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Integrating Case-Based Reasoning and Coupled Inquiry to Foster Problem-Solving Skills in Direct Current Circuits

Maria Dewati[1], Sigit Ristanto[2], Irnin Agustina Dwi Astuti[3]
[1]Department of Physics Education, Universitas Indraprasta PGRI, Jakarta, Indonesia
[2]Department of Physics Education, Universitas PGRI, Semarang, Indonesia
[3]Department of Physics Education, Universitas Indraprasta PGRI, Jakarta, Indonesia

Abstract

This study seeks to evaluate the effectiveness of the Case-Based Reasoning Embedded Coupled Inquiry (CBRCI) learning model in enhancing students' problem-solving abilities in direct current (DC) topics. The main issue identified is students' difficulty in applying DC concepts to practical problem-solving, despite studying the theory. The research design employs a one-group pretest-post-test to evaluate changes in problem-solving skills across four aspects: conceptual analysis, strategy, quantitative, and meta-analysis. The research participants were 88 students from two universities of teacher education in Java, selected through stratification to ensure proportional representation. Results show significant improvement in all aspects of problem-solving skills following CBRCI implementation. Paired t-tests revealed significant differences between pre-test and post-test scores in all aspects. Effect size analysis indicated moderate to strong improvements, with the largest effects in meta-analysis and strategy analysis. The findings suggest that the CBRCI model is effective in integrating theory and practice, as well as enhancing students' problem-solving skills. The research results contribute to the development of more interactive learning models relevant to industry needs.

Keywords: *active learning, coupled inquiry, direct current, instructional design, problem-solving skills*

Corresponding Author:
Maria Dewati
Department of Physics Education, Universitas Indraprasta PGRI, Indonesia
Jl. Raya Tengah No.80, RT.6/RW.1, Gedong, Kec. Ps. Rebo, Kota Jakarta Timur, Daerah Khusus Ibukota Jakarta 13760
Email: merrdewati@gmail.com

1. INTRODUCTION

Problem-solving is a crucial ability in the current era of globalization, where complex challenges often require innovative and effective approaches (Agbo et al., 2023; Yilmaz-Na & Sönmez, 2023). A major issue faced in education today is the insufficient development of students' problem-solving skills (Leou et al., 2006; Santos, 2017).Many students struggle to apply theoretical concepts when confronted with real-world problems, particularly in science and engineering contexts (McLaughlin & Bailey, 2023; Mogk, 2021). This situation stems from conventional learning models that prioritize memorization over conceptual understanding and application (Clements & Joswick, 2018; Mejía-Villa et al., 2023). Therefore, it is necessary to adopt instructional approaches that encourage critical and creative thinking, as well as the ability to transfer knowledge to authentic, real-life contexts.

This study focuses on direct current (DC) topics, which are fundamental in physics and engineering and have widespread applications, such as in the design of electronic systems and everyday electrical devices (Ropika et al., 2019; Siong et al., 2023) solid understanding of direct current is essential for exploring advanced topics in energy and technology (Chasiotis & Karnavas, 2018; Garzón et al., 2014) including solar power systems and electric vehicles. Students are expected to acquire strong problem-solving skills to meet professional demands and contribute to technological development (Zuza et al., 2016). Moreover, learning DC topics helps students perceive the direct connection between theoretical concepts and practical application, which can enhance motivation and interest in learning (Kock et al., 2015; Leniz et al., 2019; Newman et al., 2017).

To address these challenges, this study proposes the use of the Case-Based Reasoning Embedded Coupled Inquiry (CBRCI) instructional model. This model combines the contextual, experience-based principles of case-based reasoning with the student-driven investigative structure of coupled inquiry learning. The integration of these two approaches is expected to support deeper learning and foster problem-solving skills more effectively.

Therefore, this study aims to develop and evaluate the effectiveness of the CBRCI instructional model in improving students' problem-solving skills related to DC circuit concepts. It is expected that the implementation of this model will not only enhance conceptual understanding but also promote the transfer of knowledge into practical and technological applications. The outcomes of this research are anticipated to provide theoretical contributions to learning model development and practical implications for physics education.

The outcomes of this research are anticipated to contribute to the development of innovative instructional models and offer practical implications for improving physics education, particularly in problem-solving.

2. LITERATURE REVIEW

2.1 Problem-Solving Skills

Problem-solving is a key higher-order thinking skill in physics education, as it enables students to apply their knowledge to unfamiliar situations in a structured and logical manner (Çalişkan et al., 2010; Hidaayatullaah et al., 2020; Nadapdap & Istiyono, 2017). Propose a four-step process involving understanding the problem, planning a solution, implementing the plan, and evaluating the results (Docktor et al., 2015; Heller & Heller, 2010; Polya, 2014). These stages promote critical and analytical thinking. Heller and Heller (2010) also emphasize the importance of encouraging students to reason through real-world problems and reflect on their thinking. Moreover, the involvement of various cognitive processes throughout the problem-solving cycle has also been highlighted by previous research (Dewati et al., 2019; Gick & Gick, 2011).

In the context of physics, effective problem-solving requires strong conceptual understanding and analytical skills (Docktor et al., 2016; Riantoni et al., 2017). Prior research has identified four core components essential to this process, conceptual, strategic, quantitative, and meta-analysis (Dewati et al., 2019; Gerace & Beatty, 2005; Hidaayatullaah et al., 2020). The effective application of these components often distinguishes expert problem solvers from novices. While experts tend to approach problems qualitatively, employing multiple representations such as diagrams and graphs, novices typically rely on formulaic procedures without fully understanding the underlying concepts or context (Finkelstein et al., 2005; Rosengrant et al., 2006, 2017; Yuliati et al., 2018). Applying these components systematically promotes higher-order thinking, encouraging students to evaluate, reflect, and refine their problem-solving strategies (Gerace & Beatty, 2005).

2.2 Coupled Inquiry

Coupled inquiry blends guided and open inquiry methods, encouraging students to investigate problems and gradually become more independent.(Dunkhase, 2003; Leonard & Penick, 2000; Martin-hansen, 2010; Yakob et al., 2020). The model includes five stages: engage, explore, explain, elaborate, and evaluate (Bybee et al., 2006), each supporting active learning and deeper understanding (Bybee et al., 2006; Dunkhase, 2003).

2.3 Case-Based Reasoning

Case Based Reasoning is a learning model that promotes experience-based problem solving by retrieving and adapting solutions from previous cases to address new, similar problems (Assiroj et al., 2018; Mohammed et al., 2018). Through its four stages, retrieval, reuse, revise, and retain. CBR enables students to apply proven strategies efficiently while continuously refining their knowledge (Hunter, 2015; Kolodner, 1992; Kolodner et al., 2009). This model accelerates decision-making and supports effective learning by helping learners avoid repeating ineffective solutions (Tawfik & Kolodner, 2016). However, CBR requires creative reasoning and proper instructional guidance to ensure students accurately adapt solutions to different contexts and avoid misconceptions, when implemented effectively, CBR enhances problem-based learning and fosters the development of adaptable, real-world problem-solving skills (Kolodner et al., 2009).

2.4 Theoretical Foundation of the CBRCI Model

The CBRCI model was developed to improve students' problem-solving skills, particularly in the field of Physics education. The development of the CBRCI model is based on the need for collaborative and active learning, where students not only passively receive information but are also directly involved in the process of exploration, analysis, and problem-solving relevant to the learning material and everyday life. CBRCI combines the principles of case-based learning with an integrated inquiry approach that allows students to practice finding solutions to real problems through various stages, from problem formulation, problem-solving processing, and data processing, to evaluation.

The CBRCI model is based on the principle that active student involvement in the learning process encourages improvement in analytical abilities, meta-analysis, and responsibility for their learning process. The CBRCI syntax, consisting of five stages (formulating problem, problem-solving processing, association, discussion, and evaluation), is systematically designed to ensure students are involved in deep concept understanding and development of problem-solving strategies. Modern educational theories such as student-cantered learning become the main foundation in CBRCI development, where students are expected to work collaboratively, develop critical thinking skills, and enhance strategic thinking abilities. This model allows students to learn independently and take responsibility for the learning process, with instructors acting as facilitators and motivators.

The stages and activities in the CBRCI model are designed to provide a holistic learning experience for students, starting from problem identification, and data processing, to evaluation of learning outcomes. Each stage is designed sequentially to facilitate the development of students' critical thinking, conceptual analysis, and problem-solving abilities. The first stage, formulating problems, involves formulating problems based on themes relevant to life, where students learn to analyze problems conceptually. The formulating problem stage serves to build a foundation for further problem-solving processes. In the second stage, problem-solving processing, students design strategies to process the identified problems, including developing hypotheses and conducting experiments or literature studies. The problem-solving processing stage helps students develop strategy analysis skills. In the third stage, association, students are expected to be able to process data qualitatively, that is then discussed further in the discussion stage, where preliminary analysis results are tested and presented to get feedback from other groups and instructors. The last stage, evaluation, is an evaluation and revision of the resulting solutions to ensure problem-solving is under the concepts learned. Each stage in the CBRCI model serves to ensure that students not only understand the concepts taught but are also able to apply knowledge in more complex situations.

Table 1 presents the summary of the CBRCI model stages, which integrates Case-Based Reasoning and Coupled Inquiry into a five-phase instructional structure designed to enhance problem-solving skills.

Table 1. Summary of CBRCI Model Stages

CBRCI Model Stages	Main Activities
Formulating Problem	Identify and formulate problems; work in groups for exploration.
Problem-Solving Processing	Design problem-solving strategies; formulate hypotheses; conduct experiments.
Association	Analyze data obtained from experiments or simulations; develop preliminary solutions.
Discussion	Discuss analysis results and preliminary solutions; receive feedback from instructors and other groups.

CBRCI Model Stages	Main Activities
Evaluation	Evaluate and revise solutions based on received input; review material concepts.

3. METHODS

3.1 Research Design

This study used a one-group pretest-posttest design to evaluate the effectiveness of the CBRCI instructional model in improving students' problem-solving skills in direct current (DC) topics. The design allowed for direct comparison of students' performance before and after the intervention within the same group.

3.2 Participants

The population consisted of 113 students from two teacher education universities in Java: Universitas Indraprasta PGRI Jakarta and Universitas PGRI Semarang. A stratified random sampling method was used to obtain a proportional and representative sample of 88 students, considering similarities in curriculum, lecturer qualifications, and laboratory facilities at both institutions.

3.3 Instruments

The instrument used was a two-tier diagnostic test, consisting of multiple-choice questions and written reasoning. It covered four dimensions of problem-solving: (1) Conceptual Analysis (5 items), (2) Strategy Analysis (4 items), (3) Quantitative Analysis (3 items), and (4) Meta-Analysis (4 items). The same items were used for pre-test and post-test.

To reduce memory bias, a polytomous scoring system was applied, assessing both the accuracy of answers and reasoning. Content validity was verified using Aiken's V, exceeding 0.70 for all items. Construct validity was tested via Confirmatory Factor Analysis (CFA), yielding acceptable fit indices: GFI = 0.97, CFI = 0.89, RMSEA = 0.07.

3.4 Intervention

The CBRCI instructional model was implemented through five stages: (1) Formulating Problems, (2) Problem-Solving Processing, (3) Association, (4) Discussion, and (5) Evaluation. These stages guided students from initial problem exploration to solution refinement through group discussion and reflection. The model emphasizes contextual learning, collaborative inquiry, and reasoning-based assessment. A summary of the CBRCI model stages is presented in Table 1.

3.5 Data Analysis

Paired t-tests were used to compare pre-test and post-test results across the four problem-solving dimensions. Effect size was also calculated to assess the magnitude of the CBRCI model's impact.

4. RESULT AND DISCUSSION

4.1 Result

This section presents the analysis of changes in students' mean problem-solving skills scores before and after the implementation of the CBRCI model. The results are summarized in Table 2.

Table 2. Results of Paired T-Test on Changes in Mean Problem-Solving Skills Scores

Pair Problem-Solving Skills	Mean Difference (SD)	*t*	*df*	*p*-value
Conceptual Analysis	-1.136 (2.56)	-4.163	87	< .0001
Strategy Analysis	-1.227 (2.09)	-5.498	87	< .0001
Quantitative Analysis	-.932 (1.86)	-4.695	87	< .0001
Meta-Analysis	-1.159 (1.81)	-5.999	87	< .0001

Note: SD = Standard Deviation; df = Degrees of Freedom.

The results of the tests conducted after the implementation of the CBRCI instructional model revealed a significant difference between the average pre-test and post-test scores in problem-solving skills, which were measured across four aspects: conceptual analysis, strategy analysis, quantitative analysis, and meta-analysis.

For the conceptual analysis aspect, the mean difference was -1.136 (SD = 2.56), with a t-value of -4.163, statistically significant at $p < .0001$. In the strategy analysis aspect, the mean difference was -1.227 (SD = 2.09), with a t-value of -5.498, also significant at $p < .0001$. The quantitative analysis aspect showed a mean difference of -0.932 (SD = 1.86) with a t-value of -4.695, again significant at $p < .0001$. Finally, in the meta-analysis aspect, the mean difference was -1.159 (SD = 1.81), with a t-value of -5.999, which was likewise significant at $p < .0001$.

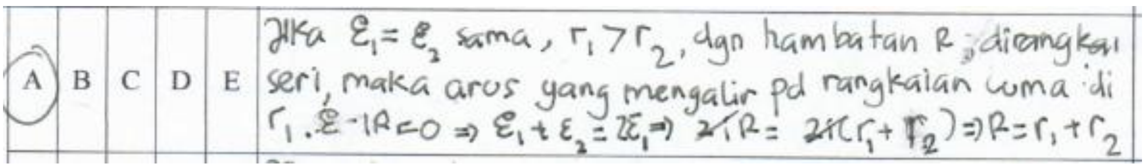
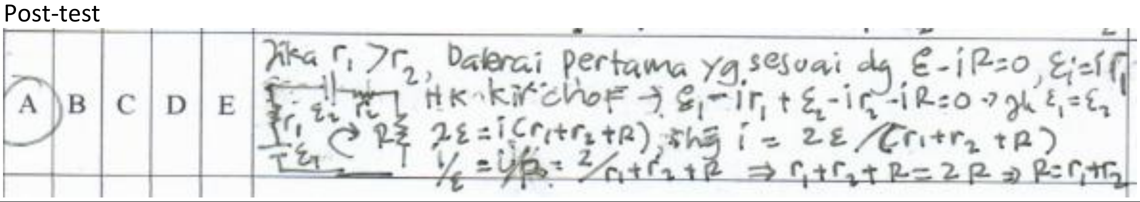
These results indicate a statistically significant improvement in students' problem-solving skills across all four aspects following the implementation of the CBRCI model. Although the t-values are negative, they reflect an increase in performance from pre-test to post-test, as post-test scores were higher. The magnitude of the mean differences suggests the strongest impact occurred in the strategy analysis (M = -1.227) and meta-analysis (M = -1.159) aspects.

Overall, the findings provide strong evidence that the CBRCI instructional model effectively enhances multiple dimensions of students' problem-solving abilities.

4.1.1 Conceptual Analysis

Changes in students' conceptual understanding were analyzed based on their performance in identifying, connecting, and applying key physics principles. The conceptual analysis aspect of problem-solving skills refers to students' ability to identify, understand, and apply key physics concepts relevant to a problem. This includes recognizing core principles, connecting related ideas, and evaluating the assumptions behind a situation. Conceptual analysis forms the foundation for deeper reasoning before performing calculations. An example of a test item used to assess this aspect, along with patterns of students' responses, is shown in Table 3.

Table 3. Sample Test Items for the Conceptual Analysis Aspect and Patterns of Change in Students Responses

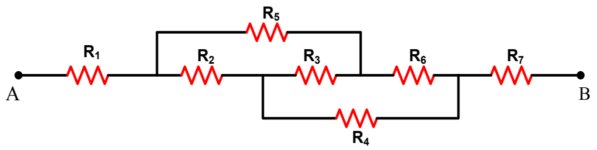
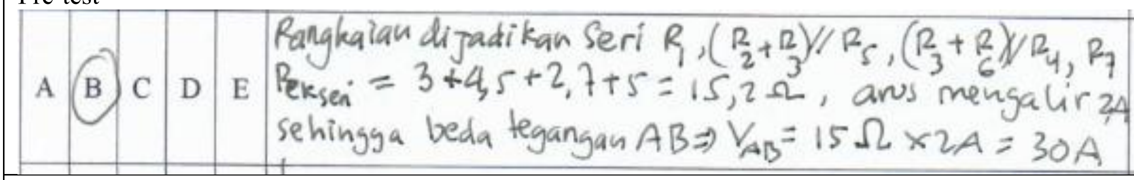
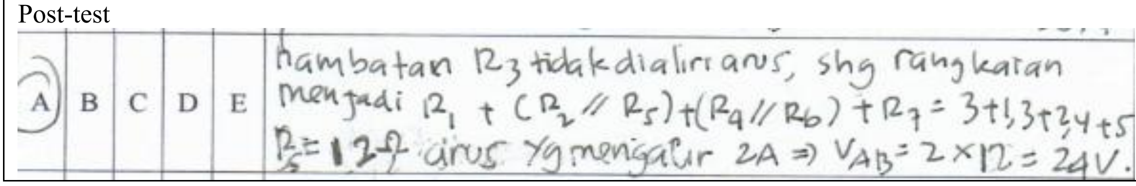
Assessment Item
Two batteries have the same electromotive force. $\varepsilon_1 = \varepsilon_2$, but different internal resistances. The batteries are connected in series with a load resistor. $r_1 > r_2$, What is the value of the load resistor RRR that makes the potential difference at the terminals of one of the batteries zero …. a. $R = r_1 + r_2$ d. $R = \frac{1}{2} r_1 + r_2$ b. $R = 2r_1 - r_1 - r_2$ e. $R = \frac{1}{2} r_1 - r_2$ c. $R = 2r_1 - r_2$ Reason: …………………………………………
Response Changes
Pre-test

Post-test


The assessment task for conceptual analysis asks students to understand key ideas like electromotive force (EMF), internal resistance, and the voltage across a battery. They need to calculate the load resistance that makes the voltage across one battery zero. In the pre-test, students had difficulty understanding these basic concepts, especially EMF, internal resistance, and battery voltage. This was shown by their inability to find the load resistance that causes zero voltage. However, after using the CBRCI learning model, students improved a lot in analyzing these concepts. They showed better understanding and could answer the questions correctly. This means the CBRCI model helped deepen their understanding and connect theory to real-life use. Comparing pre-test and post-test results supports this, with a mean difference of -1.136 (SD = 2.56), a t-value of -4.163, and a significance level of $p < .0001$. This proves that the CBRCI model had a positive and significant effect on improving students' conceptual analysis skills.

4.1.2 Strategy Analysis

The strategy analysis aspect of problem-solving refers to students' ability to plan and select appropriate steps to solve a problem. This involves not only understanding relevant concepts, but also identifying effective methods, procedures, or algorithms to achieve a solution. Strategy analysis requires critical thinking to evaluate the suitability of chosen approaches, considering the problem's goals, constraints, and available resources. An example of a test item used to assess this aspect, along with the changes in student responses, is shown in Table 4.

Table 4. Sample Test Items for the Strategy Analysis Aspect and Patterns of Change in Students Responses

Assessment Item
 Consider the electrical circuit in the picture above, there are seven barriers assembled in a mixed form, while the size of each resistance is, $R_1 = 3\Omega$, $R_3 = R_7 = 5\Omega$, $R_2 = R_4 = 4\Omega$, $R_5 = 2\Omega$, and $R_6 = 6\Omega$. At points A and B connected to a voltage source V, the current flowing in the circuit is equal to $2A$. The measured voltage source passing through point AB is …. a. 24 V d. 35 V b. 30 V e. 40 V c. 32 V Reason: …………………………………………
Response Changes
Pre-test
 A (B) C D E Rangkaian dijadikan seri R_1, $(R_2+R_3)//R_5$, $(R_3+R_6)//R_4$, R_7 $R_{seri} = 3+4,5+2,7+5 = 15,2\ \Omega$, arus mengalir 2A sehingga beda tegangan AB ⇒ $V_{AB} = 15\ \Omega \times 2A = 30A$
Post-test
 (A) B C D E hambatan R_3 tidak dialiri arus, shg rangkaian menjadi $R_1 + (R_2 // R_5) + (R_4 // R_6) + R_7 = 3+1,3+2,4+5$ $R_s = 12\ \Omega$ arus yg mengalir 2A ⇒ $V_{AB} = 2 \times 12 = 24V$.

In this assessment, students were given an electrical circuit containing seven resistors arranged between points A and B, along with known resistance values and total current. They were required to calculate the voltage between points A and B by selecting the appropriate method based on the characteristics of a mixed circuit.

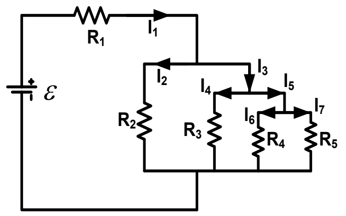
During the pre-test, most students struggled to determine a systematic approach and failed to plan the necessary steps to calculate the source voltage accurately. However, after the CBRCI intervention, students showed marked improvement in planning and selecting correct strategies. They demonstrated more logical and structured thinking in solving the problem.

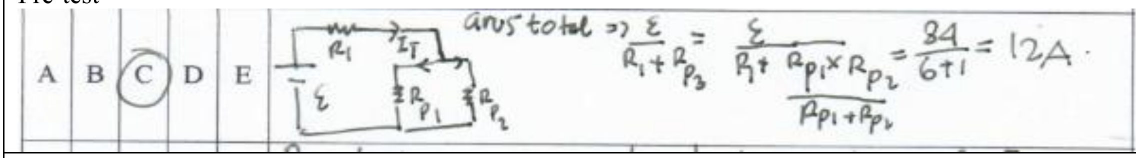
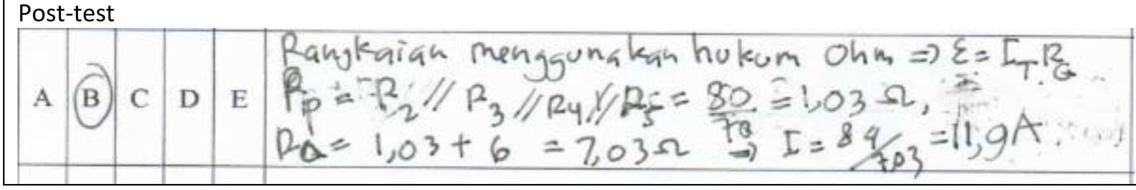
This improvement is reflected in the strategy analysis results, with a mean difference of -1.227 (SD = 2.09) and a t-value of -5.498, which is statistically significant at $p < .0001$. These findings indicate that the CBRCI model positively influenced students' ability to analyze and plan problem-solving strategies effectively.

4.1.3 Quantitative Analysis

The quantitative analysis aspect of problem-solving refers to students' ability to apply mathematical concepts and perform numerical calculations to solve physics problems. This includes using relevant formulas, manipulating variables, and interpreting numerical data systematically. It also involves evaluating the reasonableness of results to ensure consistency with theoretical expectations. Quantitative analysis is essential for producing accurate and evidence-based solutions. An example of a test item used to assess this aspect, along with changes in students' responses, is shown in Table 5.

Table 5. Sample Test Items for the Quantitative Analysis Aspect and Patterns of Change in Students' Responses

<table>
<tr><td>Assessment Item</td></tr>
<tr><td>

Look at the circuit picture above, a battery that has a large EMF of 84 V, strung on five bulbs as shown in the picture. As each bulb has a large resistance, $R_1 = 6\Omega, R_2 = 10\Omega, R_3 = 8\Omega, R_4 = 4\Omega, R_5 = 2\Omega$. The amount of total current flowing in the circuit and the potential difference that exists in the resistance R_2, R_3, R_4, R_5 is ….
a. $I_t = 8{,}7A, V_p = 10{,}2V$ c. $I_t = 11{,}5A, V_P = 11{,}9V$
b. $I_t = 10{,}2A, V_p = 12{,}5V$ d. $I_t = 12A, V_P = 8{,}85V$
e. $I_t = 15A, V_P = 9{,}35V$
Reason: ……………………………………………</td></tr>
<tr><td>Response Changes</td></tr>
<tr><td>Pre-test
</td></tr>
<tr><td>Post-test
</td></tr>
</table>

In this assessment, students were presented with a circuit containing five resistors with known resistance values and an 84V battery. They were required to calculate the total current in the circuit and the potential difference across resistors $R_2, R_3, R_4,$ and R_5. Solving this problem required applying key electrical principles, including Ohm's law and Kirchhoff's laws.

In the pre-test, most students struggled to apply these concepts accurately, indicating gaps in both conceptual understanding and mathematical reasoning. After the CBRCI intervention, students showed marked improvement in applying electrical laws to solve current and voltage problems.

From the perspective of quantitative analysis, the CBRCI model helped students build a stronger conceptual foundation and improved their ability to perform accurate calculations. This is supported by a mean difference of -0.932 (SD = 1.86) and a t-value of -4.695, which is statistically significant at $p < .0001$. These findings indicate that the CBRCI model effectively enhances students' quantitative problem-solving skills in the context of electrical circuits.

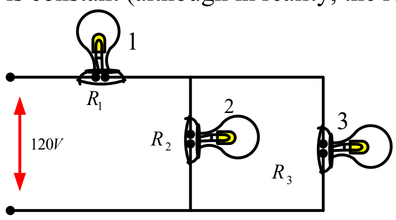
4.1.4 Meta- Analysis

The meta-analysis aspect of problem-solving refers to students' ability to reflect on and evaluate their problem-solving process. This includes reviewing the steps taken, assessing the effectiveness of selected strategies, and analyzing the accuracy of the final results. Meta-analysis involves identifying errors, recognizing strengths and weaknesses, and using the experience to improve future problem-solving efforts. In essence, it is a reflective process that supports continuous learning and skill refinement. An example of a test item used to assess this aspect, along with changes in student responses, is presented in Table 6.

Table 6. Sample Test Items for the Meta-Analysis Aspect and Patterns of Change in Students' Responses

Assessment Item

Three light bulbs have the same power and voltage, they are 60W and 120V. These three light bulbs are connected to a 120V voltage source as shown in the figure below. It is assumed that the resistance of each light bulb is constant (although in reality, the resistance can increase sharply according to the current).



Solve the total power supplied by the electric voltage source and the potential difference across the 2nd and 3rd light bulbs!

a. $P = 40W; V_{23} = 50V$

b. $P = 40W; V_{23} = 40V$

c. $P = 50W; V_{23} = 50V$

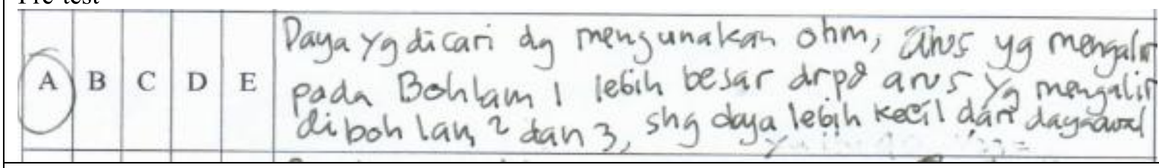
d. $P = 50W; V_{23} = 40V$

e. $P = 60W; V_{23} = 30V$

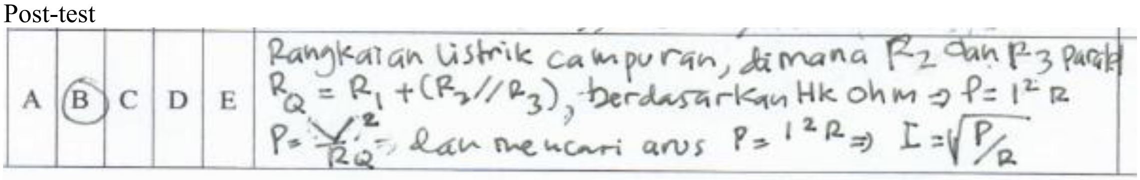
Reason: ……………………………………………

Response Changes

Pre-test



Post-test



In this assessment, students were given a problem involving three light bulbs connected to a 120V power supply, assuming constant resistance. They were required to calculate the total power and the potential difference across each bulb by applying concepts of power, voltage, and resistance.

In the pre-test, most students struggled to integrate these concepts and critically assess the problem-solving process. However, after the CBRCI intervention, students demonstrated significant improvement in evaluating and refining their approaches. They became more capable of applying multiple concepts coherently and analyzing the effectiveness of their strategies.

From a meta-analysis perspective, the CBRCI model supported the development of reflective thinking, enabling students not only to understand the problem-solving process but also to assess and improve it. This improvement is reflected in the post-test results, with a mean difference of -1.159 (SD = 1.81) and a t-value of -5.999, statistically significant at $p < .0001$. These results affirm that the CBRCI model effectively enhances students' metacognitive problem-solving abilities.

4.1.5 Effect Size of the CBRCI Model on Each Aspect of Problem-Solving Skills

The results of the effect size analysis of the CBRCI model on each aspect of problem-solving skills are presented in Table 7.

Table 7. Effect Size CBRCI model

Problem-Solving Skills	n	Pre-Test		Post Test		Effect Size
		M	SD	M	SD	
Conceptual Analysis	88	9.39	1.466	10.52	1.813	0.599
Strategy Analysis	88	8.33	1.506	9.56	1.429	0.745
Quantitative Analysis	88	6.39	1.426	7.32	1.130	0.697
Meta-Analysis	88	8.13	1.388	9.28	1.222	0,867

The effect size analysis revealed varying levels of improvement across the four aspects of problem-solving skills. The conceptual analysis aspect showed a moderate effect size of 0.599, while the strategy analysis aspect demonstrated a stronger effect size of 0.745, indicating substantial improvement in students' strategic thinking. The quantitative analysis aspect yielded an effect size of 0.697, suggesting a notable enhancement in students' calculation skills. The meta-analysis aspect recorded the highest effect size of 0.867, reflecting a strong improvement in students' reflective and evaluative abilities. Overall, these findings indicate that the CBRCI model has a considerable and positive impact on enhancing all dimensions of students' problem-solving skills.

4.2 Discussion

4.2.1 Changes in Problem-Solving Skills

The implementation of the CBRCI model significantly improved students' problem-solving skills across four key aspects: conceptual analysis, strategy analysis, quantitative analysis, and meta-analysis. Paired t-test results showed significant improvements in all aspects, with p-values < 0.001. The greatest mean improvement was in strategy analysis (-1.227), followed by meta-analysis (-1.159), conceptual analysis (-1.136), and quantitative analysis (-0.932). These findings suggest that the CBRCI model promotes effective skill development, supported by active student engagement, instructor guidance, and adaptive teaching strategies.

These results are consistent with prior studies, which have shown that learning models emphasizing critical and reflective thinking significantly enhance students' analytical skills and that active engagement, contextual relevance, and instructor competence support learning success (Hmelo-Silver et al., 2007; Zuza et al., 2016). Differences in findings across studies may be attributed to contextual variables such as learner motivation, student background, and instructional conditions (Bramwell-Lalor & Rainford, 2014; Facione, 2000; Ho et al., 2013; Pérez & Torelló, 2012; Van den Hurk et al., 2016). Instructor expertise and instructional design quality also significantly influence outcomes (Barrows & Tamblyn, 1980; Chen & Wu, 2023; Jundu et al., 2020; Li & Mak, 2022).

This study contributes empirical evidence that the CBRCI model significantly improves all measured aspects of problem-solving. Paired t-test results indicate increased student awareness and correction of conceptual misunderstandings. CBRCI supports the simultaneous development of complex skills such as strategy formulation and metacognitive reflection.

4.2.2 Effect Size of the CBRCI Model

Effect size analysis confirmed the model's substantial impact. Conceptual analysis had a moderate effect (ES = 0.599), while strategy analysis (ES = 0.745) and quantitative analysis (ES = 0.697) were moderate to strong. The strongest effect was in meta-analysis (ES = 0.867), indicating that the CBRCI model significantly develops students' reflective thinking. The emphasis on research-based tasks likely contributed to improvements in this domain.

These findings align with prior research, which reported similar effect sizes for cognitive-based learning models in higher education, particularly in enhancing strategic and conceptual skills (Abrahamson & Kapur, 2018; Kapon & Schvartzer, 2023; Rodrigues et al., 2023). The meta-analysis effects observed in this study are consistent with previous research emphasizing the importance of reflective thinking in learning outcomes(Furtak et al., 2012; Qian & Clark, 2016; Siew et al., 2017; Van den Hurk et al., 2016).

Compared to simulation- or collaboration-based models, the CBRCI model demonstrated slightly higher effect sizes, especially in quantitative analysis (ES = 0.697), surpassing the typical range of 0.3–0.6 reported in previous studies (Merl, 2023; Stenberg et al., 2022; ŽivkoviĿ, 2016). This suggests that CBRCI effectively supports the development of high-level analytical and mathematical skills.

Overall, these findings highlight the relevance of the CBRCI model in both higher and school education settings. Its cognitive and research-based approach fosters deep learning, enhances analytical thinking, and prepares students to address real-world problems through reflective and evaluative reasoning. Unlike traditional models that emphasize procedural learning, CBRCI enables students to build advanced problem-solving capacities essential for 21st-century learning demands.

5. CONCLUSION

Based on the findings of this study, it can be concluded that the CBRCI learning model has a significant and positive impact on enhancing students' problem-solving skills, particularly in the context of direct current (DC) topics. The results indicate improvements across all four aspects, conceptual analysis, strategy analysis, quantitative analysis, and meta-analysis with effect sizes ranging from moderate to high. The greatest improvement was observed in the meta-analysis aspect (ES = 0.867), reflecting the model's strength in fostering reflective and analytical thinking. Improvements in strategy (ES = 0.745) and quantitative analysis (ES = 0.697) also demonstrate the model's effectiveness in strengthening students' ability to reason systematically and apply appropriate problem-solving strategies.

The CBRCI model encourages students to engage deeply with the learning process by integrating prior experiences, inquiry, and reflection. Unlike traditional instructional models that often emphasize rote procedures, CBRCI supports the development of higher-order thinking, including critical evaluation and decision-making. These results affirm that the model not only strengthens students' conceptual understanding but also prepares them to solve real-world problems with greater confidence and skill.

Despite these promising results, several limitations must be acknowledged. The study involved a limited sample from three universities, which may not fully represent broader educational settings. The evaluation focused primarily on quantitative outcomes through pre-test and post-test analysis, without capturing qualitative insights into students' learning processes. Moreover, external factors such as student motivation and the relatively short duration of the intervention may have influenced the outcomes.

Based on these limitations, future studies should consider expanding the sample to include more diverse institutions, as well as conducting longitudinal research to assess the sustained impact of the CBRCI model. Qualitative approaches, such as interviews, observations, and case studies, could also provide richer insights into students' cognitive and behavioral changes during learning. Additionally, exploring the integration of CBRCI with digital learning tools may enhance its scalability and effectiveness in varied educational environments.

These findings provide practical implications for physics educators, curriculum designers, and teacher education programs aiming to cultivate students' critical thinking and problem-solving abilities through research-based and inquiry-driven instruction.

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BIOGRAPHIES OF AUTHORS

	**Maria Dewati** Dr. Maria is a dedicated academic with a doctoral degree in Science Education. She currently serves as a lecturer at Universitas Indraprasta PGRI, specializing in the Physics Education Study Program. Her research interests span across Physics, Science Education (IPA), the development of educational instruments and learning models, educational media, and curriculum design. Dr. Maria is passionate about improving the quality of science learning through innovative approaches and practical applications in education. She can be reached via email at: merrdewati@gmail.com Link Orchid: https://orcid.org/0000-0002-0980-4115) https://scholar.google.com/citations?hl=id&user=X97XUw0AAAAJ ID Scopus 57213838438.
	**Sigit Ristanto** Dr. Sigit Ristanto is a dedicated academic with a doctoral degree in Physics. He currently serves as a lecturer at Universitas PGRI Semarang, specializing in the Physics Education Study Program. He is interested in physics research and learning. She can be reached via email at: sigitristanto@upgris.ac.id Link Orchid: https://orcid.org/my-orcid?orcid=0000-0003-1395-8739 Google Scholar: https://scholar.google.com/citations?user=E154XSgAAAAJ&hl=id Link Scopus: https://www.scopus.com/authid/detail.uri?authorId=55501777000
	Irnin Agustina Dwi Astuti is a lecturer in the Department of Physics Education, Universitas Indraprasta PGRI, Indonesia. She focuses on teaching educational technology, ICT for learning, and physics education. She can be contacted at email: irnin.agustina@gmail.com Link orchid: https://orcid.org/0000-0003-1974-6550 Google Scholar: https://scholar.google.com/citations?user=6FzgfLoAAAAJ&hl=id Link Scopus: https://www.scopus.com/authid/detail.uri?authorId=57205061058 Scopus ID: 57205061058