JOURNAL OF BALTIC SCIENCE EDUCATION

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

This is an open access article under the Creative Commons Attribution 4.0 International License

EFFECTS OF STEM PROJECT-BASED LEARNING ON ELECTRICITY ACHIEVEMENT, CRITICAL THINKING, AND INTEREST IN RURAL PHYSICS EDUCATION IN P. R. CHINA

Xiangying Xue,
Yuan Li,
Huanjing Wang

Abstract. *STEM-integrated project-based learning (STEM-PjBL) can support science learning, but evidence from under-resourced rural schools in P. R. China remains limited. This study developed a low-cost STEM-integrated project-based learning module on electricity (STEM-E-PjBL, where "E" denotes electricity) and examined its effects on Grade 9 students' electricity achievement, critical thinking skills, and science learning interest. A pragmatist mixed-methods approach was used, combining a quasi-experimental pretest-posttest nonequivalent control-group design with semi-structured interviews. One hundred students from two intact classes in one rural middle school participated. The experimental group (n = 50) completed the six-week STEM-E-PjBL module, whereas the control group (n = 50) received conventional physics lessons. Quantitative data were collected using an electricity achievement test, a critical thinking scale, and a science learning interest questionnaire. Thirty experimental-group students were interviewed and classified as high-, medium-, or low-gain students according to their pretest-posttest gains on the electricity achievement test, enabling differentiated analysis of students' learning experiences. ANCOVA showed significant experimental-group advantages in all three outcomes, with large effect sizes. Interviews indicated that hands-on activities, authentic contexts, and collaborative inquiry supported understanding, reasoning, motivation, and engagement, with different gain groups emphasizing different forms of support and learning value. The STEM-E-PjBL module offers a feasible approach for improving rural students' electricity learning and supporting equitable STEM education.*

Keywords: *critical thinking skills, electricity education, rural education, science learning interest, STEM project-based learning*

Xiangying Xue
Qufu Normal University, P. R. China
Yuan Li
Nanyang Normal University, P. R. China
Huanjing Wang
Qufu Normal University, P. R. China

Introduction

As innovation-driven economies place increasing demands on scientific and technological literacy, a central challenge for contemporary science education is no longer whether STEM (Science, Technology, Engineering, and Mathematics) education should be prioritized, but how its benefits can be equitably realized across unevenly resourced educational contexts (Belbase et al., 2021; Zhan & Niu, 2023). In P. R. China, national policies have increasingly emphasized the cultivation of critical thinking, innovation, and scientific literacy (Liang & Chang, 2022; Xie et al., 2025). However, substantial disparities in educational resources persist, particularly in rural areas of P. R. China (Song, 2023; Ying & Hatta, 2025a). Many rural schools face limited teaching expertise, insufficient experience with digital teaching, inadequate laboratory facilities, and a shortage of high-quality STEM curriculum resources (Li et al., 2025; Rehman et al., 2025). These constraints reduce the quality of science learning and opportunities to rural students and may further reinforce educational inequities between rural and urban schools (Chen, 2024; Murphy, 2020; Zenda, 2024).

Within the Chinese compulsory physics curriculum, electricity is a core content area and a cognitively demanding topic because it involves abstract and highly interrelated concepts such as current, voltage, resistance, and circuit relationships (Li & Singh, 2016; Ministry of Education of the People's Republic of China, 2022; Moodley & Gaigher, 2019). Students are expected to understand invisible and highly interrelated concepts such as electric current, voltage, and resistance (Hermawati, 2022). In many rural middle schools, physics teaching remains largely lecture-based and teacher-centered, reflecting broader examination-oriented classroom practices in P. R. China (Cheng & Chen, 2022; Zhang & Lamb, 2025). Such teaching often prioritizes formula memorization and repetitive problem-solving, while providing

https://doi.org/10.33225/jbse/26.25.739

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

fewer opportunities for authentic application, experimentation, and active student engagement (Amirova, 2025; Hatch & Clark, 2021; Nkanyani et al., 2024). This learning context may lead students to experience low confidence, frustration, and a perception that physics is abstract, monotonous, and weakly connected to everyday life (Tang et al., 2024; Verawati & Nisrina, 2025).

Critical thinking is increasingly regarded as a key twenty-first-century competency and has become an important focus of educational reform in P. R. China (Chen et al., 2024; Xie et al., 2025). In physics education, critical thinking extends beyond conceptual understanding to include evaluating evidence, interpreting experimental findings, and judging alternative explanations (Jamil et al., 2024; Ubaidillah et al., 2023). However, classroom practices that emphasize standard answers and fixed problem-solving procedures may limit students' opportunities to question, justify, and evaluate scientific ideas (Chen et al., 2024; Mendoza-Figueroa et al., 2025). This issue is particularly relevant in rural learning contexts, where students may have fewer opportunities for independent reasoning, open-ended inquiry, and evidence-based discussion (Kurniawan et al., 2023; Shafiyeva, 2021).

In addition to academic achievement and critical thinking, science learning interest is crucial for students' sustained engagement in STEM learning (Amalina et al., 2025; LaForce et al., 2017; Perez et al., 2019). Existing evidence indicates that science learning interest is positively related to classroom participation, depth of learning engagement, and students' intentions to continue with science-related studies and careers (Harefa et al., 2023; Kaleva et al., 2023). However, in many rural middle school contexts, science learning often remains centered on knowledge memorization, partly due to limited experimental opportunities and weak connections between curriculum content and students' everyday experiences (Meng & Jumaat, 2024; Zhao, 2015). Electricity learning may further intensify these difficulties, as abstract concepts and complex calculations can increase cognitive burden, learning anxiety, and declining interest (Firdaus et al., 2025; Pitterson & Streveler, 2016). Prolonged exposure to passive learning environments may therefore weaken students' intrinsic motivation toward science and hinder the development of scientific literacy (Haw et al., 2021; Manzano-León et al., 2022; Owens et al., 2020).

Against this background, project-based learning (PjBL) has been widely recognized as an inquiry-oriented approach with the potential to improve academic achievement, critical thinking, and learning motivation by engaging students in collaborative exploration of authentic and complex problems (Almulla, 2020; Kokotsaki et al., 2016; Spires et al., 2022; Zulkarnaen et al., 2025). The integration of PjBL and STEM education can support student-centered, contextualized, and interdisciplinary learning by helping students relate scientific concepts to practical problem solving (Chistyakov et al., 2023; Diana & Sukma, 2021). Existing international evidence has reported positive effects of STEM-PjBL on achievement and higher-order thinking across diverse student populations (Han et al., 2015).

Despite this growing evidence, several gaps remain. First, most empirical studies of STEM-PjBL have been conducted in well-resourced urban schools or economically developed regions, whereas its effectiveness in under-resourced rural settings remains insufficiently examined (Chen & Lin, 2019; Zhang, 2024). Second, although electricity is a conceptually demanding and curriculum-central topic, relatively few PjBL studies have focused on electricity or energy, and those that have done so have often been situated at the primary level or framed around general energy literacy rather than STEM-integrated electricity modules for ninth-grade students (Karaçallı & Korur, 2014; Karpudewan et al., 2016). Third, academic achievement, critical thinking, and science learning interest have often been examined separately rather than as interrelated outcomes within a coherent intervention (Han et al., 2015; Zhang & Ma, 2023). Fourth, limited evidence is available on how low-cost and readily implementable STEM-PjBL modules can be designed and sustained under conditions of limited equipment, teaching expertise, and curriculum resources, or how such modules influence student outcomes in rural schools (Chen & Lin, 2019; Li et al., 2025; Rehman et al., 2025; Zhang, 2024).

Addressing these gaps is significant both nationally and internationally. Nationally, this study responds to P. R. China's policy commitment to narrowing the urban–rural education gap and localizing STEM education in resource-constrained schools. Internationally, it contributes to discussions on equitable and inquiry-based science education by examining a low-cost and transferable module that may inform comparable under-resourced contexts. Accordingly, this study developed a STEM-integrated project-based learning module on electricity, hereafter referred to as STEM-E-PjBL, with "E" denoting electricity, and examined its effects on rural ninth-grade students' electricity achievement, critical thinking skills, and science learning interest. It also explored students' learning experiences during the module through qualitative inquiry. By integrating cognitive, affective, and experiential dimensions, the study seeks to provide empirical evidence on how STEM-PjBL can be adapted to support meaningful science learning in rural middle school contexts.

https://doi.org/10.33225/jbse/26.25.739

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Literature Review

STEM Education and Project-Based Learning (PjBL)

STEM education is increasingly understood as an integrative educational approach rather than a simple aggregation of science, technology, engineering, and mathematics. Its central value lies in engaging students with complex, authentic problems that require the application of interdisciplinary knowledge (Bybee, 2010; English, 2016). This orientation resonates with the project method influenced by Deweyan educational thought, which emphasized purposeful activity, inquiry, and learning through experience (Kilpatrick, 1918; Peterson, 2012; Zhang et al., 2022). In contemporary STEM education, PjBL is therefore not merely a general student-centered strategy; it becomes particularly meaningful when project tasks require learners to connect conceptual understanding with engineering design, technological tools, mathematical reasoning, collaboration, and evidence-based decision making (Blumenfeld et al., 1991; Nguyen, 2025; Nurhidayah et al., 2021).

Accordingly, combining PjBL with STEM education has been regarded as a useful approach for promoting contextualized and practice-oriented science learning. STEM-PjBL can provide students with opportunities to apply disciplinary knowledge across problem situations, engage in inquiry, and produce meaningful artifacts or solutions (Chistyakov et al., 2023; Santhosh et al., 2023; Simamora, 2024). Research syntheses generally indicate positive associations between STEM-PjBL and students' academic achievement, critical thinking, analytical reasoning, communication, collaboration, and learning engagement (Azzahra et al., 2025; Bell, 2010; Feziyasti et al., 2025; Han et al., 2015; Kokotsaki et al., 2016; Setyawati et al., 2022). However, its effectiveness should not be assumed as automatic. Prior reviews emphasize that outcomes depend on the quality of project design, teacher scaffolding, assessment alignment, available time, and learning resources (Condliffe, 2017; Kokotsaki et al., 2016; Margot & Kettler, 2019). These conditions are especially consequential in rural and resource-constrained schools, where inadequate teacher preparation, limited interdisciplinary curriculum experience, and unequal access to resources may shape the implementation and effects of STEM-PjBL (Haryadi & Pujiastuti, 2022; Margot & Kettler, 2019; Utomo et al., 2025). Thus, the key issue is not whether STEM-PjBL has theoretical value, but under what contextual and pedagogical conditions it can be implemented effectively.

Challenges in Rural Middle School Students' Electricity Learning

Electricity learning in rural middle schools in P. R. China is shaped by the intersection of resource constraints, prevailing classroom practices, and the conceptual complexity of electricity itself (Cheng & Chen, 2022; Hermawati, 2022; Moodley & Gaigher, 2019; Ying & Hatta, 2025b; Zhang & Lamb, 2025; Zhang et al., 2025). Outdated laboratory facilities, insufficient qualified teachers, and limited access to digital learning materials can restrict inquiry-based and experiment-oriented science learning. Yet meaningful inquiry depends on precisely these forms of support, including adequate materials, teacher scaffolding, sufficient time for investigation, and opportunities for students to observe, test, discuss, and construct evidence-based arguments (Furtak et al., 2012; Hermawati, 2022; Hmelo-Silver et al., 2007; National Research Council, 2006; Zhang et al., 2025). When such conditions are weak, electricity lessons may rely heavily on verbal explanation, textbook exercises, and procedural problem solving.

These contextual constraints are compounded by the abstract nature of electricity. Students often struggle to construct coherent explanations of circuit behavior, especially when they must coordinate conceptual models, measurement results, and observable phenomena (Dounas-Frazer et al., 2016; Van De Bogart et al., 2017; Van De Bogart & Stetzer, 2018). Classroom practices that prioritize correct answers and repeated calculation procedures may allow students to apply formulas without developing a deeper understanding of the underlying principles (Abdollahi et al., 2022; Stanger-Hall, 2012; Yaki, 2022). Over time, this mode of learning may weaken students' learning confidence, reduce their willingness to engage in open-ended inquiry, and diminish their intrinsic motivation toward physics learning (Khouna et al., 2025; Rendon et al., 2022).

Improving electricity learning in such contexts therefore requires more than adding isolated activities to existing lessons. These challenges point to the need for structured pedagogical designs that translate abstract concepts into concrete learning experiences, embed circuit principles in authentic problem contexts, and support students in testing, revising, and justifying their ideas (Furtak et al., 2012; Hmelo-Silver et al., 2007; Kokotsaki et al., 2016; National Research Council, 2006). STEM-PjBL is aligned with this need because project- and design-oriented learning can connect circuit concepts with observable functions and practical problem solving (Blumenfeld et al., 1991; Dounas-Frazer et al., 2016; Kokotsaki et al., 2016). For rural schools, however, such modules must be low-cost,

https://doi.org/10.33225/jbse/26.25.739

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

manageable for teachers, and aligned with curriculum requirements. This makes rural electricity learning a suitable context for examining the feasibility and educational value of locally adaptable STEM-PjBL.

Fostering Critical Thinking and Sustained Interest Through STEM-PjBL in Science Learning

STEM-PjBL offers a pedagogical context for fostering critical thinking, as students are required to engage in inquiry, design activities, evidence-based reasoning, and collaborative problem solving (Feziyasti et al., 2025; Furtak et al., 2012; Kokotsaki et al., 2016). In project-based STEM activities, students are expected to identify problems, plan solutions, analyze data, evaluate evidence, refine designs, and justify conclusions. By engaging students in these processes, STEM-PjBL provides repeated opportunities for higher-order cognitive activity, which prior research has linked to the development of students' critical thinking (Nisa, 2025; Setyawati et al., 2022).

Science learning interest should be understood as a multidimensional affective construct rather than a single undifferentiated outcome. Interest research typically distinguishes situational interest, elicited by specific features of a learning activity or environment, from individual interest, a more stable disposition toward a domain (Hidi & Renninger, 2006; Renninger & Hidi, 2016). In science education, hands-on inquiry, real-life relevance, and collaborative problem solving may generate situational interest by making learning activities more meaningful and engaging (Hulleman & Harackiewicz, 2009; Palmer, 2009). Repeated positive experiences may gradually contribute to more sustained interest in science, although short-term interventions are better interpreted as influencing students' learning-related and situationally responsive interest rather than fully developed individual interest. Against this conceptual background, students' science learning interest may be strengthened when scientific concepts are embedded in authentic and contextually meaningful project tasks (Nurhilal et al., 2024). Interest is better understood as a developmental process rather than a fixed learner attribute, shaped by the learning environment, the perceived value of tasks, and students' opportunities for meaningful participation (Hidi & Renninger, 2006; Potvin & Hasni, 2014). Project tasks can connect scientific concepts with observable phenomena, practical challenges, and collaborative artifact construction, thereby stimulating situational interest. When students perceive science learning as useful and connected to real-life problem solving, such interest may develop into more sustained engagement and intrinsic motivation (Harackiewicz et al., 2016; LaForce et al., 2017; Suryaningsih et al., 2022; Wijnia et al., 2024).

In project-based STEM learning, critical thinking and science learning interest may be mutually reinforcing rather than separate outcomes. Collaborative inquiry requires students to evaluate evidence, revise explanations, communicate ideas, and justify solutions; at the same time, meaningful participation and visible project outcomes can strengthen engagement and motivation (Le et al., 2023; Suciana et al., 2023). Taken together, the literature suggests that STEM-PjBL has the potential to support cognitive and affective learning outcomes simultaneously. However, further evidence is needed on how low-cost STEM-PjBL modules can support electricity achievement, critical thinking, and science learning interest in rural middle school contexts in P. R. China. This need provides the basis for the research questions addressed in the present study.

Theoretical Orientation

This study was informed by constructivist learning theory and embodied cognition, which served as sensitizing theoretical perspectives for module design and interpretation rather than as directly measured constructs. Constructivist learning theory views understanding as something learners build through active engagement with problems, materials, peers, and prior knowledge, rather than as information transmitted directly from teacher to student (Piaget, 1970; Vygotsky, 1978; Taber, 2019). In the present study, this perspective informed the design of project tasks that required students to explore electricity problems, discuss alternative solutions, build and test circuits, and revise their ideas through collaborative inquiry.

Embodied cognition further suggests that conceptual understanding is shaped by learners' interaction with physical materials, tools, and situated actions (Barsalou, 2008; Skulmowski & Rey, 2018; Kersting et al., 2021). This perspective is particularly relevant to electricity learning because many electricity concepts, such as current, voltage, resistance, and circuit relationships, are abstract, not directly observable, and commonly associated with persistent student difficulties (McDermott & Shaffer, 1992; Engelhardt & Beichner, 2004; Li & Singh, 2016). Accordingly, the STEM-E-PjBL module incorporated hands-on circuit construction, manipulation of everyday materials, visual representations, and project-based design activities to help students connect abstract electricity principles with concrete experiences.

https://doi.org/10.33225/jbse/26.25.739

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

These two perspectives jointly informed the pedagogical logic of the module. Constructivism supported the use of collaborative inquiry, problem solving, and reflection, whereas embodied cognition supported the use of hands-on manipulation, visualization, and situated project tasks. However, the study did not directly measure constructivist learning processes or embodied cognition mechanisms. Instead, the outcomes focused on electricity achievement, critical thinking skills, and science learning interest, while qualitative interviews were used to explore how students experienced the learning processes embedded in the module.

Research Questions

Given the continuing challenges of low achievement, limited critical thinking, and declining interest in science among rural middle school students, there is a clear need for pedagogical approaches that are both educationally meaningful and feasible in resource-constrained settings. This study developed a STEM-integrated project-based learning module on electricity (STEM-E-PjBL) for rural ninth-grade students and examined its effects on electricity achievement, critical thinking skills, and science learning interest. Beyond assessing these outcomes, the study also investigated students' experiences after the intervention, with attention to whether high-, medium-, and low-achievement-gain students perceived the module in similar or different ways. By focusing on a low-cost and locally adaptable intervention, the study offers empirical evidence and practical insights for implementing STEM-PjBL in rural middle schools in P. R. China and for advancing more equitable STEM education. Specifically, the study addressed the following research questions:

1) How can a STEM-E-PjBL learning module be developed for rural ninth-grade students in a resource-constrained middle school in P. R. China?
2) After controlling for pretest scores, does the STEM-E-PjBL module significantly improve students' electricity achievement, critical thinking skills, and science learning interest?
3) What learning experiences do rural ninth-grade students report after participating in the STEM-E-PjBL electricity module, and how do these experiences vary across high-, medium-, and low-achievement-gain students?

Research Methodology

Design

Within a pragmatist mixed-methods framework, an explanatory sequential design was employed. Quantitative data were collected and analyzed in the initial phase, and qualitative interviews were subsequently conducted to help explain and contextualize the quantitative results. The study was conducted over six weeks during the fall semester at a resource-constrained rural lower-secondary school in P. R. China. It developed and evaluated a STEM-integrated project-based learning module on electricity (STEM-E-PjBL) for ninth-grade students. In the quantitative phase, a quasi-experimental pretest-posttest nonequivalent control-group design was used to assess the effects of the module on students' electricity achievement, critical thinking skills, and science learning interest. The qualitative phase comprised semi-structured interviews, conducted after the intervention with 30 students drawn from the experimental group, which explored students' reported learning experiences and provided contextual interpretation of the quantitative results.

Participants

Using cluster and purposive sampling, the study included two intact ninth-grade classes from the rural school described above. Each was a pre-existing class of 50 students, yielding a total of 100 students who voluntarily participated. The intact classes were retained to preserve authentic classroom conditions and to avoid disrupting the school's normal teaching arrangements. The experimental group included 50 students, with 32 boys and 18 girls, whereas the control group included 50 students, with 29 boys and 21 girls. All participants were between 14 and 16 years old. Most of their parents were ordinary workers, farmers, or self-employed, and the students generally had limited educational support and learning resources at home. Approximately 95% had no prior experience in STEM-related activities or competitions and almost no access to extracurricular STEM tutoring, with their science learning depending mainly on regular school classrooms. The two classes did not differ significantly in age or

https://doi.org/10.33225/jbse/26.25.739

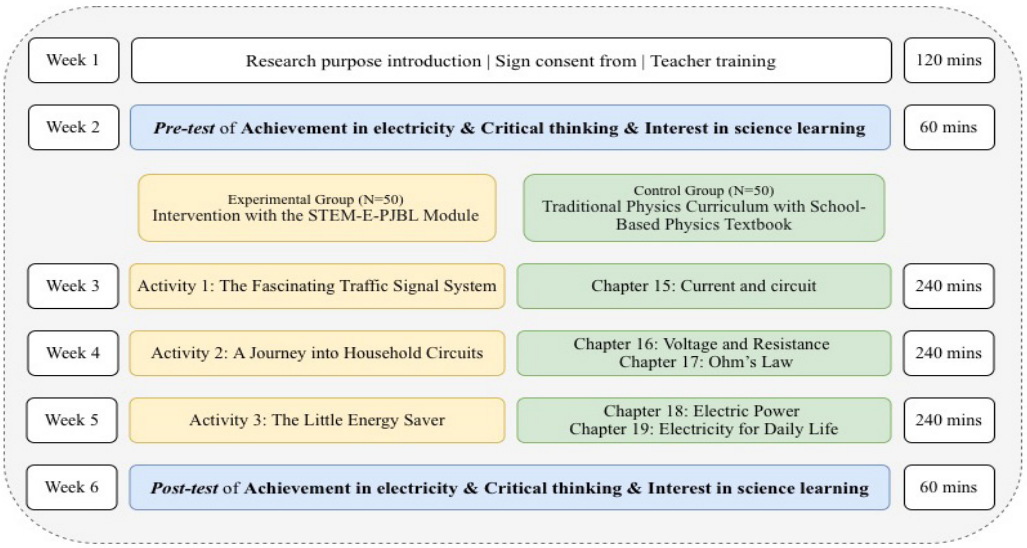
ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

pretest scores, indicating baseline comparability before the intervention. The large effect sizes observed across all three outcomes (η_p^2 = .19–.29) further indicate substantial between-group differences following the intervention.

Intervention Procedure

Figure 1 presents the six-week intervention procedure. During Week 1, the research purpose was introduced to the students, consent forms were collected, and the participating teachers were trained. In Week 2, the pretests of electricity achievement, critical thinking skills, and science learning interest were administered, and students' questions about the study were addressed. From Week 3 to Week 5, three STEM-E-PjBL activities were implemented sequentially in the experimental group, with each activity lasting four hours. During the same period, the control group received conventional physics lessons based on the school's physics textbook and followed the school's regular teaching schedule. The control lessons covered the same electricity topics as the experimental group, including current and circuits, voltage and resistance, Ohm's law, electric power, and electricity in daily life. In these lessons, the teacher mainly explained textbook concepts, demonstrated example problems, guided students through formula application, and assigned textbook exercises. Students primarily listened to teacher explanations, took notes, answered teacher questions, and completed individual practice tasks. Unlike the experimental group, the control group did not engage in STEM-integrated project tasks, group-based product design, hands-on construction, or project presentation activities. In Week 6, the same three measures were re-administered as posttests.

Figure 1
Flowchart of the research procedure



Instruments

The quantitative data were collected using one achievement test and two questionnaires. The Achievement in Electricity Test (AET) was adapted from the China Senior High School Entrance Examination (ZZKST), a standardized and authoritative assessment designed by local educational authorities to evaluate middle school graduates and determine their eligibility for admission to academic upper-secondary schools. Three experienced physics teachers selected 18 test items from the authentic ZZKST papers of the past three years in the local municipality. The final version comprised 27 sub-items, yielding a maximum score of 27 points, and was administered within a 35-minute time limit. In this study, electricity achievement was defined as students' overall performance on the AET. Drawing on distinctions among conceptual knowledge, procedural knowledge, and application in educational assessment and learning research (Anderson & Krathwohl, 2001; Rittle-Johnson & Schneider, 2015), the AET was designed to assess three interrelated aspects of electricity learning: conceptual understanding, procedural

https://doi.org/10.33225/jbse/26.25.739

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

knowledge, and application, as shown in Table 1. Although these aspects were conceptually distinguished in the test design, the present study used the total AET score as an overall indicator of students' integrated mastery of the electricity curriculum.

Table 1
Dimensions of Electricity Achievement Measured by the AET

Dimension	Operational definition	Example content
Conceptual understanding	Understanding key concepts and relationships in electricity	Current, voltage, resistance, series circuits, parallel circuits
Procedural knowledge	Using formulas, circuit rules, and calculation procedures accurately	Ohm's law, circuit calculations, identification of circuit rules
Application	Applying electricity principles to contextualized or practical problems	Home circuits, safe electricity use, energy-saving situations

To further examine the quality of the AET items, item analysis was conducted using students' pretest responses before the main analysis. For each item, difficulty was determined by the proportion of correct responses, and discrimination was estimated through the upper-lower group method. Specifically, students were ranked by their total AET scores, and the upper 27% and lower 27% were compared for each item. The item difficulty indices ranged from .32 to .78, indicating an appropriate range of item difficulty. The item discrimination indices ranged from .24 to .61, suggesting acceptable discrimination among students with different levels of electricity achievement. These results, together with the KR-20 coefficient of .89, provided evidence for the quality of the AET.

The critical thinking questionnaire was developed with reference to Chai et al.'s (2015) instrument, supported by subsequent validation studies (Chiu & Hwang, 2024; Gülen, 2019; Lin et al., 2019). Three experts revised the items to suit the cognitive level of ninth-grade students. The finalized questionnaire contained 14 items, each rated on a 5-point Likert scale. Representative items included "I think about whether what I have learned in this learning activity is correct." Evidence of measurement quality was provided by a scale-level content validity index of .93 and a Cronbach's alpha coefficient of .91, suggesting satisfactory internal consistency.

The science learning interest questionnaire was developed by drawing on the scales of Avery (2013) and Kier et al. (2014), combined with the science-related component of Davidson (2018) for item categorization. In this study, the questionnaire was used to capture students' learning-related interest in science, including their enjoyment of science activities, perceived relevance of science to everyday life, engagement in science tasks, and intention to continue science-related learning. Consistent with the conceptual distinction outlined in the literature review, the measure reflected students' affective responses to science learning after the module rather than a long-term assessment of stable individual interest. The finalized scale contained 14 items rated on a 5-point Likert scale, with evidence of strong content validity (S-CVI = .93) and good internal consistency (Cronbach's alpha = .93).

Semi-structured interviews provided qualitative evidence to contextualize the quantitative results and examine students' perceived changes in electricity learning, critical thinking, and science learning interest, together with their experiences of the STEM-E-PjBL module. To establish the quality of the interview protocol, two experts and one experienced physics teacher reviewed the draft in terms of clarity, relevance, coverage, and consistency with the research objectives. Five students then participated in a pilot interview to examine the comprehensibility of the questions. Revisions were made based on their feedback, resulting in a final protocol consisting of four sections and six questions. Each interview lasted approximately 20 minutes. After the intervention, 30 students from the experimental group (n = 50) took part in semi-structured interviews on a voluntary basis. The interviewees spanned a range of attainment, comprising high-, medium-, and low-gain students in roughly balanced proportions, as defined by their score gains from pretest to posttest on the Achievement in Electricity Test (AET), and included both boys and girls. The sample therefore represented students with different levels of improvement, providing more targeted interpretive support for the quantitative findings. Table 2 presents the interview guide.

https://doi.org/10.33225/jbse/26.25.739

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Table 2
Semi-structured Interview Protocol

Part	Topic	Guiding Questions
Part A	Electricity Learning Outcomes	Do you think this learning module helped you understand electricity concepts? Please explain in detail. Which activity best helped you learn electricity knowledge? Please explain why.
Part B	Critical Thinking	Compared with your regular classroom, did these activities require you to think more deeply? In what specific aspects? Do you think this learning module helped improve your thinking or reasoning skills? Please provide a concrete example.
Part C	Science Learning Interest	Did this learning module increase your interest in learning science? Please explain.
Part D	STEM-E-PjBL Experience	What are your feelings about using the STEM-E-PjBL learning module to learn electricity?

Data Analysis

Quantitative data from the electricity achievement test, critical thinking scale, and science learning interest questionnaire were analyzed using IBM SPSS Statistics. Before the main analysis, the distributions of the variables were checked through skewness and kurtosis values, which suggested no serious departure from normality. Descriptive statistics were then used to summarize students' pretest and posttest scores. To compare the two groups after the intervention, ANCOVA was conducted for each outcome variable, with the corresponding pretest score included as the covariate. This adjustment was made because the study used intact classes rather than random assignment. The assumptions for ANCOVA were checked before analysis, including normality, equal variances, and homogeneity of regression slopes. Effect sizes were reported as partial eta squared (η_p^2) for each outcome.

Qualitative interview data were examined using thematic analysis (Braun & Clarke, 2006).The analysis proceeded in three steps: (a) an initial coding framework was established on the basis of the core dependent variables from the quantitative phase; (b) two educational researchers independently conducted open coding and then inductively categorized and synthesized recurring views and experiences in students' responses into thematic codes; and (c) the frequency of each theme was calculated to identify students' predominant perceptions and shared experiences. Inter-rater agreement was .85 (Huberman & Miles, 2002), and coding disagreements were resolved by a third researcher. Theme frequencies were also compared across the high-, medium-, and low-gain groups to examine whether students with different levels of achievement gain reported similar or different learning experiences.

Ethical Considerations

Prior to implementation, this study obtained the necessary ethical approval and institutional permission from the participating school. The researchers explained the research purpose and implementation procedures to the school principal, teachers, students, and their guardians. The study was conducted only after guardians had signed informed consent forms. All participants joined the study voluntarily and retained the right to withdraw at any stage without any negative consequences. All data were anonymized throughout the research process, and participant confidentiality was carefully maintained. As a token of appreciation, students who completed all study activities received a lunch voucher provided by the school.

Development of the STEM-E-PjBL Module

Previous research has indicated that learning modules, as supportive learning resources, can facilitate students' understanding and development of specific knowledge content and related skills (Arifin & Siew, 2023; Jacobson et al., 2006; Lumbantoruan et al., 2024). This study selected the school-based physics textbook for ninth grade in central China and developed the STEM-E-PjBL module based on the revised ADDIE model (Allen, 2006).

https://doi.org/10.33225/jbse/26.25.739

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Analysis Phase

At the initial stage, semi-structured interviews were conducted with rural middle school physics teachers and students to identify key challenges in electricity teaching. These challenges included the abstract nature of electricity concepts, limited opportunities for developing critical thinking in classroom learning, and low levels of student learning interest. Concurrently, the interview results revealed that a shortage of teaching resources and inadequate experimental materials were significant practical constraints for implementing STEM teaching in rural schools. Therefore, "low-cost and easy-to-implement" was established as a key design principle for module development to enhance feasibility and applicability in rural educational contexts.

Design Phase

Based on the identified learning needs and classroom constraints, this study designed three project themes closely related to real-life contexts around the core electricity content of the ninth-grade curriculum: "The Fascinating Traffic Signal System" (basic circuit principles), "A Journey into Household Circuits" (home circuits and safe electricity use), and "The Little Energy Saver" (Ohm's law and energy efficiency). The three projects were grounded in authentic contextual problems and combined scientific knowledge with engineering practices, with the aim of improving students' application of electricity concepts and increasing their learning engagement.

In line with the theoretical orientation of the study, the module design translated constructivist principles into collaborative inquiry, problem solving, peer discussion, and reflection activities. Embodied cognition was reflected in hands-on circuit construction, visual representations, and the use of concrete materials to support students' understanding of abstract electricity concepts. In this way, the project tasks were designed not only to cover curriculum content but also to create learning opportunities through which students could construct, test, revise, and apply their understanding in situated contexts.

To ensure alignment between learning activities and curriculum standards, the researchers systematically planned each activity in the STEM-E-PjBL module based on the electricity learning objectives of the school-based textbook. In designing these learning activities, the researchers also considered the three aspects of electricity learning assessed by the AET, namely conceptual understanding, procedural knowledge, and application, so that the module activities and outcome assessment were aligned. As shown in Table 3, the objectives for each activity were organized in line with the revised Bloom's taxonomy, beginning with understanding and gradually extending to applying, analyzing, evaluating, and creating. This progression was intended to support students in building foundational knowledge while gradually strengthening their critical thinking and problem-solving skills (Adams, 2015; Marta et al., 2024). Additionally, during the project design process, the researchers considered the resource conditions of rural schools, prioritizing learning tasks that could be accomplished with everyday materials to reduce implementation costs and improve classroom operability. The development of the STEM-E-PjBL module integrated the four disciplinary domains of STEM education, ensuring interdisciplinary integration across activities, as shown in Table 4.

Table 3
Learning Objectives of Each STEM-E-PjBL Activity Mapped to Textbook Content and Bloom's Cognitive Domain

Activity	Electricity Content of the Textbook	Learning Objectives	Bloom's Cognitive Domain
The Fascinating Traffic Signal System	Current, resistance, series and parallel circuits	Identify and explain the roles of current and resistance in series and parallel circuits	Understand
		Construct a functional traffic signal circuit model using basic components	Apply / Create
		Analyze and compare alternative circuit designs for efficiency and reliability	Analyze / Evaluate
		Reflect on the relevance of traffic signal systems to real-life safety applications	Evaluate
A Journey into Household Circuits	Household electricity, switches, fuses, grounding, safety rules	Describe the basic components of a household circuit (live wire, neutral wire, ground wire)	Understand
		Simulate household circuit connections and detect potential safety hazards	Apply / Analyze
		Propose and justify improved safety measures for household wiring	Evaluate / Create
		Reflect on the significance of safe electricity use in everyday life	Evaluate

https://doi.org/10.33225/jbse/26.25.739

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Activity	Electricity Content of the Textbook	Learning Objectives	Bloom's Cognitive Domain
The Little Energy Saver	Ohm's law, electrical power, efficiency, energy conservation	Apply Ohm's law to determine the relationships among current, voltage, and resistance	Apply
		Design and test a multi-mode energy-saving lamp with adjustable power levels	Create / Apply
		Compare and evaluate the energy efficiency of different design alternatives	Analyze / Evaluate
		Reflect on the implications of energy conservation for sustainable development	Evaluate

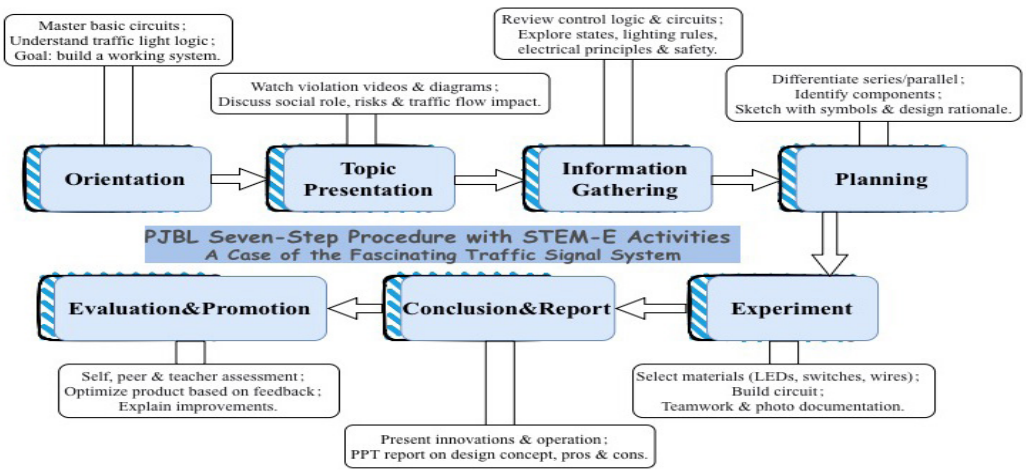
Table 4
Overview of STEM Knowledge Integration in the Three Activities

Activity	Science	Technology	Engineering	Mathematics
The Fascinating Traffic Signal System	Concepts of electric current, resistance, series and parallel circuits	Use of electrical components (LEDs, switches, resistors, wires)	Design and construct a traffic signal model under constraints of time, materials, and functionality	Apply Ohm's law qualitatively; calculate current/voltage in simple series-parallel circuits
A Journey into Household Circuits	Household electricity, fuses, grounding, safety rules	Use of wiring, switches, fuses, circuit breakers	Plan and simulate a household circuit model that prioritizes safety and reliability within a scaled model	Apply formulas for power and current; analyze load distribution in household circuits
The Little Energy Saver	Ohm's law, electrical power, energy conservation	Use of variable resistors, lamps, and switches to regulate power	Design and test a multi-mode energy-saving lamp with efficiency as the optimization goal	Apply Ohm's law quantitatively; calculate electrical power and energy consumption under different resistance settings

Development Phase

The STEM-E-PjBL module was designed based on the project-based learning (PjBL) model proposed by Boondee et al. (2011). The model comprises seven steps: orientation, project theme presentation, information gathering, planning, experimentation, conclusion and reporting, and evaluation and dissemination. The three thematic activities within the module were all implemented strictly following the above procedure, guiding students through an iterative project-based learning process that involved sustained problem exploration, solution design, and outcome refinement. An example of the PjBL design for "The Fascinating Traffic Signal System" activity is illustrated in Figure 2.

Figure 2
Integration of PjBL with STEM-E in the "Fascinating Traffic Signal System" Activity



https://doi.org/10.33225/jbse/26.25.739

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Considering the limited experimental resources in rural schools, this study emphasized low cost and easy accessibility in material selection. All experimental activities employed common and inexpensive materials, such as batteries, wires, small bulbs, switches, resistors, and cardboard boxes, ensuring that schools could conduct the relevant teaching activities without relying on expensive equipment. Concurrently, the research team developed a student learning manual and a teacher guide to support teaching consistency and operational standardization in classroom implementation. Selected examples of module activities are shown in Figure 3.

Figure 3
Sample Content Excerpts from the STEM-E-PjBL Module

Implementation Phase

Before the intervention, the participating teachers received a short structured training session on the STEM-E-PjBL approach and its classroom procedures. During the six-week module, which was integrated into the regular school timetable, students in the experimental group worked in groups of five and progressed through problem exploration, solution design, model construction, testing, and refinement. Across the three project activities, students applied core electricity concepts such as series and parallel circuits, switches, conductors, and power sources to authentic contexts, producing functional artifacts such as a sequenced traffic-light model, a household lighting circuit, and an energy-saving device (Figure 4). Each group then presented its work publicly, consolidating and reflecting on what they had learned and thereby strengthening their understanding of electricity concepts and engineering practices.

https://doi.org/10.33225/jbse/26.25.739

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Figure 4
Representative student-designed projects during STEM-E-PjBL implementation

Evaluation Phase

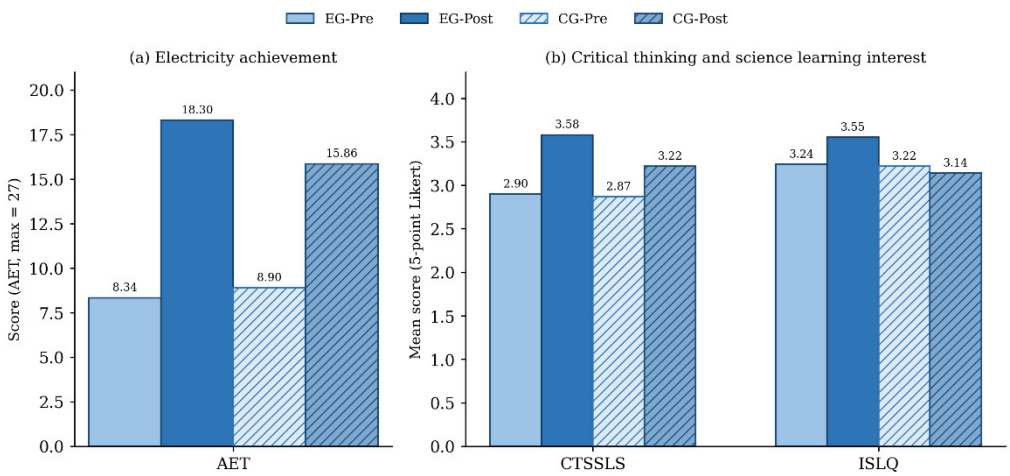
An evaluation framework was developed to examine how the STEM-E-PjBL module influenced students' learning outcomes and learning experiences. The evaluation content consisted of two main components: dependent variable measurement and project work assessment. For dependent variables, changes in students' electricity achievement, critical thinking skills, and science learning interest were examined through pretest and posttest measures. In addition, students were required to present their final project outcomes in groups and engage in inter-group oral peer assessment covering aspects such as design rationality, functionality, and presentation quality. This component was used for formative feedback rather than formal scoring.

Research Results

Quantitative Data Analysis Results

Descriptive statistics were first calculated for the pretest and posttest scores of both the experimental group (EG) and the control group (CG). Figure 5 shows the pretest and posttest mean scores of the two groups on the Achievement in Electricity Test (AET), the Critical Thinking Skills in Science Learning Scale (CTSSLS), and the Interest in Science Learning Questionnaire (ISLQ).

Figure 5
Pretest and posttest means of EG and CG on the AET, CTSSLS, and ISLQ



https://doi.org/10.33225/jbse/26.25.739

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

As shown in Table 5, the two groups showed similar pretest AET scores, although the experimental group scored slightly lower than the control group. Both groups improved at posttest, but the gain was substantially larger for the experimental group (M = 18.30, SD = 3.04) than for the control group (M = 15.86, SD = 2.81).

Table 5
Descriptive Statistics on AET, CTSSLS and ISLQ in the EG and the CG

Measure	EG				CG			
	Pre-test		Post-test		Pre-test		Post-test	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
AET	8.34	2.44	18.30	3.04	8.90	2.56	15.86	2.81
CTSSLS	2.90	0.27	3.58	0.38	2.87	0.33	3.22	0.48
ISLQ	3.24	0.29	3.55	0.39	3.22	0.27	3.14	0.35

Note. AET = Achievement in Electricity Test, CTSSLS = Critical Thinking Skills in Science Learning Scale, ISLQ = Interest in Science Learning Questionnaire, EG = experimental group, CG = control group.

A similar pattern emerged on the CTSSLS, where the groups started from comparable pretest levels. Both improved at posttest, yet the experimental group gained more (M = 3.58, SD = 0.38) than the control group (M = 3.22, SD = 0.48).

The two groups had highly similar ISLQ pretest scores, with only a minimal difference between them. Following the intervention, the experimental group showed an increase in science learning interest (M = 3.55, SD = 0.39), whereas the control group exhibited a slight decrease in posttest scores (M = 3.14, SD = 0.35).

To evaluate the effects of the STEM-E-PjBL module on electricity achievement, critical thinking skills, and science learning interest, ANCOVA was used to compare posttest scores between the experimental group (EG) and control group (CG), with the corresponding pretest scores entered as covariates. The posttest scores on the AET, CTSSLS, and ISLQ served as the dependent variables.

Before conducting ANCOVA, the relevant assumptions were checked. The Kolmogorov-Smirnov test showed no significant departure from normality for any variable ($p > .05$), and Levene's test supported the assumption of equal variances. The group-by-covariate interaction was also non-significant, indicating that the relationship between the covariate and the dependent variable was comparable across groups. These results suggested that the assumptions for ANCOVA were met.

Table 6 shows that, after pretest scores were controlled, students in the experimental group achieved significantly higher electricity achievement scores than those in the control group, $F(1, 97) = 38.68$, $p < .001$, $\eta_p^2 = .285$. For critical thinking skills, the experimental group also obtained significantly higher scores than the control group, $F(1, 97) = 22.66$, $p < .001$, $\eta_p^2 = .189$. The same pattern was found for science learning interest, with the experimental group again scoring significantly higher than the control group, $F(1, 97) = 36.20$, $p < .001$, $\eta_p^2 = .272$.

Across the three outcomes, the η_p^2 values (.285, .189, and .272) indicate large effects (Cohen, 2013), suggesting that the STEM-E-PjBL module had substantial effects on students' electricity achievement, critical thinking skills, and science learning interest.

Table 6
ANCOVA Results for the AET, CTSSLS, and ISLQ

Measure	Group	*F*	*p*	η^2
AET	EG CG	38.676	< .001	.285
CTSSLS	EG CG	22.658	< .001	.189
ISLQ	EG CG	36.202	< .001	.272

https://doi.org/10.33225/jbse/26.25.739

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Qualitative Data Analysis Results

Through thematic analysis, several core themes were identified. Table 7 presents the themes, codes, overall coding frequencies, and their distribution across high-, medium-, and low-gain students. To provide a more differentiated interpretation of students' learning experiences, achievement gain was calculated for all 50 students in the experimental group by subtracting each student's pretest score from the posttest score on the Achievement in Electricity Test (AET). The 50 gain scores were then ranked and divided into three approximately equal gain-level intervals. Because the interviews had been conducted on a voluntary basis, the 30 interviewees were not evenly distributed across these intervals. Based on their AET gain scores, the interviewees were classified as high-gain students (n = 13), medium-gain students (n = 9), and low-gain students (n = 8). Percentages in Table 7 were calculated within each gain group.

Table 7
Summary of Qualitative Coding Results from Student Interviews

Research focus	Codes generated from students' responses	Overall (n = 30)	High-gain n (%)	Medium-gain n (%)	Low-gain n (%)
Electricity achievement	Improved understanding of circuit concepts	24	9 (69.2)	8 (88.9)	7 (87.5)
	Better understanding through hands-on experiments	21	7 (53.8)	8 (88.9)	6 (75.0)
	Visual learning helped comprehension	15	4 (30.8)	4 (44.4)	7 (87.5)
	Group discussion facilitated learning	13	4 (30.8)	5 (55.6)	4 (50.0)
Critical thinking	Required deeper thinking than traditional classes	25	12 (92.3)	7 (77.8)	6 (75.0)
	Improved problem-solving ability	22	11 (84.6)	7 (77.8)	4 (50.0)
	Increased reasoning during circuit design	19	8 (61.5)	6 (66.7)	5 (62.5)
	Encouraged analysis and troubleshooting	17	7 (53.8)	7 (77.8)	3 (37.5)
	Developed collaborative thinking	14	6 (46.2)	3 (33.3)	5 (62.5)
Science learning interest	Increased interest in science learning	26	13 (100.0)	8 (88.9)	5 (62.5)
	Real-life applications increased motivation	20	9 (69.2)	6 (66.7)	5 (62.5)
	STEM projects made learning more engaging	18	7 (53.8)	8 (88.9)	3 (37.5)
	Interest in future science learning increased	13	5 (38.5)	4 (44.4)	4 (50.0)
STEM-E-PjBL experience	Module was more interactive than traditional lessons	24	11 (84.6)	8 (88.9)	5 (62.5)
	Preferred collaborative learning environment	20	8 (61.5)	7 (77.8)	5 (62.5)
	Felt more confident in learning electricity	18	7 (53.8)	5 (55.6)	6 (75.0)
	Activities were challenging but meaningful	15	4 (30.8)	4 (44.4)	7 (87.5)
	Some activities required more time and guidance	7	2 (15.4)	3 (33.3)	2 (25.0)

Overall, students' experiences with the STEM-E-PjBL module were predominantly positive, with "increased interest in science learning" being the most frequently occurring theme. The subgroup distribution further suggested that students with different levels of achievement gain shared several common experiences but also emphasized different aspects of the module. For example, all high-gain students referred to increased interest in science learning, 13 out of 13 (100.0%), compared with 8 out of 9 medium-gain students (88.9%) and 5 out of 8 low-gain students (62.5%). Similarly, the code "required deeper thinking than traditional classes" appeared frequently across all three groups, but was most prominent among high-gain students, 12 out of 13 (92.3%). By contrast, codes related to visual and concrete learning appeared particularly salient among low-gain students; for instance, "visual learning helped comprehension" was mentioned by 7 out of 8 low-gain students (87.5%), compared with 4 out of 13 high-gain students (30.8%) and 4 out of 9 medium-gain students (44.4%). A similar pattern was found for "activities were challenging but meaningful," which was reported by 7 out of 8 low-gain students (87.5%). These patterns suggest that high-gain students tended to emphasize interest, deeper thinking, and problem solving, whereas low-gain students more often highlighted the value of visualization, hands-on support, and meaningful challenge.

https://doi.org/10.33225/jbse/26.25.739

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Regarding electricity achievement, most students reported that the STEM-E-PjBL module helped them understand abstract electricity concepts. Through designing the traffic signal system and constructing circuits, students were able to relate theoretical knowledge to real-world situations. Many students noted that hands-on practice and group collaboration significantly enhanced their understanding of series circuits, parallel circuits, and the principles of current flow. This was reflected in the relatively high frequency of "improved understanding of circuit concepts" across all three groups: 9 high-gain students (69.2%), 8 medium-gain students (88.9%), and 7 low-gain students (87.5%). One student remarked:

> *"Previously, I just memorized formulas when learning circuits, but after building the traffic light circuit myself, I truly understood the difference between series and parallel connections." (S3)*

At the same time, a few students indicated that they still encountered difficulties with certain complex circuit connections and required additional guidance from the teacher. This need for support was especially relevant for lower-gain students, among whom visual learning and meaningful challenge were more frequently emphasized.

Concerning critical thinking skills, most students believed that the STEM-E-PjBL module placed greater emphasis on thinking and problem-solving compared to traditional classrooms. Throughout the project implementation, students continuously analyzed problems, discussed solutions, and conducted testing and adjustments, which fostered their reasoning and reflective abilities. The code "improved problem-solving ability" was reported by 11 high-gain students (84.6%), 7 medium-gain students (77.8%), and 4 low-gain students (50.0%), suggesting that perceived gains in problem solving were especially strong among students with higher achievement gains. Students commented:

> *"In previous classes, we mainly listened to the teacher. This time, we had to think for ourselves about why the circuit failed and discuss how to fix it." (S12)*
>
> *"When the traffic light did not work properly, we needed to check the problem step by step, which taught me how to analyze and reason." (S5)*

Additionally, several students acknowledged that the discussion process within group collaboration helped them consider problems from different perspectives, further strengthening their critical thinking development.

In terms of science learning interest, most students indicated that the module strengthened their interest in science and encouraged more active engagement in learning. Compared with traditional lecture-based teaching, students generally perceived the STEM-E-PjBL module as more interesting and engaging, particularly because of its hands-on activities, real-world problem contexts, and collaborative learning format. The subgroup results indicated that increased interest was especially strong among high- and medium-gain students but was also evident among low-gain students. Students stated:

> *"I used to find science class rather dull, but building the traffic light project was very enjoyable, and I was more willing to participate in class activities." (S29)*
>
> *"Through hands-on making and experimentation, I realized that science is not just about content in textbooks; it is related to real life." (S18)*

Furthermore, some students indicated that the module made them more willing to pursue further science-related learning. The code "interest in future science learning increased" was reported by 5 high-gain students (38.5%), 4 medium-gain students (44.4%), and 4 low-gain students (50.0%), indicating that this forward-looking interest was not limited to the highest-gain group.

In general, most students responded positively to the STEM-E-PjBL module and described it as providing a more interactive, open-ended, and challenging learning experience. Students generally believed that group collaboration, problem-based inquiry, and project practice made the classroom more dynamic and enhanced their sense of engagement. For example, "module was more interactive than traditional lessons" was reported by 11 high-gain students (84.6%), 8 medium-gain students (88.9%), and 5 low-gain students (62.5%). Students noted:

> *"This learning approach is very different from before. We not only had to learn knowledge but also work together to solve problems." (S6)*

https://doi.org/10.33225/jbse/26.25.739

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

"Although some tasks were quite difficult, I felt a strong sense of achievement after completing them." (S17)

Meanwhile, a few students considered that some activities were time-consuming and required more teacher guidance and support during the experimental procedures. Overall, the qualitative findings suggest that the STEM-E-PjBL module enhanced students' learning experiences and classroom participation across all three gain groups, while also indicating that students with lower gains may benefit from more explicit scaffolding, visual support, and sufficient time for experimentation.

Discussion

This study integrated STEM education with electricity content to develop a STEM-E-PjBL module for rural ninth-grade students in P. R. China and examined its effects on their electricity achievement, critical thinking skills, and science learning interest. Compared with students who received conventional physics lessons, those in the experimental group demonstrated significantly greater improvement across all three outcomes, with large effect sizes. Although evidence for STEM-PjBL has so far been generated mainly in well-resourced settings (Çavuş et al., 2026; Pasaribu et al., 2025; Salmah et al., 2025), the present findings indicate that it can also promote science learning and higher-order thinking in under-resourced rural Chinese schools.

For electricity achievement, the experimental group scored significantly higher than the control group, indicating that the module supported students' understanding and application of electricity concepts. This result is consistent with evidence that combining STEM education with project-based learning enhances science learning through practical inquiry and authentic problem contexts (Chistyakov et al., 2023; Safitri, 2024). A plausible explanation is that STEM-based activities strengthen knowledge construction and conceptual understanding, while the project structure promotes knowledge transfer and engagement (Diana & Sukma, 2021; Zulkarnaen et al., 2025). The present study extends this evidence to rural students with limited learning resources (Kurt & Akoğlu, 2023), for whom a contextualized, design-oriented approach appears to provide richer learning experiences than conventional lessons.

A similar pattern was found for critical thinking. The greater improvement in the experimental group suggests that the module fostered students' analytical, reasoning, and problem-solving abilities. This finding corroborates research indicating that the inquiry, collaboration, and reflection emphasized in project-based learning, combined with the interdisciplinary integration emphasized in STEM education, jointly support higher-order thinking and decision-making in authentic contexts (Affandy et al., 2024; Auliyani et al., 2025; Le et al., 2023; Simamora, 2024). Interpreted through the theoretical orientation of this study, these gains may be partly associated with the combination of constructivist and embodied learning opportunities embedded in the module. Collaborative inquiry, peer discussion, and iterative problem solving encouraged students to actively construct and revise their understanding, while hands-on circuit construction and the manipulation of concrete materials made abstract electricity concepts more visible, tangible, and experientially accessible (Almulla, 2023; Hidayatullah, 2024; Zhou & Qu, 2024). In this sense, the module appeared to support critical thinking not only by increasing students' exposure to inquiry-based tasks, but also by creating conditions in which students could test ideas, evaluate evidence, troubleshoot problems, and justify their solutions in situated learning contexts.

Science learning interest also differed significantly between groups, with students in the experimental group reporting higher levels of interest than those in the control group. This is consistent with evidence that STEM education and project-based learning strengthen students' identification with science through collaborative inquiry, hands-on activities, and authentic contexts (Duo & Ishak, 2024; Mims et al., 2025). Student-centered approaches tend to promote more active participation and engagement than lecture-based teaching (Bhardwaj et al., 2025; Mat & Jamaludin, 2024). For rural students, open and interactive learning environments may contribute to more positive science-related attitudes and stronger willingness to continue learning science (Chen & Lin, 2019; Cheng & Yang, 2023). The experimental group's interest increased, whereas the control group's declined slightly. This contrast can be interpreted in relation to the distinction between situational and individual interest. The gain observed in the experimental group likely reflects students' strengthened learning-related and situationally responsive interest during the intervention, as the module provided hands-on tasks, real-life relevance, and collaborative problem-solving opportunities that made science learning more meaningful and engaging. By contrast, the slight decline in the control group is consistent with the well-documented decrease

https://doi.org/10.33225/jbse/26.25.739

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

of science interest under conventional, examination-oriented conditions (Potvin & Hasni, 2014). Thus, the findings suggest that the STEM-E-PjBL module helped sustain and enhance students' science learning interest over the study period by creating a more active, authentic, and participatory learning environment.

The interview data substantiate and help explain these quantitative patterns. Most students perceived the module as more interesting and interactive than conventional classes and reported that it helped them understand electricity concepts more deeply. Many also noted that it demanded more thinking and collaborative discussion, which they felt strengthened their analysis and reasoning, and that the hands-on activities and authentic contexts heightened their interest and sense of engagement. The subgroup analysis further adds nuance to these findings. High-gain students particularly emphasized increased science learning interest, deeper thinking, and improved problem solving, suggesting that students who achieved greater academic improvement may have benefited from the module's cognitive demands and open-ended inquiry opportunities. Medium-gain students also reported strong benefits from hands-on experimentation, interactivity, and collaborative learning, indicating that the module was broadly accessible rather than effective only for the highest-gaining students. Low-gain students, while showing less emphasis on problem-solving gains, more frequently valued visual learning, concrete manipulation, and meaningful challenge, suggesting that the module offered important forms of learning support for students who may have struggled with abstract electricity concepts. These differentiated perceptions indicate that STEM-E-PjBL may support students through multiple pathways: by deepening reasoning for higher-gain students, sustaining engagement for medium-gain students, and making abstract concepts more visible and manageable for lower-gain students.

Overall, the qualitative findings suggest that the module supported not only students' academic achievement but also the development of higher-order thinking and more positive attitudes toward science learning. More importantly, the comparison across high-, medium-, and low-gain students indicates that students' experiences of the module were not uniform. Rather, the module appeared to offer different forms of value for different types of learners, further supporting the suitability of STEM-E-PjBL as a flexible and inclusive pedagogical approach for resource-constrained rural classrooms.

Conclusion and Implications

This study developed and evaluated a low-cost, locally adaptable STEM-E-PjBL module on electricity for rural ninth-grade students in P. R. China. In this quasi-experimental study, after controlling for pretest scores, students in the experimental group showed significantly higher adjusted posttest scores than those in the control group on electricity achievement, critical thinking skills, and science learning interest, with large effect sizes. The qualitative findings further supported these results by showing that students perceived the module as more engaging, interactive, and cognitively demanding than conventional teaching. The comparison across high-, medium-, and low-gain students also suggested that the module supported different learners in different ways: higher-gain students tended to emphasize deeper thinking and interest, whereas lower-gain students particularly valued visual support, hands-on learning, and meaningful challenge.

Collectively, these findings offer several theoretical and practical implications. Theoretically, the study supports constructivist learning theory and embodied cognition as useful perspectives for designing and interpreting rural electricity-focused STEM-PjBL. By engaging students with authentic problems, peers, materials, circuits, and visual representations, the module helped students approach abstract electricity concepts through active construction and concrete experience rather than mainly through formula memorization. Practically, the findings suggest that rural STEM innovation need not rely on expensive laboratories or advanced digital equipment. Low-cost materials, structured project tasks, visual scaffolding, and collaborative inquiry can create accessible opportunities for meaningful electricity learning in resource-constrained classrooms. The differentiated responses of high-, medium-, and low-gain students further suggest that teachers should provide flexible scaffolding, including deeper reasoning opportunities for some learners and more concrete manipulation, visual guidance, and staged support for others.

Limitations and Future Research

Certain limitations should be acknowledged. First, the study was conducted with two intact classes from one rural school in a single region of central China, which limits the external validity of the findings. Although the school was selected because it reflected the resource constraints commonly faced by many rural schools,

https://doi.org/10.33225/jbse/26.25.739

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

this context-specific design means that the findings cannot be assumed to generalize to other rural contexts in P. R. China or to rural schools internationally. Future research should therefore include multiple rural schools across different regions, socioeconomic contexts, and school types to examine the transferability and robustness of the STEM-E-PjBL module. Second, the intervention lasted only six weeks, which limits conclusions about the sustainability of the observed gains. The present study can show short-term improvements in electricity achievement, critical thinking skills, and science learning interest, but it cannot determine whether these effects are maintained over time or whether longer participation in STEM-E-PjBL would support the development of more complex STEM competencies, such as sustained engineering design thinking, interdisciplinary problem solving, and long-term scientific inquiry practices. Longitudinal and follow-up studies are therefore needed to examine the durability and developmental trajectory of these outcomes. Finally, the interviewees participated voluntarily, which may have introduced self-selection bias, as students who were more willing to be interviewed may have differed from their peers in engagement, confidence, or attitudes.

Future research should pay closer attention to how low-cost STEM-PjBL modules can be translated into regular rural classroom practice. This includes examining how teachers adapt project tasks to different school conditions, how teacher professional development can support effective implementation, and what forms of classroom scaffolding are most useful for students with different learning profiles. In particular, further studies could explore how visual guidance, staged task support, peer collaboration, and differentiated questioning help lower-gain learners engage more productively with abstract electricity concepts. Such work would clarify not only whether STEM-PjBL is effective, but also how it can be implemented, supported, and scaled in ways that contribute to more equitable rural science education.

Acknowledgements

The cooperation of the participating students and teachers is gratefully acknowledged.

Ethical Approval

This study was approved by the Human Research Ethics Committee, Universiti Sains Malaysia (USM/JEPeM/PP/26010132). Signed parental consent was obtained for all participants.

Declaration of Interests

The authors declared no conflicts of interests.

References

Abdollahi, M., Darbani, S., & Parsakia, K. (2022). Structural equations the effect of logical-critical thinking style with academic achievement with the mediating role of action control in high school students. *Journal of Assessment and Research in Applied Counseling, 4*(3), 64–78. https://doi.org/10.52547/jarac.4.4.64

Adams, N. (2015). Bloom's taxonomy of cognitive learning objectives. *Journal of the Medical Library Association: JMLA, 103*(3), 152–155. https://doi.org/10.3163/1536-5050.103.3.010

Affandy, H., Sunarno, W., & Suryana, R. (2024). Integrating creative pedagogy into problem-based learning: The effects on higher order thinking skills in science education. *Thinking Skills and Creativity, 53*, Article 101575. https://doi.org/10.1016/j.tsc.2024.101575

Allen, W. C. (2006). Overview and evolution of the ADDIE training system. *Advances in Developing Human Resources, 8*(4), 430–441. https://doi.org/10.1177/1523422306292942

Almulla, M. (2020). The effectiveness of the project-based learning (PBL) approach as a way to engage students in learning. *SAGE Open, 10*(3), 118–125. https://doi.org/10.1177/2158244020938702

Almulla, M. (2023). Constructivism learning theory: A paradigm for students' critical thinking, creativity, and problem solving to affect academic performance in higher education. *Cogent Education, 10*, Article 2172929. https://doi.org/10.1080/2331186x.2023.2172929

Amalina, I., Vidákovich, T., & Karimova, K. (2025). Factors influencing student interest in STEM careers: Motivational, cognitive, and socioeconomic status. *Humanities and Social Sciences Communications, 12*(1), Article 102. https://doi.org/10.1057/s41599-025-04446-2

https://doi.org/10.33225/jbse/26.25.739

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Amirova, N. (2025). Traditional vs. non-traditional teaching in secondary education: A comparative analysis. *Porta Universorum, 1*(3), 101–109. https://doi.org/10.69760/portuni.010309

Anderson, L. W., & Krathwohl, D. R. (Eds.). (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. Longman.

Arifin, S., & Siew, N. M. (2023). Integration of socioscientific approach and design thinking: An entrepreneurial creative thinking module for STEM education. *Journal of Baltic Science Education, 22*(5), 767–780. https://doi.org/10.33225/jbse/23.22.767

Auliyani, C. N., Arianto, F., & Kholidya, C. F. (2025). A systematic literature review of project-based learning integrated with STEM education: Examining implementation strategies, outcomes, and challenges. *Jurnal Visi Ilmu Pendidikan, 17*(1), 214–231. https://doi.org/10.26418/jvip.v17i1.85610

Avery, L. M. (2013). Rural science education: Valuing local knowledge. *Theory Into Practice, 52*(1), 28–35. https://doi.org/10.1080/07351690.2013.743769

Azzahra, M. Z., Anggereini, E., & Yusnaidar, Y. (2025). Increasing critical thinking skills through STEM-PjBL learning models: Research trend and systematic literature review. *EduFisika: Jurnal Pendidikan Fisika, 10*(1), 117–128. https://doi.org/10.59052/edufisika.v10i1.43461

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology, 59*(1), 617–645. https://doi.org/10.1146/annurev.psych.59.103006.093639

Belbase, S., Mainali, B., Kasemsukpipat, W., Tairab, H., Gochoo, M., & Jarrah, A. (2021). At the dawn of science, technology, engineering, arts, and mathematics (STEAM) education: Prospects, priorities, processes, and problems. *International Journal of Mathematical Education in Science and Technology, 53*(11), 2919–2955. https://doi.org/10.1080/0020739X.2021.1922943

Bell, S. (2010). Project-based learning for the 21st century: Skills for the future. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas, 83*(2), 39–43. https://doi.org/10.1080/00098650903505415

Bhardwaj, V., Zhang, S., Tan, Y., & Pandey, V. (2025). Redefining learning: student-centered strategies for academic and personal growth. *Frontiers in Education, 10* (1), Article 1518602. https://doi.org/10.3389/feduc.2025.1518602

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist, 26*(3–4), 369–398. https://doi.org/10.1080/00461520.1991.9653139

Boondee, V., Kidrakarn, P., & Sa-Ngiamvibool, W. (2011). A learning and teaching model using project-based learning (PBL) on the web to promote cooperative learning. *European Journal of Social Sciences, 21*(3), 498–506.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Bybee, R. W. (2010). What is STEM education? *Science, 329*(5995), 996–997. https://doi.org/10.1126/science.1194998

Çavuş, E., İdil, Ş., & Dönmez, İ. (2026). Effects of a design-based research approach on fourth-grade students' critical thinking, problem-solving skills, computational thinking, and creativity self-efficacy. *International Journal of Technology and Design Education, 36*(1), 41–61. https://doi.org/10.1007/s10798-025-09989-8

Chai, C. S., Deng, F., Tsai, P. S., Koh, J. H. L., & Tsai, C. C. (2015). Assessing multidimensional students' perceptions of twenty-first-century learning practices. *Asia Pacific Education Review, 16*(3), 389–398. https://doi.org/10.1007/s12564-015-9379-4

Chen, C., & Lin, J. (2019). A practical action research study of the impact of Maker-Centered STEM-PjBL on a rural middle school in Taiwan. *International Journal of Science and Mathematics Education, 17*(Suppl. 1), 85–108. https://doi.org/10.1007/s10763-019-09961-8

Chen, J., Wang, X., & Zheng, X. (2024). The investigation of critical thinking disposition among Chinese primary and middle school students. *Thinking Skills and Creativity, 51*, Article 101444. https://doi.org/10.1016/j.tsc.2023.101444

Chen, Y. (2024). Differences of primary education resources between urban and rural areas. *International Journal of Education and Humanities, 17*(2), 223–225. https://doi.org/10.54097/7w9qq88

Cheng, C., & Yang, Y. (2023). Impact of smart classrooms combined with student-centered pedagogies on rural students' learning outcomes: Pedagogy and duration as moderator variables. *Computers & Education, 207*(1), Article 104911. https://doi.org/10.1016/j.compedu.2023.104911

Cheng, H. Y., & Chen, L. (2022). Investigating how student-centered and teacher-centered teaching paradigms relate to the academic motivation and learning behaviors of secondary school students in China. *Journal for the Study of Education and Development, 45*(4), 793–824. https://doi.org/10.1080/02103702.2022.2096299

Chistyakov, A., Zhdanov, S., Avdeeva, E., Dyadichenko, E., Kunitsyna, M., & Yagudina, R. (2023). Exploring the characteristics and effectiveness of project-based learning for science and STEAM education. *Eurasia Journal of Mathematics, Science and Technology Education, 19*(5), Article em2256. https://doi.org/10.29333/ejmste/13128

Chiu, M. C., & Hwang, G. J. (2024). Enhancing students' critical thinking and creative thinking: An integrated mind mapping and robot-based learning approach. *Education and Information Technologies, 29*(17), 22779–22812. https://doi.org/10.1007/s10639-024-12752-6

Cohen, J. (2013). *Statistical power analysis for the behavioral sciences* (2nd ed.). Routledge. https://doi.org/10.4324/9780203771587

Condliffe, B. (2017). *Project-based learning: A literature review* (Working paper). MDRC. https://www.mdrc.org/sites/default/files/Project-Based_Learning-LitRev_Final.pdf

Davidson, V. C. (2018). *The effect of STEM problem-based learning on achievement in simple machines, interest in learning science and self-regulated learning in science among junior secondary school students in Nigeria* [Doctoral dissertation, Universiti Sains Malaysia].

https://doi.org/10.33225/jbse/26.25.739

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Diana, N., Yohannes, & Sukma, Y. (2021). The effectiveness of implementing project-based learning (PjBL) model in STEM education: A literature review. *Journal of Physics: Conference Series, 1882*(1), Article 012146. https://doi.org/10.1088/1742-6596/1882/1/012146

Dounas-Frazer, D. R., Van De Bogart, K. L., Stetzer, M. R., & Lewandowski, H. J. (2016). Investigating the role of model-based reasoning while troubleshooting an electric circuit. *Physical Review Physics Education Research, 12*(1), Article 010137. https://doi.org/10.1103/PhysRevPhysEducRes.12.010137

Duo, H., & Ishak, N. (2024). The effectiveness of STEM project-based learning on scientific identity: Quasi-experimental evidence from Chinese college students. *International Journal of Academic Research in Progressive Education and Development, 13*(3), 1151–1161. https://doi.org/10.6007/ijarped/v13-i3/21868

Engelhardt, P. V., & Beichner, R. J. (2004). Students' understanding of direct current resistive electrical circuits. *American Journal of Physics, 72*(1), 98–115. https://doi.org/10.1119/1.1614813

English, L. D. (2016). STEM education K–12: Perspectives on integration. *International Journal of STEM Education, 3*, Article 3. https://doi.org/10.1186/s40594-016-0036-1

Feziyasti, A., Saputri, I., Asrizal, A., & Mufit, F. (2025). The effect of project-based learning model (PjBL) with STEM approach to promote students' critical and creative thinking skills: A meta-analysis. *Radiasi: Jurnal Berkala Pendidikan Fisika, 18*(1), 11–22. https://doi.org/10.37729/radiasi.v18i1.6004

Firdaus, T., Amelia, A., Alifiyah, F. L. N., Nahdliyah, A. S., & Fausiyeh, F. (2025). Trends and effects of psychological and cognitive load in education. *Journal of Education and Learning Reviews, 2*(2), 97–128. https://doi.org/10.60027/jelr.2025.1084

Furtak, E. M., Seidel, T., Iverson, H., & Briggs, D. C. (2012). Experimental and quasi-experimental studies of inquiry-based science teaching: A meta-analysis. *Review of Educational Research, 82*(3), 300–329. https://doi.org/10.3102/0034654312457206

Gülen, S. (2019). Development of critical thinking skills scale for science lesson. *European Journal of Education Studies, 6*(4), 161–179. https://doi.org/10.5281/zenodo.3335835

Han, S., Capraro, R., & Capraro, M. M. (2015). How science, technology, engineering, and mathematics (STEM) project-based learning (PBL) affects high, middle, and low achievers differently: The impact of student factors on achievement. *International Journal of Science and Mathematics Education, 13*(5), 1089–1113. https://doi.org/10.1007/s10763-014-9526-0

Harackiewicz, J. M., Smith, J. L., & Priniski, S. J. (2016). Interest matters: The importance of promoting interest in education. *Policy Insights from the Behavioral and Brain Sciences, 3*(2), 220–227. https://doi.org/10.1177/2372732216655542

Harefa, D., Sarumaha, M., Telaumbanua, K., Telaumbanua, T., Laia, B., & Hulu, F. (2023). Relationship student learning interest to the learning outcomes of natural sciences. *International Journal of Educational Research & Social Sciences, 4*(2), 240–246. https://doi.org/10.51601/ijersc.v4i2.614

Haryadi, R., & Pujiastuti, H. (2022). Enhancing pre-service physics teachers' higher-order thinking skills through STEM-PjBL model. *International Journal of STEM Education for Sustainability*, *2*(2), 156–171. https://doi.org/10.53889/ijses.v2i2.38

Hatch, L., & Clark, S. (2021). A study of the instructional decisions and lesson planning strategies of highly effective rural elementary school teachers. *Teaching and Teacher Education, 108*, Article 103505. https://doi.org/10.1016/j.tate.2021.103505

Haw, L., Sharif, S., & Han, C. (2021). Science learning motivation in rural schools. *Scholars Journal of Arts, Humanities and Social Sciences, 9*(5), 188–193. https://doi.org/10.36347/sjahss.2021.v09i05.007

Hermawati, T. (2022). Analysing science teachers' difficulties in teaching the concept of electricity in junior high school. *Research in Physics Education, 1*(1), 33–44. https://doi.org/10.31980/ripe.v1i1.2154

Hidayatullah, U. (2024). Implications of constructivism learning theory on students' critical thinking skills: A theoretical study. *Abjadia: International Journal of Education, 9*(2), 449–460. https://doi.org/10.18860/abj.v9i2.28331

Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist, 41*(2), 111–127. https://doi.org/10.1207/s15326985ep4102_4

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark. *Educational Psychologist, 42*(2), 99–107. https://doi.org/10.1080/00461520701263368

Huberman, A. M., & Miles, M. B. (Eds.). (2002). *The qualitative researcher's companion*. SAGE Publications.

Hulleman, C. S., & Harackiewicz, J. M. (2009). Promoting interest and performance in high school science classes. *Science, 326*(5958), 1410–1412. https://doi.org/10.1126/science.1177067

Jacobson, S. K., McDuff, M. D., & Monroe, M. C. (2006). *Conservation education and outreach techniques: A handbook of techniques*. Oxford University Press.

Jamil, M., Hafeez, F., & Muhammad, N. (2024). Critical thinking development for 21st century: Analysis of physics curriculum. *Journal of Social & Organizational Matters, 3*(1), 1–10. https://doi.org/10.56976/jsom.v3i1.45

Kaleva, S., Celik, I., Nogueiras, G., Pursiainen, J., & Muukkonen, H. (2023). Examining the predictors of STEM career interest among upper secondary students in Finland. *Educational Research and Evaluation, 28*(1), 3–24. https://doi.org/10.1080/13803611.2022.2161579

Karaçallı, S., & Korur, F. (2014). The effects of project-based learning on students' academic achievement, attitude, and retention of knowledge: The subject of "Electricity in Our Lives." *School Science and Mathematics, 114*(5), 224–235. https://doi.org/10.1111/ssm.12071

Karpudewan, M., Ponniah, J., & Md. Zain, A. N. (2016). Project-based learning: An approach to promote energy literacy among secondary school students. *The Asia-Pacific Education Researcher, 25*(2), 229–237. https://doi.org/10.1007/s40299-015-0256-z

https://doi.org/10.33225/jbse/26.25.739

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Kersting, M., Haglund, J., & Steier, R. (2021). A growing body of knowledge: On four different senses of embodiment in science education. *Science & Education, 30*(1), 1183–1210. https://doi.org/10.1007/s11191-021-00232-z

Khouna, J., Achour, M., Fakhar, H., & Tahiri, A. (2025). An investigation of secondary pupils' misconception about electric current and voltage concepts. *International Research Journal of Multidisciplinary Scope, 6*(3), 215–226. https://doi.org/10.47857/irjms.2025.v06i03.04481

Kier, M. W., Blanchard, M. R., Osborne, J. W., & Albert, J. L. (2014). The development of the STEM career interest survey (STEM-CIS). *Research in Science Education, 44*(3), 461–481. https://doi.org/10.1007/s11165-013-9389-3

Kilpatrick, W. H. (1918). The project method: The use of the purposeful act in the education process. *Teachers College Record*, *19*(4), 319–335.

Kokotsaki, D., Menzies, V., & Wiggins, A. (2016). Project-based learning: A review of the literature. *Improving Schools, 19*(3), 267–277. https://doi.org/10.1177/1365480216659733

Kurniawan, D. A., Wirayuda, R. P., Putri, W. A., Rini, E. F. S., Ginting, A. A. B., & Ratnawati, T. (2023). Impact of science process skills on thinking skills in rural and urban schools. *International Journal of Instruction, 16*(2), 803–822. https://doi.org/10.29333/iji.2023.16242a

Kurt, G., & Akoğlu, K. (2023). Project-based learning in science education: A comprehensive literature review. *Interdisciplinary Journal of Environmental and Science Education, 19*(3), Article e2311. https://doi.org/10.29333/ijese/13677

LaForce, M., Noble, E., & Blackwell, C. (2017). Problem-based learning (PBL) and student interest in STEM careers: The roles of motivation and ability beliefs. *Education Sciences, 7*(4), Article 92. https://doi.org/10.3390/educsci7040092

Le, H., Nguyen, V., & Nguyen, T. (2023). Integrated STEM approaches and associated outcomes of K-12 student learning: A systematic review. *Education Sciences, 13*(3), Article 297. https://doi.org/10.3390/educsci13030297

Li, J., & Singh, C. (2016). Students' difficulties with equations involving circuit elements. *Physical Review Physics Education Research, 12*(1), Article 010115. https://doi.org/10.1103/PhysRevPhysEducRes.12.010115

Li, L., Huang, C., Morgan, C., Luttgen, K., Chow, E., & Yang, S. (2025). Empowering rural students through computational thinking and real-world STEM applications: Insights from an innovative high school curriculum. *Frontiers in Education, 9*, Article 1452470. https://doi.org/10.3389/feduc.2024.1452470

Liang, B., & Chang, H. (2022). Effectiveness of research and practice on the improvement of scientific literacy based on extra-curricular learning ——A case of a certain engineering college in China. *2022 ASEE Annual Conference & Exposition Proceedings*. https://doi.org/10.18260/1-2--41885

Lin, H. C., Hwang, G. J., & Hsu, Y. D. (2019). Effects of ASQ-based flipped learning on nurse practitioner learners' nursing skills, learning achievement and learning perceptions. *Computers & Education, 139*, 207–221. https://doi.org/10.1016/j.compedu.2019.05.014

Lumbantoruan, J., & Manalu, R. (2024). Effectiveness of learning mathematics derivative materials using modules equipped with cooperative models in high schools. *International Journal of Evaluation and Research in Education (IJERE), 13*(1), 523–533. https://doi.org/10.11591/ijere.v13i1.25354

Manzano-León, A., Rodríguez-Ferrer, J., & Aguilar-Parra, J. (2022). Gamification in science education: Challenging disengagement in socially deprived communities. *Journal of Chemical Education, 100*(1), 170–177. https://doi.org/10.1021/acs.jchemed.2c00089

Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. *International Journal of STEM Education, 6*(1), Article 2. https://doi.org/10.1186/s40594-018-0151-2

Marta, M., Purnomo, D., & Gusmameli, G. (2024). Konsep taksonomi Bloom dalam desain pembelajaran. *Lencana: Jurnal Inovasi Ilmu Pendidikan, 3*(1), 227–246. https://doi.org/10.55606/lencana.v3i1.4572

Mat, N., & Jamaludin, K. (2024). Effectiveness of practices and applications of student-centered teaching and learning in primary schools: A systematic literature review. *International Journal of Academic Research in Progressive Education and Development, 13*(3), 1025–1044. https://doi.org/10.6007/ijarped/v13-i3/21733

McDermott, L. C., & Shaffer, P. S. (1992). Research as a guide for curriculum development: An example from introductory electricity. Part I: Investigation of student understanding. *American Journal of Physics, 60*(11), 994–1003. https://doi.org/10.1119/1.17003

Mendoza-Figueroa, J., Zambrano-Loor, L., Gómez-Cabrera, R., & Narváez-Salinas, L. (2025). Comparación del pensamiento crítico en estudiantes de básica media y bachillerato en instituciones urbanas y rurales. *Journal of Economic and Social Science Research, 5*(2), 101–114. https://doi.org/10.55813/gaea/jessr/v5/n2/191

Meng, F., & Jumaat, N. (2024). The effectiveness of an online inquiry-based learning environment towards secondary school students' behavioral engagement and performance in science. *International Journal of Interactive Mobile Technologies, 18*(18), 112–124. https://doi.org/10.3991/ijim.v18i18.50547

Mims, P., Lee, L., Kuldell, N., & Franklin, C. (2025). Strengthening the STEM pipeline: Impact of project-based synthetic biology program on high school students' science identity and competency. *Frontiers in Education, 9*, Article 1493356. https://doi.org/10.3389/feduc.2024.1493356

Ministry of Education of the People's Republic of China. (2022). *义务教育物理课程标准（2022年版）* [Compulsory education physics curriculum standards (2022 edition)]. Beijing Normal University Press.

Moodley, K., & Gaigher, E. (2019). Teaching electric circuits: Teachers' perceptions and learners' misconceptions. *Research in Science Education, 49*(1), 73–89. https://doi.org/10.1007/s11165-017-9615-5

Murphy, S. (2020). Science education success in a rural Australian school: Practices and arrangements contributing to high senior science enrolments and achievement in an isolated rural school. *Research in Science Education, 52*(1), 325–337. https://doi.org/10.1007/s11165-020-09947-5

https://doi.org/10.33225/jbse/26.25.739

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

National Research Council. (2006). *America's lab report: Investigations in high school science*. National Academies Press. https://doi.org/10.17226/11311

Nguyen, D. (2025). Project-based learning (PjBL) as an experiential pedagogical methodology in interdisciplinary education: A review of the literature. *International Journal of Education in Mathematics, Science and Technology, 13*(4), 1016–1039. https://doi.org/10.46328/ijemst.4869

Nisa, K. (2025). Enhancing creative thinking in high school physics through project-based learning integrating local wisdom and STEAM for quality education. *Journal of Current Studies in SDGs, 1*(1), 47–67. https://doi.org/10.63230/jocsis.1.1.10

Nkanyani, T., Mudau, A., & Sikhosana, L. (2024). Teaching and learning of physical sciences grade 11 in rural schools through rural blended learning strategy. *Eurasia Journal of Mathematics, Science and Technology Education, 20*(3), Article em2413. https://doi.org/10.29333/ejmste/14295

Nurhidayah, I., Wibowo, F., & Astra, I. (2021). Project based learning (PjBL) learning model in science learning: Literature review. *Journal of Physics: Conference Series, 2019*(1), Article 012043. https://doi.org/10.1088/1742-6596/2019/1/012043

Nurhilal, Pantiwati, Y., & Sukarsono. (2024). The urgency of using project-based learning-oriented science learning modules to enhance students' interest and learning outcomes. *Journal of Frontiers in Multidisciplinary Research, 5*(2), 117–126. https://doi.org/10.54660/.ijfmr.2024.5.2.117-126

Owens, D., Sadler, T., Barlow, A., & Smith-Walters, C. (2020). Student motivation from and resistance to active learning rooted in essential science practices. *Research in Science Education, 50*(1), 253–277. https://doi.org/10.1007/s11165-017-9688-1

Palmer, D. H. (2009). Student interest generated during an inquiry skills lesson. *Journal of Research in Science Teaching, 46*(2), 147–165. https://doi.org/10.1002/tea.20263

Pasaribu, F., Gustiningsi, T., & Ariefah, H. (2025). Effectiveness of STEM-PBL based e-modules on critical thinking skills of junior high school students. *Logaritma: Jurnal Ilmu-ilmu Pendidikan dan Sains, 13*(1), 49–60. https://doi.org/10.24952/logaritma.v13i1.14572

Perez, T., Wormington, S., Barger, M., Schwartz-Bloom, R., Lee, Y., & Linnenbrink-Garcia, L. (2019). Science expectancy, value, and cost profiles and their proximal and distal relations to undergraduate science, technology, engineering, and math persistence. *Science Education, 103*(2), 264–286. https://doi.org/10.1002/sce.21490

Peterson, B. W. (2012). Uncovering the progressive past: The origins of project based learning. *UnBoxed: A Journal of Adult Learning in Schools, 8*(1), 1–4.

Piaget, J. (1970). *Science of education and the psychology of the child*. Orion Press.

Pitterson, N. P., & Streveler, R. A. (2016). Teaching and learning complex circuit concepts: An investigation of the intersection of prior knowledge, learning activities, and design of learning environments. *2016 ASEE Annual Conference & Exposition Proceedings*. https://doi.org/10.18260/p.26018

Potvin, P., & Hasni, A. (2014). Interest, motivation and attitude towards science and technology at K–12 levels: A systematic review of 12 years of educational research. *Studies in Science Education, 50*(1), 85–129. https://doi.org/10.1080/03057267.2014.881626

Rehman, N., Huang, X., Mahmood, A., Zafeer, H., & Mohammad, N. (2025). Emerging trends and effective strategies in STEM teacher professional development: A systematic review. *Humanities and Social Sciences Communications, 12*(1), Article 32. https://doi.org/10.1057/s41599-024-04272-y

Rendon, J., Doloretos, N., Capilitan, L., Dumaan, D., Mamada, M., & Mercado, J. (2022). Alternative teaching methods in electricity and magnetism. *International Journal of Multidisciplinary: Applied Business and Education Research, 3*(8), 1600–1606. https://doi.org/10.11594/ijmaber.03.08.23

Renninger, K. A., & Hidi, S. E. (2016). *The power of interest for motivation and engagement*. Routledge. https://doi.org/10.4324/9781315771045

Rittle-Johnson, B., & Schneider, M. (2015). Developing conceptual and procedural knowledge of mathematics. In R. C. Kadosh & A. Dowker (Eds.), *The Oxford handbook of numerical cognition* (pp. 1118–1134). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199642342.013.014

Safitri, I. (2024). Transformation of student science achievement through project-based learning (PjBL): A meta-analysis study. *Scientiae Educatia, 13*(2), 146–158. https://doi.org/10.24235/sc.educatia.v13i2.18694

Salmah, U., Suwasono, P., Kurniawan, R., & Swapno, S. (2025). Implementation of PjBL-STEM learning to improve students' higher order thinking skills in direct current electricity. *Jurnal Pendidikan Sains Indonesia, 13*(2), 534–549. https://doi.org/10.24815/jpsi.v13i2.44826

Santhosh, M., Farooqi, H., Ammar, M., Siby, N., Bhadra, J., Al-Thani, N., Sellami, A., Fatima, N., & Ahmad, Z. (2023). A meta-analysis to gauge the effectiveness of STEM informal project-based learning: Investigating the potential moderator variables. *Journal of Science Education and Technology, 32*(5), 671–685. https://doi.org/10.1007/s10956-023-10063-y

Setyawati, R., Pramasdyahsari, A., Astutik, I., Aini, S., Arum, J., Widodo, W., Nusuki, U., Salmah, U., & Zuliah, N. (2022). Improving mathematical critical thinking skill through STEM-PjBL: A systematic literature review. *International Journal on Research in STEM Education, 4*(2), 1–17. https://doi.org/10.31098/ijrse.v4i2.1141

Shafiyeva, U. (2021). Assessing students' minds: Developing critical thinking or fitting into Procrustean bed. *European Journal of Education*, *4*(2), 79–92. https://doi.org/10.26417/452bxv17s

Simamora, A. (2024). A decade of science technology, engineering, and mathematics (STEM) project-based learning (PjBL): A systematic literature review. *Journal of Computers for Science and Mathematics Learning, 1*(1), 58–78. https://doi.org/10.70232/pn3nek61

Skulmowski, A., & Rey, G. D. (2018). Embodied learning: Introducing a taxonomy based on bodily engagement and task integration. *Cognitive Research: Principles and Implications, 3*, Article 6. https://doi.org/10.1186/s41235-018-0092-9

https://doi.org/10.33225/jbse/26.25.739

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Song, Z. (2023). Disparity in educational resources between urban and rural areas in China. *Journal of Advanced Research in Education, 2*(5), 64–69. https://doi.org/10.56397/jare.2023.09.06

Spires, H., Himes, M., & Krupa, E. (2022). Supporting students' science content knowledge and motivation through project-based inquiry (PBI) global in a cross-school collaboration. *Education Sciences, 12*(6), Article 412. https://doi.org/10.3390/educsci12060412

Stanger-Hall, K. (2012). Multiple-choice exams: An obstacle for higher-level thinking in introductory science classes. *CBE Life Sciences Education, 11*(3), 294–306. https://doi.org/10.1187/cbe.11-11-0100

Suciana, D., & Sausan, I. (2023). A meta-analysis study: The effect of problem based learning integrated with STEM on learning outcomes. *European Journal of Education and Pedagogy, 4*(2), 133–138. https://doi.org/10.24018/ejedu.2023.4.2.619

Suryaningsih, S., Nisa, F., Muslim, B., & Aldiansyah, F. (2022). Learning innovations: Students' interest and motivation on STEAM-PjBL. *International Journal of STEM Education for Sustainability, 2*(1), 66–77. https://doi.org/10.53889/ijses.v2i1.40

Taber, K. S. (2019). Constructivism in education: Interpretations and criticisms from science education. In G. W. Noblit (Ed.), *Oxford research encyclopedia of education*. Oxford University Press. https://doi.org/10.1093/acrefore/9780190264093.013.90

Tang, H., Qian, Y., & Porter-Voss, S. (2024). Enhancing rural students' computer science self-efficacy in a robotics-based language arts course. *Education and Information Technologies, 29*(18), 25533–25550. https://doi.org/10.1007/s10639-024-12875-w

Ubaidillah, M., Hartono, H., Marwoto, P., Wiyanto, W., & Subali, B. (2023). How to improve critical thinking in physics learning? A systematic literature review. *Journal of Educational, Cultural and Psychological Studies (ECPS Journal), 28*(1), 161–187. https://doi.org/10.7358/ecps-2023-028-ubai

Utomo, R. H., Sudiyanto, S., & Supianto, S. (2025). The role of STEM-based project-based learning in developing future competencies: A systematic review. *Teknodika, 23*(1), 12–25. https://doi.org/10.20961/teknodika.v23i1.97895

Van De Bogart, K. L., Dounas-Frazer, D. R., Lewandowski, H. J., & Stetzer, M. R. (2017). Investigating the role of socially mediated metacognition during collaborative troubleshooting of electric circuits. *Physical Review Physics Education Research, 13*(2), Article 020116. https://doi.org/10.1103/PhysRevPhysEducRes.13.020116

Van De Bogart, K. L., & Stetzer, M. R. (2018). Investigating student understanding of bipolar junction transistor circuits. *Physical Review Physics Education Research, 14*(2), Article 020123. https://doi.org/10.1103/PhysRevPhysEducRes.14.020123

Verawati, N., & Nisrina, N. (2025). Reimagining physics education: Addressing student engagement, curriculum reform, and technology integration for learning. *International Journal of Ethnoscience and Technology in Education, 2*(1), 158–181. https://doi.org/10.33394/ijete.v2i1.14058

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.

Wang, X., & Chen, J. (2023). The investigation of critical thinking disposition among Chinese primary and middle school students. *Thinking Skills and Creativity, 51*, Article 101444. https://doi.org/10.1016/j.tsc.2023.101444

Wijnia, L., Noordzij, G., Arends, L., Rikers, R., & Loyens, S. (2024). The effects of problem-based, project-based, and case-based learning on students' motivation: A meta-analysis. *Educational Psychology Review, 36*(1), Article 29. https://doi.org/10.1007/s10648-024-09864-3

Xie, Y., Smith, J., & Davies, M. (2025). The evolution of critical thinking in Chinese education context: Policy and curriculum perspectives. *International Studies in Sociology of Education, 34*(4), 481–504. https://doi.org/10.1080/09620214.2025.2462967

Yaki, A. (2022). Fostering critical thinking skills using integrated STEM approach among secondary school biology students. *European Journal of STEM Education, 7*(1), Article 6. https://doi.org/10.20897/ejsteme/12481

Ying, B., & Hatta, Z. (2025a). A study of inequality in schooling and teacher-student ratios in urban and rural China. *International Journal on Recent Trends in Business and Tourism, 9*(1), 1–13. https://doi.org/10.31674/ijrtbt.2025.v09i01.001

Ying, B., & Hatta, Z. (2025b). Technological resources, teacher-student ratio differences, and educational inequality between urban and rural areas in China. *International Journal on Recent Trends in Business and Tourism, 9*(1), 14–23. https://doi.org/10.31674/ijrtbt.2025.v09i01.002

Zenda, R. (2024). The importance of teaching resources on physical sciences learners' academic achievement in rural schools: A case of South Africa. *Social Education Research, 5*(2), 407–420. https://doi.org/10.37256/ser.5220244624

Zhan, Z., & Niu, S. (2023). Subject integration and theme evolution of STEM education in K-12 and higher education research. *Humanities and Social Sciences Communications, 10*(1), Article 781. https://doi.org/10.1057/s41599-023-02303-8

Zhang, L., & Ma, Y. (2023). A study of the impact of project-based learning on student learning effects: A meta-analysis study. *Frontiers in Psychology, 14*, Article 1202728. https://doi.org/10.3389/fpsyg.2023.1202728

Zhang, W., Sun, J., & Yao, H. (2025). The impact of learning efficiency on teaching evaluation in urban-rural interactive classrooms: a moderated mediation model. *BMC Psychology, 13*(1), Article 962. https://doi.org/10.1186/s40359-025-03313-8

Zhang, W., Yang, A. C., Huang, L., Leung, D. Y., & Lau, N. (2022). Correlation between the composition of personalities and project success in project-based learning among design students. *International Journal of Technology and Design Education, 32*(5), 2873–2895. https://doi.org/10.1007/s10798-021-09716-z

Zhang, Y. (2024). A literature review on the practice and challenges of project-based learning (PBL) in teaching primary (STEM) in China. *Transactions on Social Science, Education and Humanities Research*. https://doi.org/10.62051/1fpg6q16

Zhang, Z., & Lamb, M. (2025). Teachers' questioning practices in Chinese secondary biology classrooms. *International Journal of Science and Mathematics Education, 23*(1), 987–1012. https://doi.org/10.1007/s10763-024-10500-3

Zhao, Z., & Thomas, G. (2015). Mainland Chinese students' conceptions of learning science: A phenomenographic study in Hebei and Shandong Provinces. *International Journal of Educational Research, 75*(1), 76–87. https://doi.org/10.1016/j.ijer.2015.11.008

https://doi.org/10.33225/jbse/26.25.739

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Zhou, S., & Qu, X. (2024). The design of collaborative learning activities supporting the development of higher-order thinking: Based on embodied cognition theory. *Proceedings of the 2024 9th International Conference on Distance Education and Learning,* 407–412. https://doi.org/10.1145/3675812.3675861

Zulkarnaen, Z., Rahayu, S., & Artayasa, I. (2025). Trends in project-based learning for developing critical thinking skills in science education: A bibliometric review. *International Journal of Science Education and Science, 2*(1), 26–34. https://doi.org/10.56566/ijses.v2i1.258

Received: *May 22, 2026* Revised: *July 01, 2026* Accepted: *August 12, 2026*

Cite as: Xue, X., Li, Y., & Wang, H. (2026). Effects of STEM project-based learning on electricity achievement, critical thinking, and interest in rural physics education in P. R. China. *Journal of Baltic Science Education*, *25*(4), 739–762. https://doi.org/10.33225/jbse/26.25.739

Xiangying Xue PhD, School of Communication, Qufu Normal University, P. R. China.
E-mail: cecilia0116usm@gmail.com
ORCID: https://orcid.org/0009-0003-8388-2490

Yuan Li *(Corresponding author)* Lecturer, School of Physics and Electronic Engineering, Nanyang Normal University, Henan, P. R. China.
E-mail: 20141026@nynu.edu.cn
ORCID: https://orcid.org/0009-0001-7772-4707

Huanjing Wang PhD, Professor, School of Communication, Qufu Normal University, P. R. China.
E-mail: whjqfnu@163.com
ORCID: https://orcid.org/0000-0001-6320-2249