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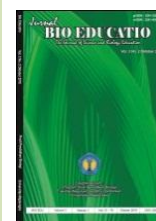
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Enhancing Students' Conceptual Understanding through a STEM-Integrated Problem-Based Learning Model

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ABSTRACT

The gender gap in conceptual understanding of physics remains underexplored, particularly in STEM-based Problem-Based Learning (PBL). This study aims to analyze the improvement in students' conceptual understanding of direct-current electrical circuits through STEM-based PBL from a gender perspective. A quasi-experimental design with a nonequivalent comparison-group was employed, involving second-semester male and female students at a university in Majalengka, Indonesia. Data were collected using a validated conceptual understanding test and analyzed using normalized gain (N-gain). The results indicate that STEM-based PBL improved conceptual understanding in both groups to a moderate extent, with N-gains of 0.48 for male students and 0.32 for female students. This difference suggests variations in cognitive engagement, where male students tended to be more dominant in practical and engineering-related tasks, while female students demonstrated stronger performance in conceptual analysis. These findings highlight that the effectiveness of STEM-based PBL is influenced by gender-related factors. This study contributes to the development of more inclusive and gender-responsive STEM-based physics instruction.

INTRODUCTION

The persistent gender gap in STEM-oriented physics education continues to challenge efforts to achieve equitable learning outcomes, particularly in conceptual understanding. Although STEM pedagogies are widely promoted to enhance higher-order thinking and authentic problem solving, recent evidence indicates that male and female students often experience these learning environments differently. Such disparities are evident not only in participation and persistence but also in how learners construct, interpret, and apply physics concepts, which are shaped by psychological and socio-cultural influences (Wang & Degol, 2017; Cheryan et al., 2017). In physics classrooms, conceptual learning remains essential because students frequently struggle to connect abstract principles with observable phenomena. Consequently, the key issue is no longer merely whether STEM instruction is effective, but whether it adequately addresses the characteristics of diverse learners. This concern becomes more urgent in higher education contexts where physics

serves as a gateway discipline for many STEM careers and where unresolved inequities may reinforce long-term gender imbalances across scientific fields.

Recent scholarship has increasingly examined instructional strategies that can reduce inequities while improving physics learning outcomes. Prior studies reported that female students commonly demonstrate lower self-efficacy in physics than male students despite achieving similar academic performance (Maharani et al., 2019). This pattern aligns with longitudinal evidence showing lower levels of confidence, interest, and perceived value among female learners, which may reduce persistence in STEM pathways (Marshman et al., 2021). At the same time, active learning environments have shown promise in narrowing such disparities. Problem-Based Learning (PBL), especially when integrated with STEM principles, has been associated with stronger motivation, collaboration, science process skills, and conceptual mastery through contextualized inquiry (Hmelo-Silver, 2017; Jannati, 2016; Jannati, 2017; Milana & Jannati, 2018). Furthermore, recent review studies indicate that STEM-integrated problem solving can positively influence both cognitive achievement and attitudes toward physics. Collectively, these findings suggest that learner-centered pedagogies offer substantial potential for improving conceptual understanding across diverse student populations.

Despite these advances, important limitations remain in the current literature. Most previous investigations have evaluated the effectiveness of STEM-based PBL using aggregate achievement scores, implicitly treating students as a homogeneous population. As a result, the interaction between pedagogy and learner characteristics has received insufficient attention, particularly regarding gender-related differences in conceptual change. This omission limits the explanatory power of earlier findings because an instructional model may benefit one group more than another. Moreover, empirical evidence has not always been consistent, as some studies found uneven outcomes across student groups under similar instructional conditions (Su & Rounds, 2015). Another notable limitation concerns the research context. Studies integrating gender perspectives into physics instruction within Indonesian higher education remain relatively scarce, despite the rapid expansion of STEM initiatives nationally. Therefore, a more nuanced investigation is needed to determine whether STEM-based PBL improves conceptual understanding equally for male and female students in context-specific settings.

Responding to these limitations, the present study offers several forms of novelty and contribution. First, it extends the theoretical discussion of gendered learning in STEM by examining how pedagogical design and learner characteristics jointly influence conceptual understanding in physics. Rather than assuming gender as a background variable, this study positions gender as a potentially meaningful moderator of instructional effectiveness. Second, from a methodological standpoint, the study employs comparative analysis to evaluate improvement patterns between male and female students after participation in STEM-based PBL. This approach moves beyond conventional aggregate comparisons commonly reported in earlier research. Third, from a contextual perspective, the study contributes evidence from Indonesian higher education, which remains underrepresented in international discussions on inclusive STEM pedagogy. By focusing on direct current circuits, a topic known for conceptual complexity and practical relevance, the study also provides insight into how authentic problem-solving can support deeper scientific reasoning.

Accordingly, this study aims to analyze improvements in students' conceptual understanding in physics through the implementation of STEM-based Problem-Based Learning, while considering gender differences. Specifically, the research addresses two questions: (1) Does STEM-based PBL significantly improve students' conceptual understanding of direct current circuits? and (2) Are there significant differences in the magnitude of improvement between male and female students? Based on these questions, two hypotheses are proposed: STEM-based PBL significantly enhances students' conceptual understanding, and there are gender differences in the degree of conceptual improvement achieved through the intervention. The significance of this study lies in its potential to inform more inclusive instructional design, enabling lecturers and curriculum developers to align STEM innovation with learner diversity. Ultimately, the findings are expected to support evidence-based strategies that improve both academic quality and educational equity in tertiary physics education.

METHOD

Research Design

This study employed a quantitative quasi-experimental method using a nonequivalent comparison-group pretest–posttest design. The design was selected because random assignment of students into experimental groups was not feasible due to institutional regulations requiring the use of intact classes for administrative and pedagogical continuity. Quasi-experimental procedures are widely considered appropriate for investigating causal relationships in authentic educational settings while maintaining ecological validity. In the present study, both groups received the same instructional treatment, namely STEM-based Problem-Based Learning (PBL), and differed only in gender composition. Accordingly, the design did not compare treatment versus non-treatment conditions but rather examined whether the same intervention produced different learning outcomes among male and female students. Pretest and posttest measures were administered to assess changes in conceptual understanding before and after the intervention. This design was considered suitable because the primary objective of the study was to analyze improvement in physics conceptual understanding and to determine whether gender functioned as a meaningful comparative factor under equivalent instructional conditions.

Data Sources / Participants

The participants were second-semester undergraduate students enrolled in engineering and teacher education programs at a university in Majalengka, Indonesia, during the 2023/2024 academic year. The target population consisted of students taking introductory physics courses that included topics on direct current electricity. A purposive sampling technique was used to select classes with relatively similar academic backgrounds, curriculum exposure, and instructor experience to maintain group comparability. The final sample involved two intact classes. One class consisted predominantly of male students, while the other consisted predominantly of female students, enabling gender-based comparison within the same academic context. The use of intact classes reduced disruption to the regular teaching schedule and preserved natural classroom interactions. However, because participants were not randomly selected or randomly assigned, potential selection bias may remain. Therefore, the findings should be interpreted cautiously and generalized primarily to contexts with similar institutional, curricular, and participant characteristics.

Instruments / Data Collection

Data were collected using a conceptual understanding test and supporting observational instruments. The main instrument was a 30-item multiple-choice test designed to measure students' understanding of direct current electricity. The test covered four indicators: identification of physics concepts, interpretation of symbolic and graphical representations, application of scientific principles to problem situations, and scientific reasoning. These indicators were developed to capture both procedural and conceptual dimensions of learning. Prior to implementation, the instrument underwent expert judgment involving one language specialist and two physics education experts to evaluate content relevance, clarity, and construct alignment. A pilot test was subsequently conducted to examine psychometric quality, including item discrimination, item difficulty, and empirical validity. Internal consistency reliability was calculated using Cronbach's alpha, yielding $\alpha = 0.85$, indicating high reliability. In addition, an observation sheet was used to monitor implementation fidelity during learning sessions, while a student response questionnaire was administered after the intervention to gather perceptions of the STEM-based PBL experience.

Procedure

The research procedure was conducted in three sequential phases: preparation, implementation, and post-intervention analysis. During the preparation phase, lesson plans, worksheets, virtual laboratory materials, and assessment instruments were developed and reviewed to ensure alignment with STEM-based PBL principles. The implementation phase began with administering a pretest to both groups to identify students' baseline conceptual understanding. Subsequently, students participated in several instructional sessions focused on direct current circuits through STEM-based PBL activities. Learning tasks required students to investigate contextual problems, formulate explanations, apply engineering design thinking, test solutions using virtual laboratory simulations, and communicate findings collaboratively. Throughout the intervention, the same lecturer, learning duration, materials, and classroom procedures were maintained across groups to reduce extraneous variation. After completion of the instructional sessions, a posttest was administered using the same conceptual framework as the pretest. Finally, questionnaires and observation sheets were collected to complement the quantitative data on learning outcomes.

Data Analysis

Students' improvement in conceptual understanding was initially measured using normalized gain (N-gain), calculated as $g = \frac{T_2 - T_1}{100 - T_1}$, where T_1 represents the pretest score and T_2 represents the posttest score. Gain values were interpreted according to standard categories of low, medium, and high improvement. Descriptive statistics, including mean scores and standard deviations, were used to summarize group performance. Inferential analyses were then conducted to test the research hypotheses at the 0.05 significance level. A paired-samples t-test was used to determine whether each group demonstrated significant improvement from pretest to posttest. An independent-samples t-test was employed to compare gain scores between male and female groups. In addition, Cohen's d effect size was calculated to estimate the magnitude of observed differences and instructional impact. Prior to hypothesis testing, assumptions of normality and homogeneity of variance were examined using appropriate statistical procedures. These analyses

were selected because they directly addressed the objectives of measuring learning improvement and gender-based differences.

Ethical Considerations

Ethical standards were maintained throughout the study. Participants were informed about the purpose of the research, the voluntary nature of participation, and their right to withdraw at any stage without academic consequences. Informed consent was obtained before data collection. Participant identities were anonymized during data processing and reporting to ensure confidentiality. All collected data were used exclusively for academic research purposes and stored securely. The instructional treatment posed no physical or psychological risk because it was integrated into regular course activities using approved educational procedures. In reporting the findings, the researchers ensured honesty, transparency, and proper acknowledgment of all referenced sources in accordance with academic integrity standards.

RESULTS

Descriptive Analysis of Learning Outcomes

Table 1 presents a comprehensive overview of the descriptive statistics of students' conceptual understanding scores before and after the implementation of STEM-based Problem-Based Learning (PBL) in both comparison groups. The table includes the number of participants, mean pretest and posttest scores, standard deviations, normalized gain values, and gain classification categories. These indicators were reported to provide an initial quantitative profile of students' learning progress and to identify general patterns of change following the instructional intervention. The pretest scores represent students' baseline understanding of direct current electricity before exposure to STEM-based PBL, whereas the posttest scores reflect their level of conceptual mastery after completing the learning sessions. Comparison of these two measurements allows the extent of learning improvement to be observed within each group. Standard deviation values were also included to examine the dispersion of scores and the degree of heterogeneity among students' performances before and after treatment. Meanwhile, normalized gain (N-gain) scores were calculated to estimate the intervention's relative effectiveness by expressing the proportion of actual improvement relative to the maximum possible improvement. By presenting these descriptive indicators simultaneously, Table 1 provides an empirical foundation for subsequent inferential analyses regarding within-group improvement and between-group differences. In addition, the descriptive data provide an important preliminary assessment of whether STEM-based PBL generated consistent conceptual advancement among male and female students, or whether meaningful variation emerged between the two groups, thereby offering an initial indication of each group's comparative responsiveness to the instructional treatment.

Table 1. Descriptive Statistics of Conceptual Understanding

Group	N	Pretest Mean	Posttest Mean	SD (Pre)	SD (Post)	N-gain	Category
Male	30	45.20	71.80	8.50	7.90	0.48	Moderate
Female	30	44.75	64.30	9.10	8.40	0.32	Moderate

Baseline scores indicate that the two groups entered the intervention with relatively comparable prior understanding of direct current electricity. Following the implementation of STEM-based PBL, both groups demonstrated clear increases in posttest performance. The male group improved by 26.60 score points, whereas the female group improved by 19.55 points. Similarly, normalized gain analysis classified both groups within the moderate improvement category. However, the magnitude of gain was higher among male students ($g = 0.48$) than female students ($g = 0.32$), suggesting differential responsiveness to the instructional treatment. A reduction in standard deviation from pretest to posttest was also observed in both groups, indicating that conceptual achievement became more homogeneous after the intervention. This pattern may reflect the capacity of structured collaborative problem solving to support lower-performing students while simultaneously strengthening overall group performance.

Within-Group Differences

To determine whether the increases in conceptual understanding scores from pretest to posttest were statistically significant within each group, paired-samples t -tests were performed separately for male and female students. This analysis was selected because the same participants were measured at two different time points, allowing direct examination of score changes following the implementation of STEM-based Problem-Based Learning (PBL). In addition to the t -test results, mean differences, significance values, and effect sizes were calculated to provide a more comprehensive interpretation of the magnitude and practical relevance of the observed improvements. Reporting these indicators is important because statistical significance alone does not fully explain the strength of instructional impact. Therefore, the paired comparison analysis was intended to determine not only whether conceptual understanding improved after the intervention, but also the extent to which the improvement reflected meaningful educational progress within each group.

Table 2. Paired-Samples t -Test Results for Within-Group Improvement

Group	N	Pretest Mean	Posttest Mean	Mean Difference	t	df	p	Cohen's d	Interpretation
Male	30	45.20	71.80	26.60	12.45	29	<.001	1.87	Very Large Effect
Female	30	44.75	64.30	19.55	9.38	29	<.001	1.42	Large Effect

As shown in Table 2, both groups experienced statistically significant increases in conceptual understanding after participating in the STEM-based PBL intervention. The male group demonstrated a mean improvement of 26.60 points, while the female group improved by 19.55 points. The significance values ($p < .001$) indicate that these gains were highly unlikely to have occurred by chance. The magnitude of the t -statistics further suggests strong evidence of learning progress in both groups, with the male group showing a somewhat greater statistical change than the female group. Effect size analysis supports this conclusion. Male students obtained a very large effect ($d = 1.87$), whereas female students showed a large effect ($d = 1.42$). These values indicate that the intervention produced substantial educational benefits for both groups. From an analytical perspective, these findings confirm that STEM-based PBL was

effective in improving conceptual understanding of direct current electricity regardless of gender. However, the larger mean difference and stronger effect size observed among male students suggest that the degree of responsiveness to the intervention was not entirely equivalent. This pattern implies that while the instructional model was broadly successful, differences in participation patterns, confidence in hands-on experimentation, or prior learning experiences may have influenced the intensity of conceptual gains across groups.

Between-Group Differences

To examine whether the magnitude of learning improvement differed significantly between male and female students, an independent-samples *t*-test was conducted using normalized gain (N-gain) scores as the primary comparison variable. The use of N-gain scores was considered appropriate because this metric reflects proportional improvement by accounting for students' initial pretest performance and maximum possible gain. Consequently, it provides a more equitable basis for comparing learning progress across groups than raw posttest scores alone. In addition to statistical significance testing, mean differences, confidence intervals, and effect size estimates were reported to strengthen the interpretation of the practical importance of any observed group differences. This analysis was intended to determine whether STEM-based Problem-Based Learning (PBL) produced equivalent conceptual benefits for both groups or whether one group demonstrated stronger responsiveness to the intervention.

Table 3. Independent-Samples *t*-Test Results for Between-Group Differences

Variable	Male (n = 30) Mean ± SD	Female (n = 30) Mean ± SD	Mean Difference	t	df	p	95% CI	Cohen's d	Interpretation
N-gain	0.48 ± 0.14	0.32 ± 0.12	0.16	3.21	58	.002	0.06 to 0.26	0.65	Moderate Effect

As presented in Table 3, the independent-samples analysis revealed a statistically significant difference in normalized gain scores between male and female students, $t(58) = 3.21, p = .002$. The positive mean difference indicates that male students achieved higher proportional learning gains than female students following the intervention. Because the 95% confidence interval did not cross zero, the observed difference can be interpreted as statistically stable and unlikely to be attributable to sampling fluctuation. The calculated effect size was moderate ($d = 0.65$), suggesting that the difference was not only statistically significant but also educationally meaningful. In practical terms, this indicates that gender was associated with a noticeable variation in the extent to which students benefited from STEM-based PBL. Although both groups improved and reached the moderate-gain category, the male group demonstrated greater conceptual advancement over the instructional period. From an analytical perspective, these findings suggest that the effectiveness of STEM-based PBL was not entirely uniform across learner groups. Participation in an innovative instructional model alone may not automatically eliminate differences in learning outcomes related to student characteristics. Variations in prior experience with technical tasks, confidence in manipulating electrical components, problem-solving preferences, or interaction patterns during collaborative activities may have contributed to the stronger gains observed among male students.

Therefore, future instructional design should incorporate more inclusive scaffolding strategies to ensure that all learners benefit equally from STEM-oriented physics instruction.

Observational Findings During Instruction

Systematic classroom observations were conducted throughout the intervention to complement the quantitative findings and to provide contextual explanations for differences in learning gains between groups. The observation process focused on several dimensions of student engagement, including participation intensity, problem-solving behavior, use of learning tools, quality of collaboration, persistence when encountering errors, and communication during group discussions. These qualitative indicators were considered important because conceptual understanding in STEM-based Problem-Based Learning (PBL) is shaped not only by test performance but also by how students interact with tasks, peers, and instructional resources throughout the learning process. Observational evidence, therefore, served as a valuable source of triangulation for interpreting the statistical outcomes obtained from pretest–posttest comparisons.

Table 4. Summary of Classroom Observation Findings During STEM-Based PBL

Observation Aspect	Male Students	Female Students	Analytical Interpretation
Hands-on Engagement	Frequently initiated circuit assembly and component testing	Participated actively but less frequently initiated manipulation	Male students showed stronger spontaneous experimentation tendencies
Troubleshooting Behavior	More likely to retry failed circuits through rapid trial-and-error strategies	Preferred discussing possible causes before making adjustments	Different problem-solving styles emerged during technical tasks
Collaboration	Task-focused coordination during assembly stages	Stronger interaction, sharing, and discussion	Female students demonstrated more structured collaborative patterns
Documentation	Limited note-taking during experimentation	More consistent recording of observations and procedures	Female students showed stronger procedural organization
Persistence	Continued testing until circuits functioned properly	Maintained persistence through discussion and confirmation steps	Both groups were persistent, but expressed persistence differently

As shown in Table 4, both groups were actively engaged during the intervention, although they exhibited different patterns of learning participation. Male students tended to interact more intensively with physical components, frequently initiating circuit reconstruction, battery testing, wire adjustment, and repeated troubleshooting attempts. Their learning behavior reflected an exploratory orientation characterized by immediate action and iterative experimentation. This pattern may have accelerated conceptual understanding because direct manipulation of circuits

provides instant visual and functional feedback regarding current flow, connection errors, and resistance effects. In contrast, female students demonstrated stronger consistency in procedural accuracy, collaborative dialogue, and reflective analysis before executing technical adjustments. They were more likely to document observations, confirm reasoning with peers, and distribute responsibilities systematically within groups. Such behaviors indicate a more deliberative and socially coordinated approach to problem solving, which may support stable understanding but require longer processing time during dynamic experimental tasks.

From an analytical perspective, these contrasting participation profiles may partially explain the quantitative differences in N-gain scores. Tasks emphasizing repeated manipulation of electrical systems and rapid troubleshooting may have advantaged students who engaged more intensively in hands-on experimentation. Nevertheless, the stronger collaborative and organizational behaviors shown by female students represent equally valuable competencies within STEM learning environments. Therefore, future implementations of STEM-based PBL should balance technical experimentation with structured discussion, reflective scaffolding, and equitable task rotation to optimally accommodate different learning strengths.

DISCUSSION

Effectiveness of STEM-Based PBL on Conceptual Understanding

The findings demonstrate that STEM-based Problem-Based Learning (PBL) effectively improved students' conceptual understanding of direct current electricity. Significant gains in both groups indicate that the intervention successfully supported students in moving from fragmented prior knowledge toward more coherent scientific understanding. This outcome is consistent with constructivist learning theory, which posits that knowledge is actively developed through interaction with meaningful tasks, social negotiation, and reflection on experience. In the present study, the flashlight circuit functioned as an authentic learning context through which abstract principles such as current flow, potential difference, resistance, and energy conversion became observable and manipulable. By connecting theoretical concepts to familiar technological devices, students were able to anchor new knowledge in concrete experiences, thereby facilitating stronger conceptual restructuring.

The effectiveness of the intervention can also be attributed to the integration of PBL with STEM principles. Rather than passively receiving information, students were required to diagnose circuit problems, test hypotheses, redesign systems, and justify solutions collaboratively. These processes likely promoted deeper cognitive engagement than conventional lecture-based approaches because learners were continuously engaged in inquiry, decision-making, and evidence-based reasoning. Prior studies similarly reported that PBL enhances conceptual understanding in physics, particularly in conceptually demanding domains such as electricity (Arends, 2016; Lubna, 2020). Likewise, STEM-oriented instruction has been associated with improved analytical reasoning, problem transfer, and interdisciplinary thinking (Bybee, 2013; English, 2017). Therefore, the present findings strengthen existing evidence that combining problem-based pedagogy with STEM practices constitutes a robust instructional model for conceptual physics learning.

Another noteworthy result concerns the reduction of score variability after the intervention. Standard deviations decreased in both groups from pretest to posttest, suggesting

that learning outcomes became more homogeneous. This pattern implies that STEM-based PBL may not only raise average achievement, but also support students who initially possessed weaker conceptual understanding. Collaborative investigation, repeated experimentation, and peer explanation may have served as natural scaffolds, enabling lower-performing students to participate meaningfully in knowledge construction. Consequently, the intervention appears beneficial not only for high achievers but also for promoting broader conceptual inclusion within the classroom.

Gender Differences in Learning Gains

Although both groups benefited significantly from the intervention, the results also revealed statistically significant differences in learning gains between male and female students. Male students achieved higher normalized gain scores and larger within-group effect sizes, indicating stronger conceptual progress over the instructional period. This finding suggests that the impact of STEM-based PBL was positive but not entirely equivalent across learner groups. From a theoretical perspective, these differences may be associated with variations in self-efficacy, prior experience, and task orientation rather than innate cognitive ability. Observational evidence indicated that male students tended to engage more intensively in circuit assembly, troubleshooting, and iterative trial-and-error experimentation. Because these behaviors are central to engineering-oriented STEM tasks, more frequent interaction with physical systems may have accelerated conceptual change through immediate feedback. Students who repeatedly manipulate circuits can directly observe the functional consequences of wiring errors, changes in resistance, and energy transfer, thereby refining their mental models through experiential correction.

By contrast, female students demonstrated stronger consistency in collaborative discussion, procedural organization, and reflective reasoning. These strengths are equally valuable in scientific inquiry, yet may yield slower gains when assessment tasks prioritize rapid conceptual application linked to technical experimentation. This interpretation is consistent with previous studies showing that gender differences in STEM learning are often mediated by confidence, prior exposure, and perceived competence in technical tasks rather than actual academic potential (Wang & Degol, 2017). More recent evidence further suggests that female students may experience greater uncertainty in engineering-related environments, which can influence the intensity of their participation in hands-on problem solving (Verdugo-Castro et al., 2022).

Importantly, these findings should not be interpreted as evidence of inherent ability gaps between genders. Instead, they likely reflect accumulated socio-cultural and educational experiences that shape learning behavior, confidence, and role expectations. In many contexts, male students receive greater encouragement to explore mechanical systems and technical tools from an early age, whereas female students may receive fewer comparable opportunities. As a result, differences observed during the intervention may represent disparities in prior exposure rather than differences in capability. Previous research has shown that such gaps can be reduced when instructional environments intentionally foster equitable participation, shared responsibility, and inclusive support structures (Crombie, 2019).

Role of Contextual and Experimental Learning

A central contribution of this study is the use of a flashlight circuit as a context for learning. Electricity concepts are widely recognized as difficult because many relevant processes are invisible and abstract. Students commonly hold misconceptions such as believing that electric current is

“used up” by components, that batteries supply constant current regardless of circuit structure, or that bulbs closer to the battery receive more energy. Such misconceptions often persist when instruction relies heavily on formulas without experiential verification. The flashlight circuit helped address these challenges by transforming invisible electrical processes into observable phenomena. Through dismantling and reconstructing a familiar device, students examined component functions, traced conductive pathways, tested continuity, and evaluated why circuits succeeded or failed. This hands-on diagnostic reasoning likely supported conceptual visualization and reduced misconceptions regarding closed circuits and current flow. Prior research similarly reported that simple experimental contexts improve understanding of circuit behavior (Mulhall, 2019), while everyday technological examples such as torch circuits help students replace naïve conceptions with scientific explanations (Colley, 2020).

In addition, the redesign component of the task introduced an engineering design dimension that strengthened iterative learning. Students were not merely asked to understand an existing circuit, but also to improve or modify it to meet functional goals. This requirement encouraged repeated cycles of planning, testing, evaluating, and revising. Such processes align closely with contemporary STEM frameworks, emphasizing the integration of scientific concepts with engineering practice to deepen understanding and enhance the transferability of knowledge (Rahmawati, 2023). Therefore, the contextual medium likely served as a critical mechanism through which the broader instructional model produced meaningful conceptual gains.

Implications for Practice and Research

These findings carry several practical implications. First, lecturers and teachers should consider adopting STEM-based PBL for conceptually difficult physics topics because it appears to be effective in strengthening conceptual understanding while actively engaging students in inquiry. Second, instructional implementation should be designed with gender responsiveness in mind. Strategies such as structured scaffolding, rotating technical roles, guided experimentation protocols, and explicit encouragement for all students to manipulate tools may help reduce disparities in participation and outcomes. Third, assessment practices should value multiple dimensions of learning, including experimentation, collaboration, reasoning, and reflection, so that different learner strengths are recognized. Several implications for future research also emerge. Subsequent studies may examine how self-efficacy, prior technical experience, or group interaction patterns mediate gender differences in STEM-PBL environments. Longitudinal designs could determine whether repeated exposure to inclusive hands-on learning narrows observed gaps over time. In addition, future investigations involving larger and more diverse samples across institutions would improve generalizability and clarify whether the present patterns are context-specific or more widely applicable. The present study indicates that STEM-based PBL is a powerful approach for improving conceptual understanding of electricity. However, maximizing its benefits requires instructional designs that intentionally accommodate learner diversity and ensure equitable opportunities for engagement.

CONCLUSION

This study demonstrates that the implementation of STEM-based Problem-Based Learning (PBL) effectively improves students’ conceptual understanding of direct current electricity. Although both male and female students showed learning gains, the difference in the

magnitude of improvement indicates that instructional effectiveness is not uniform, but influenced by learner characteristics, particularly gender. These findings suggest that variations in learning outcomes are associated with differences in cognitive engagement and self-efficacy in handling experimental and engineering-based tasks. Therefore, STEM-based physics instruction should be designed to be more adaptive and responsive to diverse student characteristics. From a conceptual perspective, this study contributes to the development of inclusive STEM learning by highlighting the importance of integrating gender as a critical factor in evaluating instructional effectiveness. From a pedagogical perspective, the results emphasize the need to balance hands-on activities with structured conceptual support to ensure equitable and meaningful learning experiences. However, this study is limited by its quasi-experimental design without a control group and a relatively small, homogeneous sample, which may limit generalizability. Future research is recommended to involve larger, more diverse samples and to examine affective factors such as self-efficacy and learning motivation in STEM-based physics learning.

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ADDITIONAL INFORMATION

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Conflict of Interest	The authors declare no conflict of interest related to this publication.
Author Contributions	All authors made substantial contributions to this study. The first author led the conceptualization, methodology, data analysis, and manuscript drafting. The second author contributed to data collection, validation, and analysis. The third author was responsible for review, editing, and overall supervision. All authors approved the final version of the manuscript.
Data Availability	The data supporting the findings of this study are available from the corresponding author upon reasonable request.
Ethical Approval	This study was conducted in accordance with ethical research standards. Informed consent was obtained from all participants, and data confidentiality was strictly maintained.
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AI Usage Statement Artificial intelligence tools were used solely for language refinement and grammatical editing. All research design, analysis, interpretation, and conclusions were undertaken by the authors, who assume full responsibility for the manuscript.

REFERENCES

- Arends, R. I. (2016). *Learning to teach* (10th ed.). McGraw-Hill Education.
- Aslan-Tutak, F., Akaygun, S., & Tezsezen, S. (2017). Collaboratively learning to teach STEM: Change in participating pre-service teachers' awareness of STEM. *Hacettepe University Journal of Education*, 32(4), 794–816. <https://doi.org/10.16986/HUJE.2017027115>
- Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. NSTA Press.
- Cheryan, S., Ziegler, S. A., Montoya, A. K., & Jiang, L. (2017). Why are some STEM fields more gender balanced than others? *Psychological Bulletin*, 143(1), 1–35. <https://doi.org/10.1037/bul0000052>
- Crombie, G. (2019). Gender differences in students' experiences and participation in STEM education. *International Journal of Science Education*, 41(6), 1–15. <https://doi.org/10.1080/09500693.2019.1579949>
- English, L. D. (2017). Advancing elementary and middle school STEM education. *International Journal of Science and Mathematics Education*, 15(Suppl. 1), 5–24. <https://doi.org/10.1007/s10763-017-9802-x>
- Hmelo-Silver, C. E. (2017). Problem-based learning: What and how do students learn? *Educational Psychology Review*, 29(4), 495–541. <https://doi.org/10.1007/s10648-016-9386-5>
- Jannati, E. D. (2016). The implementation of problem-based learning to improve students' science process skills. *Jurnal Pendidikan IPA Indonesia*, 5(2), 123–130. <https://doi.org/10.15294/jpii.v5i2.12345>
- Jannati, E. D. (2017). The effect of problem-based learning on students' learning motivation. *Jurnal Pendidikan Sains*, 6(1), 45–52.
- Jannati, E. D. (2020). STEM-based learning innovation in science education. *Jurnal Pendidikan IPA Indonesia*, 9(3), 321–330. <https://doi.org/10.15294/jpii.v9i3.12345>
- Johnson, C. C., Peters-Burton, E. E., & Moore, T. J. (2020). *STEM road map: A framework for integrated STEM education*. Routledge. <https://doi.org/10.4324/9780429260198>
- Lubna, A. (2020). The effect of problem-based learning on students' conceptual understanding in physics. *Journal of Physics Education*, 12(2), 85–92.
- Maharani, S., Jannati, E. D., & Milana, R. (2019). Self-efficacy and conceptual understanding in physics learning. *Jurnal Pendidikan Fisika Indonesia*, 15(1), 45–52. <https://doi.org/10.15294/jpfi.v15i1.12345>
- Marshman, E., Kalender, Z. Y., Schunn, C., Nokes-Malach, T., & Singh, C. (2021). A longitudinal analysis of students' motivational characteristics in introductory physics courses. *Physical Review Physics Education Research*, 17(1), 010123. <https://doi.org/10.1103/PhysRevPhysEducRes.17.010123>
- Milana, R., & Jannati, E. D. (2018). Contextual learning to improve students' conceptual understanding in physics. *Jurnal Pendidikan Fisika*, 7(2), 98–105.
- Mulhall, P. (2019). Students' understanding of electric circuits: A review. *Physics Education*, 54(3), 1–8. <https://doi.org/10.1088/1361-6552/ab0c1d>

- Rachmat, A., et al. (2019). Contextual learning in electricity concepts. *Jurnal Pendidikan Fisika Indonesia*, 15(2), 100–110.
- Santoso, B. (2020). Analysis of students' misconceptions in electricity concepts. *Jurnal Pendidikan Sains*, 8(1), 55–62.
- Su, R., & Rounds, J. (2015). All STEM fields are not created equal: People and things interests explain gender disparities. *Psychological Science*, 26(6), 859–868. <https://doi.org/10.1177/0956797615575835>
- Verdugo-Castro, S., García-Holgado, A., & García-Peñalvo, F. J. (2022). Gender gap in STEM education: A systematic review. *Sustainability*, 14(9), 1–20. <https://doi.org/10.3390/su14095310>
- Wang, M. T., & Degol, J. L. (2017). Gender gap in STEM: Current knowledge and future directions. *Educational Psychology Review*, 29(1), 119–140. <https://doi.org/10.1007/s10648-015-9355-x>
- Wijaya, A. (2022). Reducing misconceptions in electricity through inquiry learning. *Journal of Science Education*, 16(2), 210–220.