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Exploring an AI-Collaborative Teaching Model for Knowledge Internalization in Electrical and Electronic Technology Courses

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Abstract: Generative artificial intelligence (GenAI) can assist with circuit calculations, explanations of principles, and circuit analysis, offering new support for electrical and electronic technology courses. However, students may complete exercises with AI assistance without being able to analyze circuits independently. Given the abstract nature of circuit principles and the close relationship between theoretical analysis and experimental verification in this course, this paper proposes an AI-collaborative teaching model for understanding circuit operating states, comprising analysis, critical comparison, verification, and transfer. In the analysis stage, students think independently and form preliminary judgments; in critical comparison, they use AI-supported comparison and revision to deepen their understanding of circuit principles; in verification, they apply theoretical calculation, simulation, and measurement to strengthen knowledge application; and in transfer, they independently analyze modified tasks to develop transferable abilities. The paper also proposes an assessment approach combining AI-permitted learning activities with supervised assessment of independent competence, rather than judging mastery solely from homework and laboratory reports. AC circuit analysis is used to illustrate the implementation of the model. The proposed approach offers a reference for reforming electrical and electronic technology teaching in the context of generative AI.

Keywords: Generative artificial intelligence; Electrical and electronic technology; AI-collaborative teaching; Knowledge internalization; Circuit analysis

1. Introduction

Electrical and Electronic Technology is an important foundational course for engineering majors. Besides learning calculation methods, students need to judge circuit operating states and understand the physical meaning of circuit principles. Teaching is challenging because circuit principles are abstract and circuit behavior is complex, making operating mechanisms and patterns of change difficult to understand [1]. Generative artificial intelligence (GenAI) can offer analytical methods, calculation procedures, and circuit explanations, as well as assistance with simulation and laboratory-report preparation. While these functions facilitate learning, they also make conventional assignments less reliable as evidence of mastery: a correct calculation or a well-written laboratory report does not necessarily mean that a student independently interpreted and reasoned about a circuit. Thus, the course faces two related challenges: promoting knowledge internalization and assessing students' independent competence. In this paper, knowledge internalization refers to the transformation of learned knowledge into knowledge and abilities that students can independently understand, apply, and transfer through active thinking and practice.

Existing research provides useful approaches to AI-supported teaching. Studies of generative AI in education discuss its potential for explanation, learning support, and the challenges associated with ready-made answers [2–4]. Reviews of AI applications in

Received: 20 September 2026
Revised: 07 November 2026
Accepted: 19 November 2026
Published: 26 November 2026

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higher education examine personalized support, teaching practices, and assessment [5,6]. Research on virtual and physical laboratories offers approaches to linking conceptual knowledge with practical investigation [7,8]. Studies of AI-assisted programming consider learning support and students' difficulties in evaluating generated solutions [9,10], while work on academic integrity and AI-generated-text detection raises questions about using submitted work alone to judge independent performance [11,12]. These findings offer relevant perspectives for organizing AI-assisted learning, practical verification, and course assessment.

However, much of this work focuses on learning resources, instructional approaches, and teaching efficiency. How knowledge internalization can be promoted in GenAI-assisted learning, and how students' actual mastery can be assessed, merit further attention. When AI is involved in coursework, assignment products and learning-process data alone may not reveal whether students have independently mastered the knowledge. Accordingly, this paper develops the Analysis–Critical Comparison–Verification–Transfer teaching model and proposes an assessment mechanism combining AI-permitted learning with supervised assessment of independent competence.

2. Teaching Challenges in GenAI-Assisted Electrical and Electronic Technology Courses

Existing approaches to AI-supported learning use resources such as intelligent explanations, virtual simulation, and engineering examples to support the understanding and application of abstract concepts. However, receiving a clear explanation does not mean that a student has mastered the underlying knowledge. Knowledge internalization involves not only understanding and restating a principle, but also applying it independently to analyze a problem. If students can repeat an AI-generated explanation but cannot judge a circuit state or explain their reasoning independently, their understanding remains limited. Moreover, GenAI-generated analyses are not always accurate; students must be able to examine whether the conclusions are reasonable.

The widespread use of GenAI also complicates learning assessment. Prior studies have emphasized learning processes, practical activities, and task outcomes as sources of assessment information [5–8]. Yet when AI can contribute to exercises, laboratory analysis, and report writing, the quality of submitted work may not accurately reflect independent mastery. Learning records and originality checks may provide useful information, but they cannot fully establish students' ability to analyze and solve problems on their own [11,12]. Course assessment must therefore consider AI-assisted learning processes and task quality while also using suitable independent assessments to evaluate students' actual understanding and application of knowledge.

3. An AI-Collaborative Teaching Model for Knowledge Internalization

3.1. Conceptual Basis and Design Principles

From the perspective of learning theory, research on self-explanation emphasizes learners' active articulation of the relationships between procedures and underlying principles [13]. The ICAP framework distinguishes forms of cognitive engagement and indicates that receiving explanations or recording results does not necessarily produce deep learning [14]. Research on active learning [15], instructional scaffolding [16], and learning transfer [17] likewise provides a basis for student participation, appropriate learning support, and application in new situations. Together with work on AI-supported teaching and practical laboratories [5–10], these ideas inform the proposed model. Its particular emphasis is on ensuring that students form their own judgments and can subsequently apply what they have learned without relying on GenAI.

Accordingly, the instructional design combines student agency, AI-assisted learning, and assessment of independent competence. It emphasizes active thinking and cognitive engagement, while using AI to explain concepts, suggest approaches, and provide feedback. Students are expected to analyze and verify generated conclusions rather than

allow intelligent tools to replace their own reasoning. Assessment considers both the learning process supported by AI and students' independent performance, linking learning support with ability development.

On this basis, the Analysis–Critical Comparison–Verification–Transfer teaching model is organized as follows. Students first analyze circuit structures and operating conditions independently and form an initial judgment without GenAI. They then use AI explanations and suggestions for comparison and discussion to refine their understanding. Next, they verify conclusions through theoretical calculations, simulations, or experiments and explain discrepancies between expected and observed results. Finally, they apply relevant principles when circuit parameters or operating conditions change. Teachers select suitable circuits, design tasks, and specify AI-use rules; students record key judgments, supporting reasons, and verification results; AI provides explanations, suggestions, and feedback. The assessment combines AI-supported learning outcomes with checks of independent ability.

3.2. Analysis: Preserving Cognitive Engagement through Independent Reasoning

The analysis stage aims to preserve independent thinking and cognitive engagement. Teachers use short tasks based on representative circuits to prompt students to consider circuit structure, operating conditions, and component characteristics, form preliminary judgments of operating states, and explain their reasons. To prevent GenAI from replacing this reasoning, the initial task is completed independently under classroom supervision, either on paper or in an environment that restricts access to generative tools. Teachers use the responses to identify students' prior understanding and common misconceptions. The emphasis is on preserving the reasoning process rather than on the correctness of the initial calculation alone.

3.3. Critical Comparison: Using AI Feedback to Deepen Conceptual Understanding

The critical-comparison stage aims to deepen conceptual understanding and correct misconceptions. Once students have completed their initial analysis, GenAI can be used to provide explanations and analytical suggestions. Students compare these with their own judgments, examine the reasons and conditions underlying different conclusions, and revise their understanding through questioning, discussion, and reflection. To avoid uncritical acceptance of generated answers, teachers ask students to explain why a judgment has changed and check understanding through brief in-class questions or explanations. AI serves as a source of explanation and feedback, not as proof that a student has independently mastered a principle.

3.4. Verification: Connecting Theoretical Reasoning with Practical Evidence

The verification stage focuses on knowledge application and a deeper understanding of circuit principles. Teachers organize theoretical calculation, circuit simulation, or experimental measurement to examine conclusions reached in the preceding stages and explain the relationship between theoretical results and observed phenomena. Verification methods are selected according to instructional objectives and available facilities. GenAI may provide necessary technical support, but students remain responsible for key calculations, judgments, and explanations. Teachers may ask students to state expected results before simulation or measurement and then explain any differences. Assessment emphasizes the ability to interpret evidence using circuit principles rather than the presentation of AI-generated reports or numerous simulation screenshots.

3.5. Transfer: Developing Independent Application of Circuit Knowledge

The transfer stage aims to develop the independent application of knowledge. Teachers change circuit parameters, component connections, or operating conditions to create problems related to the original task and ask students to analyze how operating states change and justify their conclusions. Instruction gradually shifts from AI-assisted practice to independent application. GenAI may be used for support during open practice, but assessment tasks are completed independently under supervision, using paper-based

tests, practical exercises, or oral explanations. The tasks emphasize flexible understanding and application of principles rather than repetition of the original problem or increased computational difficulty.

4. Assessment of Knowledge Internalization

The model adopts a dual-track assessment mechanism combining AI-permitted learning assessment with supervised assessment of independent competence. The first track examines learning activities, task completion, and the quality of analysis and verification. Teachers consider class discussions, analytical notes, and simulation or experimental results to determine whether students have used AI appropriately and checked their conclusions against circuit principles. The second track is conducted after major instructional units. Teachers set related analytical tasks with changed conditions, which students complete within a specified period without GenAI. Formula sheets and conventional calculators may be permitted under uniform rules. Short written tests, in-class analysis, or oral explanations provide direct evidence of independent understanding rather than relying on take-home assignments.

Assessment of knowledge internalization focuses on three aspects: conceptual understanding, operating-state judgment, and knowledge transfer. Students should be able to explain circuit principles and the conditions under which they apply, make justified judgments from circuit structures and operating conditions, and independently use relevant knowledge when parameters or conditions change. Teachers apply common criteria and record AI-assisted learning outcomes separately from supervised independent-assessment results. These records help identify shared misconceptions, guide targeted instruction and practice, and support further improvement of teaching. Formative assessment research provides a basis for using assessment evidence to adjust instruction [18], while research distinguishing perceived learning from demonstrated learning reinforces the importance of observing student performance [19].

Table 1 summarizes the permitted GenAI use, types of learning evidence, and assessment purposes associated with the model.

Table 1. GenAI Use Boundaries and Learning Evidence Across Teaching Activities

Teaching activity	Main learning evidence	GenAI use conditions	Assessment purpose
Initial independent analysis	Preliminary circuit-state judgment and supporting reasoning	Supervised; GenAI not permitted	Diagnostic evidence of prior understanding and independent engagement
AI-assisted critical comparison	Comparison of assumptions and explanation of conceptual revisions	GenAI permitted for explanation, comparison, and counterexamples	Formative evidence of conceptual development, not proof of mastery
Verification	Key calculations, simulation settings, and interpretation of results	Support permitted; important conclusions independently checked	Assessment of reasoning and verification quality
Open practice or projects	Application in modified situations, improvement, and reflection	GenAI permitted; main uses briefly disclosed	Formative evidence of task quality and practice
Supervised independent assessment	Principle explanation, state judgment, and transfer task	No GenAI; permitted tools standardized	Evidence of independent understanding and application

5. Instructional Application: Analysis of an AC Circuit

5.1. Learning Context and Objectives

The teaching model is illustrated through the analysis of a series RLC AC circuit, with the instructional task titled 'Analysis of AC Circuit Operating States.' The topic involves impedance, phase relationships, and resonance. Besides learning calculation methods, students need to understand how circuit parameters relate to operating states. For example, they should be able to judge whether the circuit behaves capacitively or inductively at different frequencies, explain current changes at resonance, and predict the effect of component-parameter changes.

The teaching activities therefore combine independent analysis, AI-assisted critical comparison, theoretical and practical verification, and knowledge transfer. The main objectives are to help students understand circuit behavior, make justified operating-state judgments, and apply relevant principles independently.

5.2. Four-Stage Instructional Tasks

Analysis. The teacher sets tasks involving series RLC circuits at different source frequencies. Students use the relationships between inductive reactance, capacitive reactance, and frequency to judge circuit behavior and trends in current. For example, they explain why the circuit is capacitive below its resonant frequency and inductive above it. Students complete the preliminary analysis independently under supervision, without GenAI. Their responses help the teacher identify prior understanding and misconceptions.

Critical comparison. After the independent analysis, the teacher permits GenAI and asks students to compare their own conclusions with AI-generated explanations. Discussion focuses on common misunderstandings. For example, students examine whether an increase in source frequency necessarily increases current and use resonance conditions to explain why the relationship is not always monotonic. Students revise their reasoning through comparison and questioning, and explain the basis for any changes rather than simply accepting an AI answer.

Verification. Students use theoretical calculation, circuit simulation, or experimental measurement to check their earlier conclusions. For example, Multisim can display the amplitude- and phase-frequency characteristics of a series RLC circuit, allowing students to examine current and phase behavior near resonance and compare the results with theory. Where differences occur, they check circuit parameters, model assumptions, and measurement methods. GenAI may provide supplementary explanations, but students must base their judgments on calculations and simulation or experimental evidence.

Transfer. The teacher changes component parameters or operating conditions and sets a related problem. For example, with the source frequency held constant, students examine whether changing capacitance could make a circuit change from capacitive to inductive behavior and explain their reasons. AI assistance is permitted during open practice, but independent competence is assessed under supervision without GenAI. The teacher examines whether students can analyze the changed conditions rather than repeat a previously learned solution.

5.3. Classroom Organization

Teaching may be organized across theory and laboratory sessions, following a sequence of pre-class preparation, classroom learning, and independent assessment. Before class, students receive materials on impedance, phase, and resonance and may use GenAI for review. In class, the teacher organizes independent analysis, AI-assisted critical comparison, theoretical and practical verification, and transfer activities focused on series RLC circuit behavior. Students first complete a brief supervised judgment task without GenAI. AI is then made available for comparison of explanations, followed by theoretical calculation and Multisim simulation to examine frequency-response characteristics. A physical demonstration may be included where facilities allow. The sequence ends with an independent judgment task involving changed circuit parameters.

Teachers explain AI-use requirements and assessment criteria before instruction and adjust task difficulty to students' learning backgrounds. To make efficient use of class time, independent analysis uses short judgment questions, critical comparison focuses on common misconceptions, and verification examines representative circuit conditions. Independent assessment emphasizes conceptual understanding and knowledge application. The process combines student thinking, appropriate AI support, practical verification, and independent assessment to promote knowledge internalization.

5.4. Learning Evidence and Assessment Design

Following the dual-track mechanism, learning assessment in this example consists of AI-assisted learning assessment and independent-competence assessment. The former focuses on students' analytical work, conceptual understanding, and verification. Teachers use initial circuit judgments, reasons for revised conclusions, calculations, and simulation results to examine learning progress. Records should show essential reasoning and verification; the number of AI interactions, report length, or number of screenshots is not taken as a measure of knowledge mastery.

Independent competence is assessed under supervision through tasks related to classwork but involving changed conditions. For example, students explain differences in circuit behavior on either side of resonance, judge how changes in capacitance affect resonant frequency and operating state, or explain current changes from frequency-response characteristics. GenAI is not permitted during these assessments. Teachers use common criteria to assess independent conceptual explanation, operating-state judgment, and knowledge transfer.

Table 2 presents example criteria for assessing the learning activities and independent performance in this case.

Table 2. Illustrative Learning Evidence and Assessment Criteria for the RLC Case

Assessment dimension	Observable performance	GenAI conditions	Illustrative criterion
Initial independent analysis	Identify the circuit, relevant conditions, and an initial judgment	Supervised; not permitted	A plausible judgment is accompanied by a principle-based reason
Critical comparison and verification	Compare explanations, check calculations, interpret frequency response	Assistance permitted; conclusions verified	Can reproduce a key check and explain why a judgment was revised
Independent explanation	Explain reactance, impedance, phase, and resonance	Supervised; not permitted	States the relevant relationship and its applicable conditions
Independent transfer judgment	Reassess circuit behavior after changing frequency or capacitance	Supervised; not permitted	Judgment fits the changed conditions and is adequately justified
Independent discrepancy analysis	Identify model, parameter, or measurement factors	Supervised; not permitted	Proposes a credible direction for checking the discrepancy

The dimensions in Table 2 are proposed examples for task design. Assessment weights should be determined according to the course syllabus, credit requirements, and laboratory conditions; the illustrative criteria are not measured teaching outcomes. Results from independent assessments and AI-permitted tasks should be recorded separately to distinguish task completion from independent explanation. In subsequent teaching research, comparable baseline, modified-task, and transfer assessments may be used to examine changes in students' performance without GenAI support.

6. Discussion

First, the proposed teaching model builds on previous research on AI-supported instruction. Studies of learning support, virtual and physical laboratories, practical projects, and interactive teaching provide useful ideas for improving students' understanding and application of electrical and electronic knowledge [5–10]. Building on these approaches, this paper focuses on the risk that student reasoning may be weakened when GenAI participates in learning. It connects independent analysis, AI-assisted critical comparison, practical verification, and knowledge transfer with assessment of independent competence, offering an approach that supports both AI-assisted learning and students' own analytical abilities.

Second, implementation should be adapted to the course content and students' prior knowledge. Electrical technology, analog electronics, and digital electronics differ in subject matter but all require understanding and application of fundamental principles. Learning tasks may therefore address circuit operating states, the operating regions of electronic devices, or logic functions, as appropriate. AI support and the choice of calculation, simulation, or experimental verification should reflect instructional objectives and local conditions rather than be applied mechanically.

Finally, implementation should take account of actual teaching environments. Students in different majors vary in prior knowledge, while courses differ in instructional hours and laboratory facilities. Task difficulty, the degree of AI assistance, and verification methods should be adjusted accordingly. Students with weaker foundations may need additional explanation and guidance; courses with limited laboratory facilities can combine theoretical calculation with simulation; and large classes may combine sampled in-class questioning with periodic supervised assessments to balance assessment needs and teaching workload.

7. Conclusion

To address the weakening of independent analysis during GenAI-assisted learning and the difficulty of judging mastery from submitted work, this paper proposes an AI-collaborative teaching model for knowledge internalization based on analysis, critical comparison, verification, and transfer. Independent analysis preserves cognitive engagement; AI-assisted critical comparison deepens understanding of circuit principles; theoretical and practical verification supports knowledge application; and transfer activities develop independent analytical ability. The model also defines appropriate GenAI use across teaching stages and combines AI-permitted learning assessment with supervised assessment of independent competence. It thus provides a practical instructional approach to promoting knowledge internalization and assessing students' independent abilities in electrical and electronic technology courses.

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