and OBE outcomes.

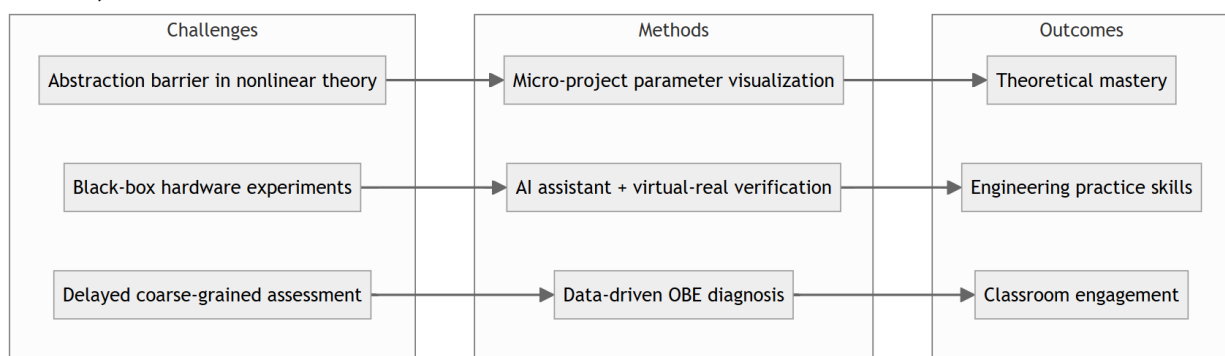


Figure 1. Research framework: from teaching challenges to OBE outcomes

2. Current Teaching Challenges

This course has long faced the dilemma of being "hard to teach, hard to learn, and hard to evaluate." The challenges manifest in three dimensions.

(1) Abstraction Barrier in Nonlinear Circuit Theory

The key distinction between high-frequency and low-frequency circuits lies in nonlinearity. Taking the resonant power amplifier (Class-C amplifier) as an example, the textbook [2] involves extensive cosine pulse decomposition formulas and piecewise-linear analysis. Traditional blackboard derivations can only present static results. They fail to demonstrate dynamic changes. Students commonly report that they can memorize formulas but cannot form mental images of the processes. They struggle to understand how circuit operating states transition among "under-voltage, critical, and over-voltage" modes when load resistance or excitation voltage changes.

The underlying cause is a structural mismatch between traditional teaching methods and the complexity of course content. Nonlinear circuit behavior is influenced by multiple coupled parameters. Static diagrams and mathematical formulas alone cannot fully capture dynamic characteristics. Students lack tools for multi-parameter engineering exploration. Tian et al. [3] confirmed that "abstract theory and high comprehension difficulty" is the primary teaching challenge in communication electronics courses.

(2) The "Black-Box" Problem in Hardware Experiments

Existing laboratory equipment often encapsulates core circuits inside sealed modules, exposing only test points. This "over-protective" design reduces students to "wiring machines." They can produce waveforms by following diagrams but understand nothing about the underlying circuit logic. When complex tasks such as superheterodyne radio alignment are involved, students

become helpless upon encountering problems like silence or howling. They simply raise their hands and wait for the instructor.

This "knowing what but not why" situation severely hinders the development of troubleshooting skills and engineering exploration spirit. Laboratory teaching should bridge theory and practice. However, a significant gap exists between current experimental processes and real engineering practice. Zhang et al. [4] similarly noted that "lack of practice" is a prominent issue. Students cannot truly understand circuit principles through experiments alone.

(3) Delayed and Coarse-Grained Learning Assessment

In large-class settings, traditional homework and final exams yield only aggregate scores. They lack in-depth diagnosis of students' cognitive structures. Instructors cannot distinguish whether errors stem from conceptual confusion, computational mistakes, or deficiency in circuit diagram interpretation. Without precise learning data, teaching adjustments rely on experience rather than evidence. This makes it difficult to implement the OBE principles of "student-centered" and "continuous improvement."

Zheng et al. [6] pointed out that traditional evaluation suffers from problems such as "technology overshadowing evaluation essence" and "lack of feedback diminishing evaluation value." Delayed feedback also reduces the timeliness of teaching interventions. By the time instructors identify weaknesses through final exams, the course has already ended. The optimal window for adjustment has been missed. Therefore, establishing a real-time and precise feedback mechanism is a key component of smart teaching.

3. AI-Empowered Smart Teaching Methods

To address the three challenges above, this study follows the "Two Qualities and One Degree" standard. Teaching content and evaluation systems are redesigned. Three innovative teaching methods are proposed.

(1) "Micro-Project"-Driven Parameter Visualization Teaching

The traditional textbook structure organized by "components to basic circuits" is replaced with a three-tier progressive project system aligned with industry standards: "fundamental units — integrated systems — innovative applications." The first tier features verification-type micro-projects such as "frequency-selective network design" and "small-signal amplification simulation" to consolidate theoretical foundations. The second tier centers on "high-efficiency wireless transmitter design." It integrates isolated topics including nonlinear power amplification, oscillation, and modulation circuits into a complete system-level design task, achieving systematic knowledge construction. The third tier introduces cutting-edge technologies such as Software Defined Radio (SDR) to enhance course depth. Figure 2 shows the three-tier micro-project system.

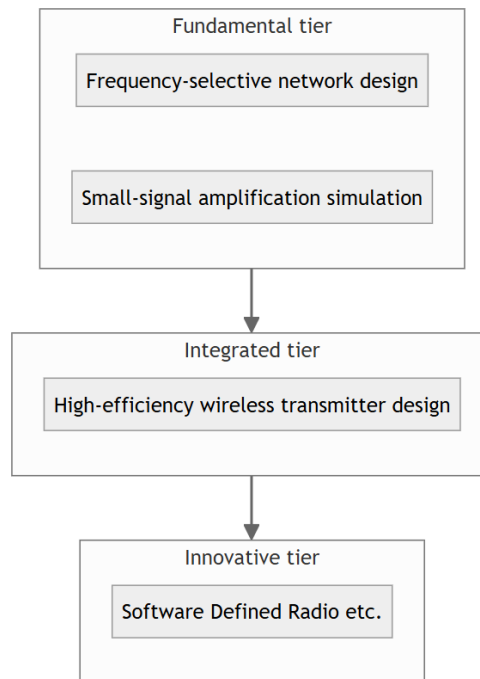


Figure 2. Three-tier progressive micro-project system

For nonlinear circuit analysis, an AI-assisted parameter visualization approach is adopted. AI helps develop Python-based interactive models. Students can dynamically adjust parameters and observe circuit behavior changes in real time. Abstract mathematical derivations are thus transformed into intuitive engineering visualizations. For example, when analyzing the load characteristics of a resonant power amplifier, students can change load resistance values through an interactive interface. They observe synchronized changes in collector current pulse waveforms, output power, and efficiency. The dynamic transitions among "under-voltage," "critical," and "over-voltage" states become visually intuitive. This approach aligns with the idea proposed by Tian et al. [3] of "making abstract knowledge tangible through AI."

Additionally, ideological and political education elements are integrated into the "transmitter design" micro-project. Cases on national radio security and spectrum resource management are introduced. Students learn to appreciate "spectrum" as a strategic national resource and develop engineering ethics awareness. While encouraging AI tool usage, the auxiliary nature of AI is emphasized to cultivate a healthy human-machine collaboration mindset and prevent technology dependence.

(2) "AI Teaching Assistant + Hardware Practice" Virtual-Real Verification Experimental Paradigm

To address the "black-box" problem, this study introduces generative AI as an experimental teaching assistant. A virtual-real mutual verification model is established. The core process consists of three stages:

Stage 1: AI-Assisted Circuit Analysis. Students upload photos of circuit boards. AI identifies circuit topology and analyzes component functions. Based on AI analysis, students complete physical-level circuit reconstruction, transitioning from blind wiring to principle-guided operation.

Stage 2: AI-Assisted Troubleshooting. During debugging, instead of the traditional "raise hand and wait" approach, students first describe fault phenomena to AI (e.g., "output waveform shows clipping" or "radio produces howling"). AI provides a fault diagnosis tree and troubleshooting logic. This process develops students' problem description skills and systematic engineering troubleshooting thinking.

Stage 3: Hardware Measurement Verification. Based on AI-suggested troubleshooting steps, students use oscilloscopes and multimeters to perform actual measurements. The "virtual reasoning — physical verification" closed loop tightly integrates AI-assisted analysis with hands-on practice. It cultivates higher-order thinking for analyzing complex engineering problems.

This "general-purpose AI + traditional lab equipment" model effectively addresses the mismatch between hardware update cycles and the pace of technological change. It applies not only to advanced laboratories but also revitalizes basic experimental equipment. It eliminates strong dependency on specific simulation software in digital teaching. Students are transformed from passive operators to active investigators.

(3) Data-Driven OBE Diagnosis and Improvement Mechanism

A comprehensive data collection and analysis system covering "pre-class, in-class, and post-class" phases is established. Li et al. [5] argued that the key to AI-empowered teaching evaluation lies in constructing a "technology-education" co-construction relationship. Under this framework, a three-phase mechanism is designed:

Pre-Class Phase: Rain Classroom is used to collect preview data, including video watching duration and quiz accuracy. A preliminary "knowledge readiness profile" is generated for each student.

In-Class Phase: Real-time quiz data is collected. AI analyzes answering patterns and error types. The focus extends beyond score levels to understanding "why errors occur." Error causes are classified into dimensions such as "conceptual confusion," "computational mistakes," and "circuit diagram interpretation deficiency." This enables precise identification of cognitive blind spots. This approach reflects the transition from "diagnostic evaluation" to "feedback-oriented evaluation" proposed by Zheng et al. [6].

Post-Class Phase: AI performs semantic analysis on class-wide high-frequency errors and generates learning diagnostic reports. Based on these reports, students with different proficiency levels are grouped heterogeneously. In group discussions, proficient students lead peers in reviewing experimental waveforms. Instructors provide targeted guidance on common weaknesses. This truly implements the OBE principle of continuous improvement.

4. Teaching Practice and Effectiveness

Through two rounds of teaching practice, preliminary results have been achieved in three dimensions: theoretical mastery, hands-on engineering skills, and classroom interaction.

(1) Improvement in Theoretical Learning

Based on Rain Classroom data comparison, students showed notable improvement in quizzes on difficult chapters such as "nonlinear circuits" after the reform. The average accuracy on objective questions exceeded 70%, representing an increase of approximately 10 percentage points over the pre-reform lecture-only mode. For the difficult topic of "resonant power amplifier load characteristics," AI-assisted parameter visualization significantly reduced student confusion about "under-voltage/over-voltage" states. Most students could correctly identify circuit operating states based on waveform characteristics.

(2) Enhancement of Engineering Practice Skills

During wireless transceiver system training, the "raise hand and wait for instructor" behavior decreased significantly. Students were more inclined to use AI tools or reference materials for independent troubleshooting. Classroom observations showed increased effective operating time and decreased passive waiting time. In the radio alignment stage, most groups were able to patiently adjust intermediate-frequency transformers until achieving optimal reception quality. This demonstrated a positive engineering practice attitude.

(3) Improvement of Classroom Interaction

The "silent classroom" phenomenon improved noticeably during group discussion sessions. Students became more willing to discuss abnormal waveforms and share debugging experiences. In post-class interviews, several students expressed that "building a working radio by hand was very rewarding." This immediate positive feedback effectively stimulated interest in subsequent learning, forming a virtuous cycle of "practice — achievement — motivation."

5. Conclusion

This study addresses three pain points in teaching High-Frequency Electronic Circuits: abstract theories difficult to visualize, black-box hardware experiments, and coarse-grained learning assessment. Based on the OBE philosophy, AI-empowered smart teaching methods are explored and practiced. A three-pronged teaching innovation system is constructed: "micro-project-driven parameter visualization," "AI teaching assistant-empowered virtual-real verification experiments," and "data-driven diagnosis and improvement." The system effectively improves students' theoretical understanding, engineering practice skills, and classroom engagement.

Two aspects deserve attention in future practice. First, technology dependence must be guarded against. The educational mission should remain central. AI should serve as "scaffolding" for student thinking, not a "replacement." Future work will optimize problem design and increase hands-on engineering troubleshooting tasks that AI cannot directly solve. This will encourage students to maintain independent engineering judgment and achieve "human-AI collaboration" rather than "human-AI substitution." Second, the "general-purpose AI + traditional lab equipment" model explored in this study features low cost and high effectiveness. It holds strong applicability and promotion value for application-oriented universities. It provides a replicable pathway for smart teaching reform in similar courses.

References

- [1] Yang Y. Research on smart teaching methods for computer majors supported by artificial intelligence technology [J]. *Journal of Machine Design*, 2026, 43(3): 207-211.
- [2] Zhang S W. *High-Frequency Electronic Circuits (6th Edition)* [M]. Beijing: Higher Education Press, 2024.
- [3] Tian J J, Ma J C. Research on teaching reform and practice of Communication Electronic Circuits under AI empowerment [J]. *Advances in Education*, 2025, 15(11): 1175-1181.
- [4] Zhang W H, Chen G. Teaching reform and innovation practice of High-Frequency Circuits from the perspective of industry-education integration [J]. *Vocational Education Development*, 2025, 14(8): 204-210.
- [5] Li J L, Niu Z D. Research on AI-empowered teaching evaluation in higher education from the "technology-education" co-construction perspective [J]. *China Higher Education Research*, 2025, 41(11): 15-23.
- [6] Zheng Y H, Wang Y Y, Yang S H. AI-empowered educational evaluation: value, challenges, and pathways [J]. *Open Education Research*, 2024(7).