

# Design-Centric Pedagogical Reformation: A Hybrid Learning Framework Integrating Virtual-Physical Experimentation

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## Abstract

This study implements a blended pedagogical reform for analog circuit experiments, integrating virtual simulations with design-oriented experiments to overcome traditional limitations. The redesigned curriculum combines 16-hour virtual experiments using an intelligent platform enabling remote real-time optimization, with 16-hour design projects from national competitions. Embedded ideological-political education enhances engineering ethics through collaborative troubleshooting. Implemented in 2024 with 47 students. Evaluation data (34 participants) demonstrate exceptional outcomes: 96.71/100 course rating (top 29% university-wide), 97.1% approval for cognitive-aligned design, and universal recognition of enhanced innovation capabilities. The hybrid model effectively bridges theory-practice gaps while synergizing technical training with value cultivation.

## Keywords

Analog Circuits, Blended Learning, Virtual-Physical Integration, Curriculum Reform, Engineering Education

## 1. Introduction

Analog circuits are a fundamental course in the electronic information discipline. As an essential practical teaching component of this course, analog circuit experiments constitute a critical part of the curriculum for electronic information-related majors. The students are expected to master the fundamental theories, knowledge, and skills related to analog circuits. In the experimental course, students gain an understanding of the working principles and analysis/design methods of commonly used electronic components and circuits, and they develop proficiency in

using electronic instruments and debugging techniques. This provides a solid foundation for subsequent related courses and the practical application of electronic technologies (Sun et al., 2023; Gao & Huang, 2025). Amidst the accelerated advancement of information technology, students exhibit intellectual vibrancy yet heightened susceptibility to harmful content. Higher education institutions, serving as primary platforms for developing competent professionals, assume significant responsibilities in delivering knowledge and fostering values-based education (Chen, 2025a, 2025b; Shen et al., 2025). This reality underscores the critical importance of incorporating values education into disciplinary teaching to realize holistic developmental goals. This paper undertakes a critical inquiry into the contemporary state of analog circuit experimentation pedagogy in higher education.

## 2. Current Status of Course Teaching

With the development of electronic technology, traditional analog circuit experiments face numerous challenges, such as the need for improvement in traditional teaching methods, the inability to meet the design requirements of complex circuits (Cao et al., 2024; Dong, 2024; Chen et al., 2021). Additionally, the lack of visualization features makes it difficult to observe the operation of various circuit components and real-time parameter changes. Furthermore, limitations on experiment time and space restrict the effectiveness of teaching (Gong et al., 2023).

### 2.1. Traditional Experimental Teaching Methods

The original analog circuit experiment course included 24 class hours of verification experiments and 8 class hours of comprehensive design experiments. Our school uniformly purchased new analog circuit experiment kits to address the issue of aging equipment. In the verification experiments, a standardized and uniform experimental kit was used. Students were required to preview the experimental content before class, listen to the teacher's explanation of the principles and operations during class, and then perform the operations using the experimental kit and instruments. They would observe and record experimental data during the process, analyze the data afterward, and submit an experimental report.

However, the functions of these experiment kits are fixed. The content and teaching model were relatively monotonous. This teaching approach involved students performing the same experiments within a fixed time-frame and following prescribed steps. In this process, students had limited participation in circuit design and experimentation, which hindered their enthusiasm for learning and did little to cultivate their hands-on skills and innovative practical abilities. Therefore, reforming the current teaching model to enhance the quality of analog circuit experiments is not only an essential means to cultivate students' innovative and practical abilities, but also an important way to improve experimental efficiency.

### 2.2. Limitations on Experiment Time and Space

To optimize utilization of the premium teaching resources and establish a student-centered teaching approach, we have implemented an innovative course se-

lection system based on fundamental discipline-specific courses. This new model features six parallel sections (approximately 300 students) for each subject. Each course is taught by multiple teachers during the same time slot. Students enjoy cross-disciplinary enrollment freedom while instructors engage in healthy professional competition, collectively enhancing teaching quality.

However, the Analog Circuits Laboratory course faces unique challenges as it shares lab facilities with other concurrent foundational courses. Faculty must coordinate schedules based on both student availability and lab room occupancy, resulting in severely constrained timetabling. Most sessions are inevitably scheduled during weekday evenings or weekends, significantly increasing the workload for both instructors and students.

### 2.3. limitations on Course Assessment and Evaluation

Traditional experimental teaching models often focus on fixed operational procedures and standardized outcomes as the core of assessment, leading to a homogenized evaluation system. Under such frameworks, student performance is predominantly judged by the compliance of lab reports or adherence to predefined results, with insufficient attention to innovative thinking, problem-solving skills, or collaborative abilities (Zhou & Zhao, 2021). Research indicates that this approach tends to cluster scores within narrow ranges (e.g., a majority of students scoring between 80 - 90 points), significantly reducing discriminative validity and failing to reflect true competency disparities. Moreover, the rigid assessment criteria may discourage students from engaging in exploratory practices. To address these issues, pedagogical reforms should integrate dynamic multi-dimensional evaluation mechanisms, enhancing both the scientific rigor and differentiation capacity of assessments.

## 3. The Reform Plan of Experimental Course

### 3.1. Curriculum Content Design

The Analog Circuit Experiment course serves as an essential component for bridging theoretical knowledge with practical application. In response to the current problems, a blended experimental teaching plan is adopted after conducting surveys and discussions (Docter & Bastemeijer, 2024; Chen, 2024).

The course team has reformed the traditional experimental framework for the Analog Circuit Experiment course. The key contents of the reform are as follows:

- **Shift from Verification-Based to Design-Oriented Learning:** The teaching content has been adjusted to reduce the focus on traditional verification-based experiments, placing greater emphasis on comprehensive and design-oriented experiments. Classic verification experiments are now conducted using a combination of software simulations and experimental kits, enhancing the connection between theoretical and practical knowledge. The virtual online experiment comprises 8 verification experiment contents (16 class hours), including single-stage amplifier circuit, two-stage amplifier circuit, differential amplifier

circuit, negative feedback amplifier circuit, proportional summing operational circuit, integral and differential operational circuit, voltage comparator, and RC sine wave oscillator circuit.

With the support of the online experimental platform, students can apply for experimental access through a client application. After logging in remotely, they can control the experimental circuits, complete circuit construction and parameter configuration, select test points, operate virtual instruments, and measure experimental data in real time. They can also capture test data and waveforms, laying a solid foundation for subsequent project-driven comprehensive design experiments. The platform features currently supports up to 40 users operating remotely at the same time, with dynamic hardware resource allocation. This eliminates the need for scheduling a unified time or experiment location, allowing students to complete experiments anytime and anywhere via a browser. Teachers can provide online support to address any issues students encounter during the experiments. This virtual simulation-based teaching model overcomes the traditional limitations of time and space in laboratory experiments.

- **Incorporation of Competition Elements:** The comprehensive experiment module includes two design-oriented experiments, totaling 16 class hours. Multiple smaller experiments have been integrated into larger, modular projects, such as the design of multifunctional audio amplifiers and adjustable DC power supplies. Some experimental topics are derived from national electronic circuit design competitions, providing students with real-world and competitive problem-solving experiences. For the Fall 2024 semester, the two design-oriented experiment topics are respectively “Audio Amplifier Design” and “Stabilized DC Power Supply Design”.

Teachers delivers the experimental design requirements, constraints on component selection, and project report guidelines to students online in advance. Students work in groups to independently plan, design, and implement their projects, promoting teamwork and self-directed learning. Students are encouraged to expand on their projects by incorporating new features and innovative ideas. They simulate the circuit using specialized software to achieve specified technical specifications and identify critical resistors and capacitors affecting performance. After teachers reviews and provides feedback on the simulation results, approved components are distributed. Students then assemble, solder, and debug circuits in the open-access laboratory under targeted instructor guidance during troubleshooting. Upon completing the physical implementation, teams conduct comprehensive analyses, document experimental data, finalize project reports, and prepare acceptance presentations.

### 3.2. Ideological-Political Education

With the deepening of higher education reform, the teaching work of Analog Circuit Experiments Course should be further optimized. It should explore how to play a leading role in the value of “ideological-political education” in the mixed

teaching mode. Teachers should exemplify positive values through their pedagogical demeanor and professional conduct to help students form constructive perspectives on the world, life purposes, and value judgments. For the Fall 2024 semester, our pedagogy in analog circuit experimentation integrates contemporary relevance and scientific ethos, inspiring emulation of distinguished researchers while fostering both technical mastery and civic-minded patriotism.

- We contextualize technical content by examining its broader implications for industrial advancement, national development, and socio-economic-cultural ecosystems in teaching fundamental instrument operation and circuit theory.
- During the operational amplifier application experiments, we teach integrated circuit fabrication design rules while cultivating a dialectical materialist perspective of nature, helping students recognize developmental patterns of phenomena and adopt top-down systems thinking approaches.
- In the hands-on circuit soldering component of design-oriented experiments, where short-circuit failures frequently occur ranging from fuse burnout to printed circuit board damage, we guide students through collaborative troubleshooting sessions using multimeters to diagnose faults, thereby reinforcing their safety awareness and enhancing team-based problem-solving competencies through practical engineering challenges.

By incorporating these value-laden components, ideological-political education becomes intrinsically embedded throughout the pedagogical continuum, creating synergistic interdependence with specialized curriculum delivery.

### **3.3. Course Assessment and Evaluation**

Adopting a learning-outcome-oriented approach, we implement a comprehensive assessment system that integrates process evaluation with summative assessment to multidimensionally examine students' mastery of fundamental circuit analysis, testing methodologies, and integrated design capabilities, as well as their innovative practical skills. The overall grading structure consists of verification experiments and comprehensive design experiments each accounting for 50% of the total score. The eight verification experiments are evaluated based on a combination of experimental duration recorded by the online platform and experimental results, while the two comprehensive design experiments are assessed through multiple criteria including the rationality of design solutions, accuracy of parameter simulations, effectiveness of presentations and physical demonstrations, individual contributions within teams, and the completeness of project reports, ensuring a holistic evaluation of both technical competencies and professional skills.

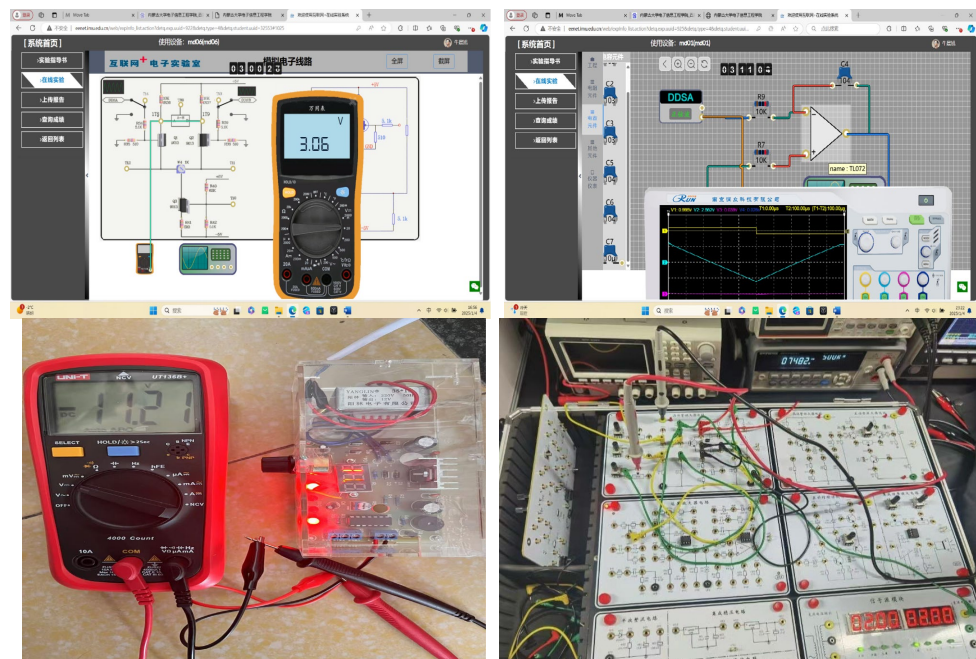
## **4. Implementation of Curriculum Reform**

### **4.1. Implementation Process of Curriculum Reform**

During virtual online experiments, students can visually observe the operational status of each circuit component, thereby gaining a more comprehensive understanding of the functional interdependencies between components. Through sim-

ulation and analysis of circuit performance characteristics, students can optimize circuit parameters and diagnose faults, effectively minimizing experimental errors and material waste while significantly enhancing experimental efficiency and measurement accuracy.

In the circuit design experiment module, students develop proficiency in component selection, soldering techniques, precise circuit connectivity, and the application of debugging tools by independently constructing and adjusting circuits. During the debugging phase, students frequently encounter various technical challenges, including signal distortion, insufficient amplification gain, and power supply voltage instability. By independently troubleshooting and resolving these issues, students cultivate keen observational abilities and systematic problem-solving skills (Figure 1).



**Figure 1.** Examples of some experimental process.

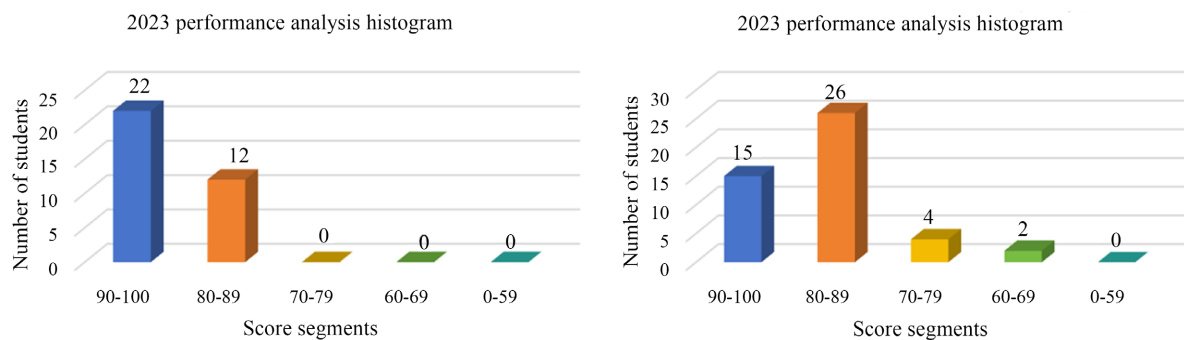
The figure presents selected implemented experimental procedures, including:

- Virtual verification experiments for differential amplifier circuit design and parameter measurement.
- Design and parametric characterization of calculus circuits.
- Offline comprehensive design experiments encompassing audio amplifier development and DC voltage regulator implementation.

#### 4.2. Outcomes of Curriculum Reform

The blended curriculum reform deeply integrates online and offline educational resources, establishing a multi-dimensional assessment system with confirmatory experiments (50%) and comprehensive design-based experiments (50%) as dual cores. In pedagogical implementation, confirmatory experiments focus on evalu-

ating mastery of fundamental theories and standardized operational skills, while design-based experiments require students to independently develop solutions through open-ended projects, emphasizing the evaluation of innovative thinking and problem-solving capabilities in complex scenarios. The assessment mechanism adopts a dynamic integration of formative assessment (40%) and summative assessment (60%). Results indicate that student performance distributions approximate a normal distribution pattern, with simultaneous improvements in classroom engagement and self-directed inquiry motivation, thereby validating the dual effectiveness of this model in scientifically quantifying learning outcomes and stimulating deep learning motivation (Figure 2).



**Figure 2.** Comparative analysis chart before and after curriculum reform.

In the exploration and practice of the teaching reform of analog circuit experiments, we are delighted to find that the reform has shown initial effectiveness from the comparison of the total score distribution curves of the two semesters from 2023 to 2024. The score distribution of the 2024 academic year basically follows a normal distribution, and the differentiation of the total scores has been significantly enhanced, which undoubtedly injects a shot in the arm into our teaching reform and fills us with confidence to further improve the reform measures and enhance the teaching effectiveness.

The normalization of the score distribution curve and the increased differentiation indicate that the teaching reform has made substantial progress in several key aspects. On the one hand, the formation of a normal distribution shows that there is a reasonable variation in students' learning levels, which not only reflects the fairness of teaching but also provides a basis for teaching according to students' aptitude. This reflects that the reformed teaching model can better adapt to students with different learning abilities, enabling them to make progress from their respective starting points. On the other hand, the enhanced differentiation helps to more accurately assess students' learning outcomes, motivate students to study hard, and also provides more effective feedback for teachers, facilitating timely adjustments to teaching strategies.

In the Fall 2024 semester, the curriculum reform initiative was implemented in a class of 47 students, with 34 voluntarily participating in the university's comprehensive teaching evaluation. The assessment examined multiple dimensions in-

cluding ideological and political education integration, pedagogical advancement, scientific teaching plan design, and appropriate methodology application. Results demonstrated outstanding performance: the Analog Circuit Experiment course achieved a score of 96.71, ranking 725th among 2498 university courses. Specifically, 33 students (97.1%) rated instruction as “Good” or higher in implementing advanced educational concepts, scientific curriculum design, logical course progression, and cognitive alignment, while 100% awarded “Good” or above for effective methodology application, clear presentation of complex concepts, and cultivation of critical thinking, innovation, and learning skills. Notably, all participants reported significant academic benefits and acknowledged the course’s substantial contribution to their personal and professional development.

## 5. Conclusion

In light of prevailing pedagogical challenges in the Analog Circuits Experiment course, this study pioneers innovative instructional reforms to amplify student agency and proactive learning. Empirical findings reveal that virtualized experimental platforms successfully eliminate spatiotemporal barriers, enhancing operational efficiency. The pedagogical integration of physical circuit assembly and iterative debugging processes has elevated students’ engineering problem-solving competence. The multi-dimensional dynamic assessment system implemented post-reform has significantly enhanced discriminative validity of academic performance through integrated quantitative metrics and qualitative evaluations, while concurrently improving classroom interaction frequency and incidence of deep learning behaviors. This empirically validates the dual efficacy of the model in scientifically quantifying learning outcomes and stimulating deep learning motivation. Despite the initial success achieved through the reform, in order to further enhance the teaching quality and students’ learning experience, it is imperative that we continue to refine the reform measures. This involves the ongoing adjustment and optimization of the teaching content, the strengthening of faculty development, and the establishment of a long-term mechanism for monitoring and evaluating teaching quality. Regular comprehensive assessments of the teaching process and its outcomes are essential to ensure the sustainable and healthy development of the teaching reform.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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