Identification of Prospective Physics Teacher's Problem Solving Skills: A Study on Simple Electrical Circuits Topic

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Problem-solving is one of the essential and crucial skills for physical learning. This study describes the problem-solving skills of college students taking physics education programs and their incorrect answers on simple electrical circuits topic. We used four essay questions representing the series, parallel, combined series-parallel, and double-loop electrical circuits concepts to measure their problem-solving skills. Meanwhile, for describing their problem-solving skills, we used five categories of problem-solving processes, consisting of useful description (UD), physics approach (PA), specific application of physics (SAP), mathematical procedures (MP), and logical progression (LP). Further, to identify their mistakes, we examined the general mistakes in each problem-solving process. Our analysis results suggested that the college students taking the physics education program have relatively high problem-solving skills in the UD and PA categories. Still, they have low skills in SAP and MP categories, with poor ability in the LP category. Their mistakes were mostly observed in drawing complete electrical circuits and the circuits with missing and changing components (UD category), the correlation between each physic concept, law, and principle with the simple electrical circuits topic (PA category), confusion and inconsistency to correctly determine the + or – symbols for every source of voltage and difficulty in using the Kirchoff's second law following the loop direction. Besides, the participants also frequently used incorrect V, and I value on the problem being reviewed (SAP category), did not re-evaluate the order and completeness of their answer, as well as the logical reasoning for the obtained V and I from their problem-solving process based on the scientific and physic concepts and characteristics (LP category).

Keywords: problem-solving skills, incorrect answers, simple electrical circuits

INTRODUCTION

In the last decade, enhancing students' problem-solving skills has been extensively discussed and investigated. In general, the research on this topic has been conducted on the primary (Yanjie Song 2018; Gu et al. 2015), secondary (De Almeida, Salvador, and Costa 2014; Vázquez-Bernal and Jiménez-Pérez 2023; Lee and Byun 2022), and higher education levels (Ceberio, Almudí, and Franco 2016; Yuliati, Riantoni, and Mufti 2018; Youngwook Song 2018; Park 2022; Kuk and Ryu 2022; Liu, Gu, and Xu 2023; Maries 2023). In specific, the available studies have examined the computer-based problem-solving (Pol et al., 2008), integration between learning and representation strategy (De Cock, 2012), strategy and assessment (Docktor et al. 2016; Yuliati, Riantoni, and Mufti 2018; Shanta and Wells 2022), Arnold and Fermi Dirac-based problem-solving competency (Niss, 2018), students' feedback and change of answers (Wancham & Tangdhanakanond, 2022), theoretical model in constructing students' difficulty based on the teaching practices (Vázquez-Bernal & Jiménez-Pérez, 2023), and design of thinking model (Liu et al., 2023).

Even though education experts have conducted numerous studies on problem-solving skills, several issues related to problem-solving skills remain unresolved. For instance, (1) college students are reported facing difficulties and having limited ideas during the problem-solving process (Pol et al. 2008; Hull et al. 2013; (Ivanjek et al., 2021); (2) college students rarely learn and resolve the physics problem while also having a minimum focus in applying the physics principles and building intuition (Mason & Singh, 2010); (3) these students rarely have reflection and learn from their mistakes during the problem-solving process (Ryan et al., 2016); and (4) they have frail conceptual understanding and neglect the problem-solving procedures (Ceberio et al., 2016).

In the electrical circuit Topics, students are reported having a number of issues, such as (1) difficulties in illustrating and interpreting the electrical circuits while also being unaware of the impacts of changes of an element on the other elements within the circuits (Kock et al. 2013; Kock et al. 2015) and (2) tendency to analyze only the modified parts of the electrical circuits (Engelhardt and Beichner 2004; Karpudewan, Ahmad, and Chandrasegaran 2017). These issues are continuously reported in the last decade. Still, several other classic problems continue to be unresolved, such as (1) most students have hardship in understanding and resolving problems of simple electrical circuits (Arnold & Millar, 1987); Carlton 1999; Lin 2017) and (2) use Ohm law incorrectly and have problems in analyzing the effects between components (Cohen et al., 1983). About the students' issues in the problem-solving process, the educational experts have proposed several strategies, for instance, (1) the use of inventive problem learning (Barak, 2013), (2) problem-solving vs. troubleshooting assignments (Safadi & Yerushalmi, 2014), (3) development of assessment rubric (Docktor et al., 2016), (4) usage of various learning methods (Jiang et al., 2018),(5) template for learning and evaluation (Burkholder et al., 2020); Price et al. 2022), (6) PheT simulation based formative assessment (Park, 2022), (7) understanding students' mistakes (Lee & Byun, 2022), (8) use of different feedbacks(Wancham & Tangdhanakanond, 2022), as well as (9) exploration of teacher's perception and experience (Lane et al., 2022).

Following those solutions, the most fundamental and crucial issues in students' problem-solving skills still have not been investigated comprehensively using the perspective of students. Without investigating this central element, the available solutions will not resolve students' issues in the problem-solving process. Therefore, investigating the detailed process of students' problem-solving and mistakes is crucial. For investigating students' problem-solving and incorrect answers, we used the problem-solving process with five categories, namely(1) useful description, (2) physics approach, (3) specific application of physics, (4) mathematical procedures, and (5) logical progression (Docktor et al., 2016). Additionally, learning from incorrect answers facilitates students to be mindful of their mistakes in interpreting physics concepts and principles (Safadi & Yerushalmi, 2014). However, the available studies rarely discuss the physical concepts and principles students use in the problem-solving process, primarily in the simple electrical circuits topic.This study aims to describe college students' problem-solving processes and their incorrect answers in simple electrical circuit Topic. In specific, this study carries two purposes, (1) to characterize the students' problem-solving process and (2) to identify their incorrect answers during the problem-solving process with simple electrical circuit topic.

METHOD

In this study, 37 college students participated (12 male and 25 female students). These students were from the Physic Education Study Program of the Faculty of Teacher Training and Education Science of Universitas Halu Oleo, Indonesia. All of our participants had attended the Fundamental of Physics course.

We used four problem-solving essay questions representing simple electrical circuit concepts for the research instrument. In detail, the questions were about (1) resistance in series circuits, (2) resistance in parallel circuits, (3) resistance in series-parallel circuits, and (4) double-loop electrical circuit. The question items were adapted from the DIRECT items (Engelhardt & Beichner, 2004). Further, the items underwent a validity test involving three physics lecturers, focusing on the language, construct, and content.

TABLE 1
SCORING RUBRIC FOR PROBLEM-SOLVING SKILLS

Category	Score 5	Score 4	Score 3	Score 2	Score 1	Score 0
Useful Description	The description is useful, appropriate, and complete.	The description is useful, but contains minor omissions or errors.	Parts of the description are not useful, missing, and/or contain errors.	Most of the description is not useful, missing, and/or contains errors.	The entire description is not useful and/or contains errors.	The solution does not include a description and it is necessary for this problem/solver.
Physics Approach	The physics approach is appropriate and complete.	The physics approach contains minor omissions or errors.	Some concepts and principles of the physics approach are missing and/or inappropriate.	Most of the physics approach is missing and/or contains errors.	All of the change concepts and principles are inappropriate.	The solution does not indicate an approach, and it is necessary for this problem/solver.
Specific Application of Physics	The specific application of physics is appropriate and complete.	The specific application of physics contains minor omissions or errors.	Parts of the specific application of physics are missing and/or contains errors.	Most of the specific application of physics is missing and/or contains errors.	The entire specific application of physics is inappropriate and/or contains errors.	The solution does not indicate an application of physics and it is necessary.
Mathematical Procedures	The mathematical procedures are appropriate and complete.	Appropriate mathematical procedures are used with minor omissions or errors.	Parts of the mathematical procedures are missing and/or contains errors.	Most of the mathematical procedures are missing and/or contains errors.	All mathematical procedures are inappropriate and/or contains errors.	There is no evidence of mathematical procedures, and they are necessary.

Category	Score 5	Score 4	Score 3	Score 2	Score 1	Score 0
Logical Progression	The entire problem solution is clear, focused, and logically connected.	The solution is clear and focused with minor inconsistencies.	Parts of the solution are unclear, unfocused, and/or inconsistent.	Most of the solution parts are unclear, unfocused, and/or inconsistent.	The entire solution is unclear, unfocused, and/or inconsistent.	There is no evidence of logical progression, and it is no necessary.

The analysis of obtained data was carried out using the five categories of problem-solving procedures, namely (1) useful description, (2) physics approach, (3) specific application of physics, (4) mathematical procedures, and (5) logical progression. The problem-solving scoring rubric is presented in Table 1.

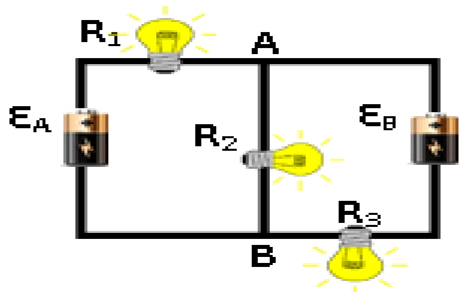
The students' problem-solving skills were described following the stages of problem-solving procedures and the five scale of assessment rubric (0-5) shown in Table 1. In evaluating students' answers, we coded and scored them based on the indicators. For the scoring of each problem-solving category, they were given a score of 0 if the students provided no answer or answers with irrelevant concepts and pictures. In contrast, the scores 1-4 were given following the completeness of the student's answers, and the score of 5 was given for the complete, suitable, clear, and logical answers. Besides, we also constructed more detailed scoring indicators following the scoring rubric in Table 1 to ease the evaluation of students' answers in simple electrical circuit Topics. The scoring indicators are presented in Table 2.

TABLE 2
INDICATORS FOR SCORING STUDENTS' PROBLEM-SOLVING SKILLS IN SIMPLE ELECTRIC CIRCUIT TOPIC

Categories	Indicators
Useful description	The known physical quantity, unknown physical quantity, figure or diagram, the direction of electric current, and the direction of loop required to answer the question
Physics Approach	General physic laws, principles, concepts, and formulas in the electric circuit topic
Specific application of physics	Particular application of the physical laws, principles, and formula based on the types or kinds of electrical circuits and the types of the quantity being questioned in the items
Mathematical procedure	Implementation of the mathematic operations, such as multiplication, division, addition, and subtraction, as well as the suitable usage of the -/+ symbol from the change of quantity in the question item
Logical progression	Coherent, procedural, thorough, logical, and scientifically correct or accurate application of the problem-solving procedures

The example of the question item for the double-loop electrical circuit is described in the following.

FIGURE 1
DOUBLE-LOOP ELECTRICAL CIRCUIT



Two batteries, A and B, with potential differences of V_A = 12 Volt and V_B = 10 Volt, are connected to three resistors with the resistance of R_1 = 3 Ω, R_2 = 2 Ω, and R_3 = 4 Ω, forming an electrical circuit shown in Figure 1, Please determine (a) the amount and direction of the electrical current on R_1, R_2, dan R_3, (b) potential difference on resistance R_3.

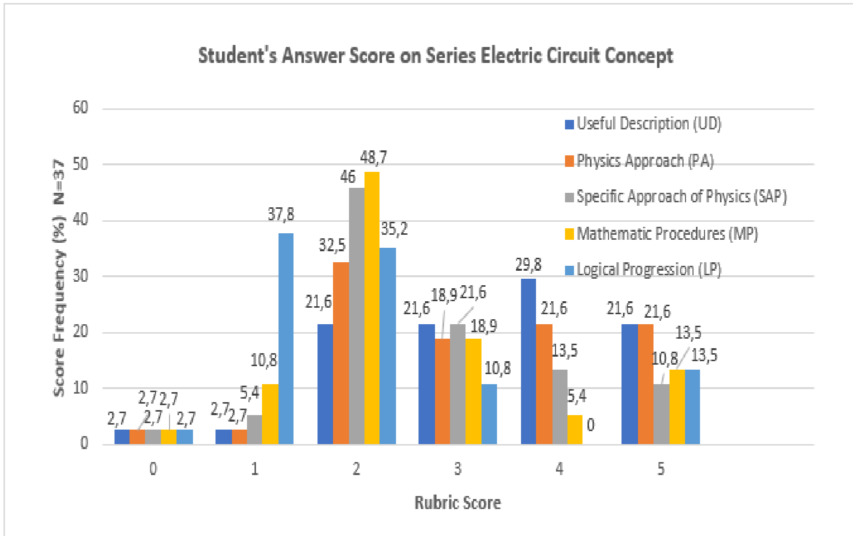
The scoring and coding of the student's answers were carried out using the indicators presented in Table 2. Then, their answers were quantified to describe each participant's problem-solving process and skills.

In addition, to identify participants' incorrect answers, we reviewed and examined their answers in every problem-solving process and category. We also conducted data reduction by selecting students who had provided answers for the four problem-solving question items to ensure that the data being analyzed came from the same respondent. Then, we conducted a further investigation to identify participants' incorrect answers based on four categories of problem-solving processes, namely (1) useful description, (2) physics approach, (3) specific application of physics, and (4) logical progression. This process was used as the reference for data analysis since it served as the fundamental and crucial process for learning, comprehending, and solving physics problems. Besides, most students face no issues using mathematics formulas and calculations during problem-solving (Ceberio et al., 2016). In the end, we chose and analyzed three incorrect answers or concepts for every problem-solving category.

RESULTS

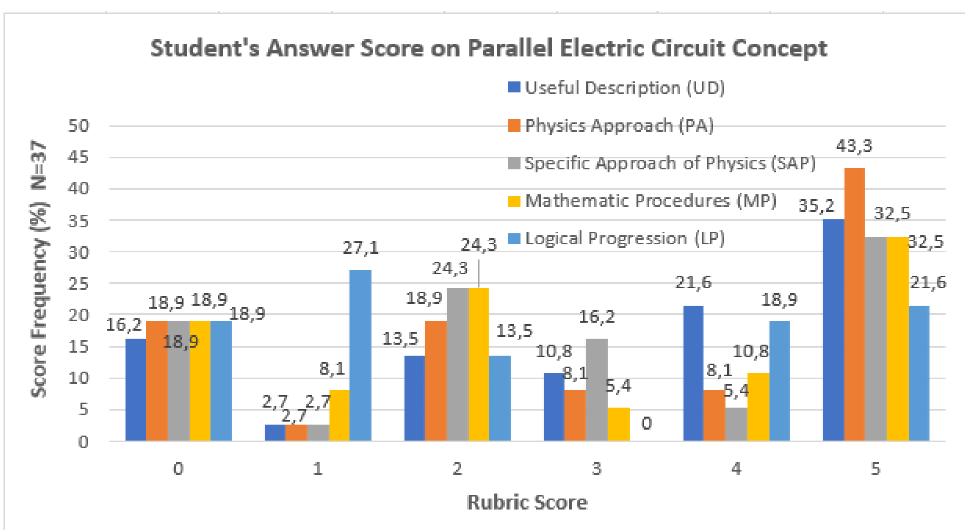
In this section, we describe students' answers on the simple electrical circuit Topic using five problem-solving categories. Figure 2 illustrates the spread of participants' problem-solving process from their answers for a series electric circuit. Of the 37 participants, their highest problem-solving skills are in the UD category.

FIGURE 2
OBTAINED PROBLEM-SOLVING PROCESS ON SERIES ELECTRICAL CIRCUIT



In addition, 29.8% of participants in the PA category had low negligence or error. In the SAP category, 32.5% of them missed most of the physical approach or used an irrelevant approach, 46% missed in the SAP category, 48.7% missed or used incorrect in the MP category, and 37.8% of their answers were unclear, not focus and not consistent in the LP category. Meanwhile, in the other problem-solving category, the participants' answers were suitable and complete, with apparent, focused, and logically linked solutions (higher than 21.6% of 37 participants). Generally, the participants' problem-solving process on the series electrical circuit are counterproductive, incomplete, and contains errors, while their solutions are unclear, not focused, and not consistent. The participants' problem-solving processes on the parallel electric circuits question item are illustrated in Figure 3.

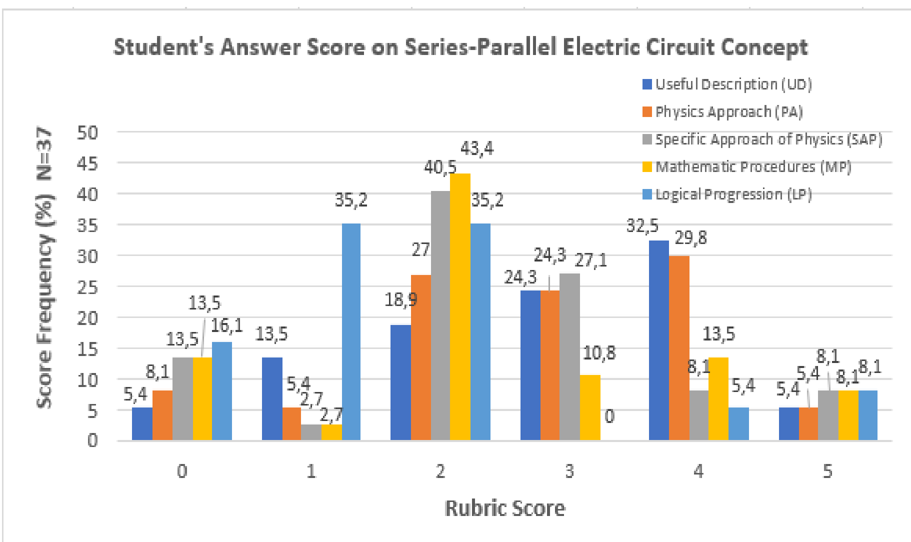
FIGURE 3
OBTAINED PROBLEM-SOLVING PROCESS ON PARALLEL ELECTRICAL CIRCUIT



As shown in Figure 3, from the total of 37 participants, the highest percentage was obtained in the UD category (35.2%). Meanwhile, in the PA category, 43.3% of participants provided a relevant and complete physics approach, and 32.5% of participants gave a complete and applicable in the SAP category and comprehensive in the MP category. For the solution, 27.1% of participants provided unclear, non-focus, and non-consistent answers in the LP category. Additionally, a number of participants presented incomplete problem-solving processes, especially in the UD category (16.2%) and the other four categories (18.9%). Largely, the participants had given relevant and thorough useful descriptions, as well as provided physic approach, specific applications of physics, and mathematical procedures on the parallel electrical circuit with apparent, focused, and logically correlated solutions for every question item. The participants' problem-solving processes on the series-parallel electric circuit are summarized in Figure 4.

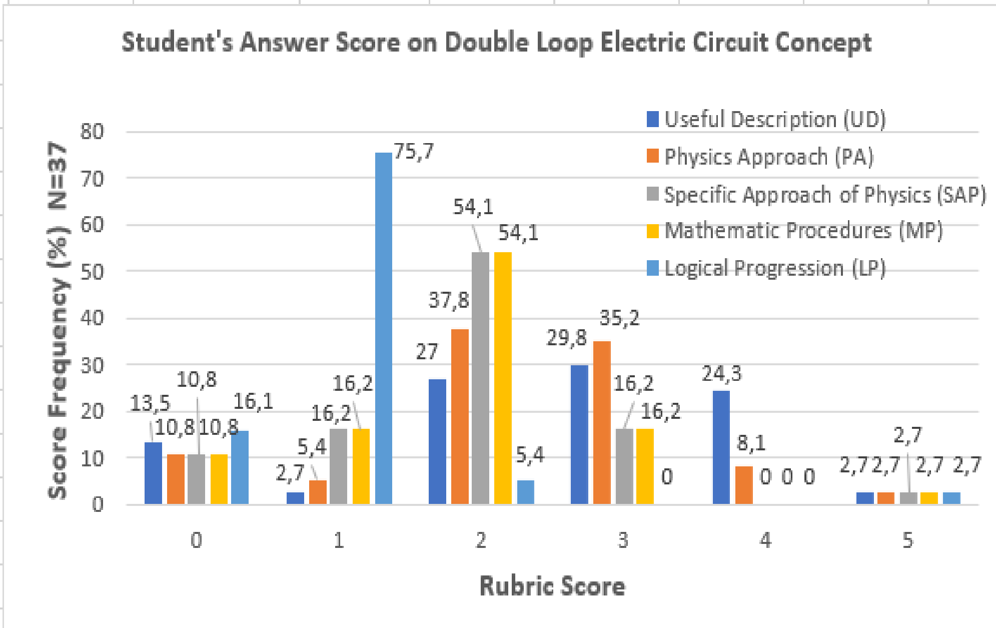
As illustrated in Figure 4, the participants scored the highest problem-solving skills in the UD category (32.5%) with useful description and low mistakes. Meanwhile, participants attained 29.8% in the PA category, 40.5% in the SAP category, 43.4% in the MP category (absence or wrong mathematic procedure), and 32.5% of the solution were unclear, not focused, and not consistent in the LP category. Several participants did not conduct the problem-solving process in this item entirely, with the highest absence or incorrect answers in the LP category (16.1%). Only a minimum number of participants conducted the problem-solving process properly and accurately with great useful description, physics approach, specific application of physics, mathematical procedure, and logical progression.

FIGURE 4
OBTAINED PROBLEM-SOLVING PROCESS ON SERIES-PARALLEL ELECTRICAL CIRCUIT



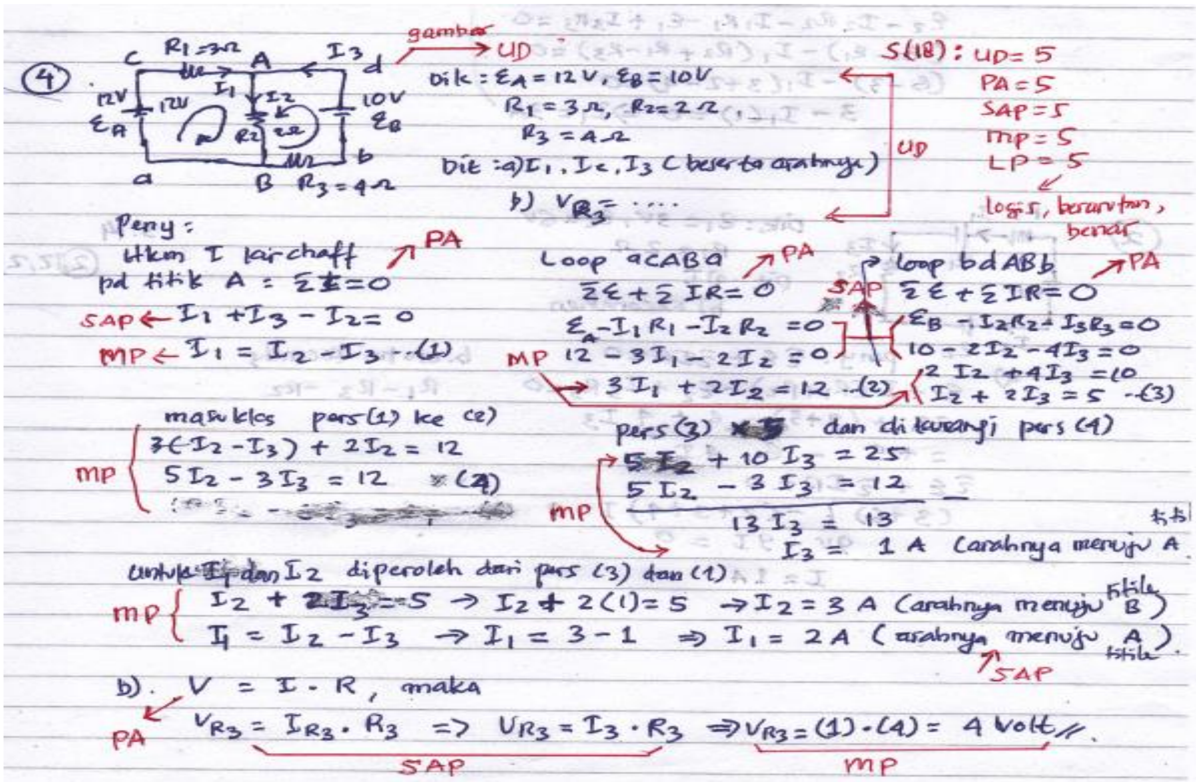
During problem-solving in the series-parallel circuits, the participants showed minimum mistakes in UD and PA categories. Most of the specific physic approaches and mathematical procedures disappeared and were incorrect, while most solutions were unclear, not-focus, and inconsistent. In addition, Figure 5 presents the participants' problem-solving skills in the double-loop electrical circuit question item.

FIGURE 5
OBTAINED PROBLEM-SOLVING PROCESS ON DOUBLE LOOP ELECTRICAL CIRCUIT



In the double loop circuit question item, we identified 29.8% mistakes in the useful description category, 37.8% in the PA category, 54.1% in the SAP category, 54.1% in the MP category, with 75.7% unclear, not focused, and non-consistent solution in the LP category. Further, several students conduct no problem-solving process, primarily in the LP category (16.1%). Only a limited number of participants (2.7%) completed the problem-solving process accurately and properly, in the categories of useful description, physics approach, specific application of physics and mathematical procedure, as well as a logical progression. In general, during the problem-solving in the series-parallel circuits, the participants provided a fruitless description, the absence or incorrect physics approach, specific application of physics, and mathematical procedural, with unclear, not focused, and inconsistent solution. The example of participants' answers to the double loop electrical circuit question item is shown in Figure 6.

FIGURE 6
EXAMPLE OF PARTICIPANTS' PROBLEM SOLVING (COMPLETE AND CORRECT)

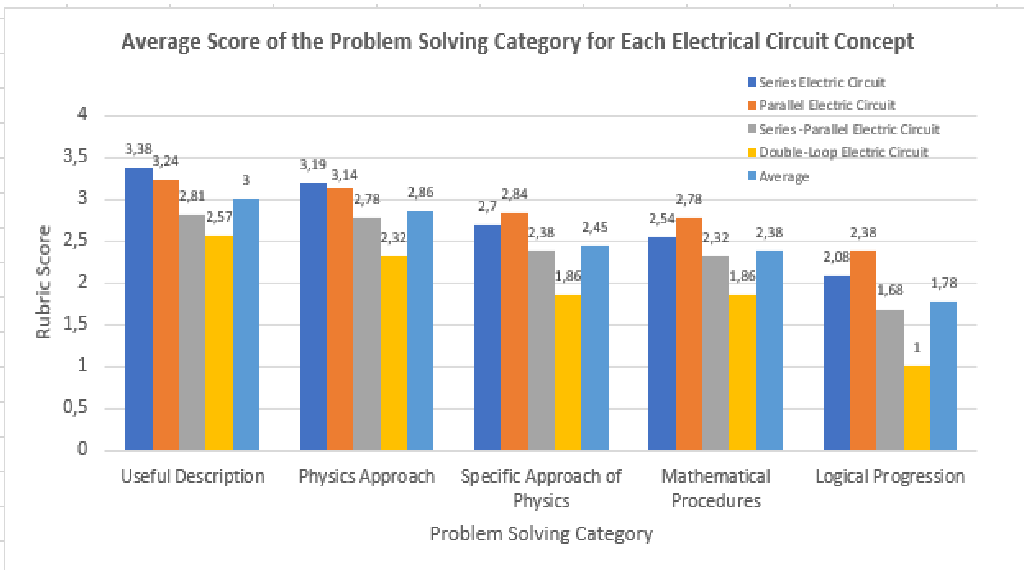


In Figure 6, we presented the complete and correct participants' answers on the double loop circuit question item. From this answer, in the UD category, we observed that the participant has (1) written the known quantities (ε_A, ε_B, R_1, R_2, R_3), (2) provided the questioned quantities (I_1, I_2, I_3, and their direction and V_{R3}), and (3) re-illustrated the electrical circuit along with the direction of each current and loop, as well as the other labels. In the PA category, we observed (1) Kirchoff I law ($\sum I = 0$), (2) Kirchoff II law ($\sum \varepsilon + \sum IR = 0$), and (3) Ohm law ($V = I.R$). Meanwhile, in the SAP category, we found (1) $\sum I = 0 \rightarrow$ at A: $I_I + I_3 - I_2 = 0$, (2) $\sum \varepsilon + \sum I.R = 0 \rightarrow$ at the loop of acABa: $\varepsilon_A - I_1.R_1 - I_2.R_2 = 0$, and loop bdABb: $\varepsilon_B - I_2.R_2 - I_3.R_3 = 0$ equipped with the values inputted in the formula and accuracy of the ε and I following the direction of the loop, and (3) $V_{R_3} = I_3.R_3$ withI_3 and R_3. In the MP category, we identified (1) multiplication and division operations, (2) addition and subtraction operations, and (3) accurate usage of + and – when the physic quantity transforms. Lastly, in the LP category, we discovered that participants had (1) confirmed the order, comprehensiveness, and the obtained final answer and (2) investigated the obtained value for every quantity being questioned based on the physic concept. Thus, the participants provided apparent, focused, and logically connected solutions.

In comparison, we provided examples of the participants' incorrect and incomplete answers to the double loop circuit question item in Figure 6. From this answer, we uncovered incomplete, missing, or incorrect descriptions. First, the figure presented no R3 symbol in the UD category, current or direction. Second, in the PA category, there was no Kirchoff I law ($\sum I = 0$) and Ohm law ($V = I.R$). Third, in the SAP category, Kirchoff's II law was applied incorrectly, in which the R_1, R_2, and R_3 were perceived as the same although following the direction of the loop. Fourth, in the MP category, several mathematical operations were missing, such as the multiplication, division, addition, and subtraction operations, while calculating each current's power. Lastly, in the LP category, many quantities being questioned were left unanswered, while some others were answered with inaccurate concepts due to the perceived same obstruction, absence of each current direction, and illogical potential difference on R_3, where it should be4 Volt since the V_{R2} is 6 Volt, $V_{R2} = \varepsilon_B - V_{R3}$ and $I_2 > I_3$, as shown in the answer in Figure 6. Therefore, the solutions for this question were unclear, focused, and inconsistent.

The obtained average score for every problem-solving category is shown in Figure 7. Universally, the participants present better skills in the UD category than the other four problem-solving categories. Besides, they face a greater challenge in the LP category. The participants tend to have issues in each problem-solving category, which grows greater following the increase of the learning Topic difficulties. However, our data analysis results also showed that the participants perform better in the specific application of physics, mathematical procedures, and logical progression categories in the parallel circuit than in other circuits. In the end, participants found the useful description to be the easiest, while the logical progression was the most complex problem-solving category in the simple electric circuit topic.

FIGURE 7
OBTAINED PROBLEM-SOLVING SKILLS ON SIMPLE ELECTRICAL CIRCUITS FOR EACH CATEGORY



The results of data analysis suggested that the participants' problem-solving skills are relatively low, with only one category with higher than three scores. In contrast, the other category scored lower than 3. In other words, most of the participants' problem-solving is counterproductive, missing, irrelevant, and contains mistakes, resulting in unclear, focused, and inconsistent solutions. The summary of the problem-solving skills of college students taking physics education programs on simple electrical circuit topic is presented in Table 3.

TABLE 3
INCORRECT ANSWERS OF PARTICIPANTS ON SIMPLE ELECTRICAL CIRCUIT TOPIC

No	Problem-Solving Category	Incorrect or inaccurate problem-solving answer
1.	Useful Description	1. Construction of an incomplete electric circuit image, in which the image is needed for the specific application of the physics category 2. Absence of new model or electrical circuit after changes of components change 3. Inability to understand the determination ofI direction in an electrical circuit, especially for a circuit with branches or more than one source of voltage
2.	Physics Approach	1. Low ability to comprehend the correlation between the physics laws and principles 2. Incomplete expression of the physic approach related to the question item 3. Improper usage of formulas (such as $R_{eq} = \frac{1}{Rn}$)
3	Specific Application of Physics	1. Inability to apply the Kirchoff II law properly, especially in the use of + and – symbols on each resistance and or source of voltage, following the specific direction of the loop 2. Frequent inaccurate usage of V and I on particular resistance 3. Inability to differentiate the values of hindrance and electrical power (Watt = Ω)
4	Logical Progression	1. Inability to re-examine the V and I values obtained from the problem-solving process to find the logical answer 2. Inability to recheck the order and completeness or correctness of the answers and solution thoroughly

DISCUSSION

By investigating the participants' problem-solving procedures in the simple electrical circuit Topic, we confirmed that the problem-solving process could be identified following its categories. Accordingly, we identify the participants' problem-solving skills, from the lowest to the ones capable of offering accurate, comprehensive, correct, and logically correlated answers to the physics concept. Different from the common problem-solving studies that investigate the participants' paradigm, working procedure, and structure in working on general problems (Walsh et al., 2007), in this study, we describe the participants' problem-solving skills in every category thoroughly (Docktor et al., 2016). Thus, we deeply examine each of the participants' answers, using the categories, involving whether they have given concrete and complete responses, their mistakes, and the correlation of their solution to each indicator. The question items requiring two or more concepts can be challenging, but college students have been equipped with the skills to resolve them.

In the first category (useful description), our analysis showed that the participants generally gave useful descriptions (more than 50% of the 37 participants) for the series electric circuits, parallel circuits, combined circuits, and double loop circuits question items. On average, their answers have been in 3 to 5 levels (from 0 to 5 levels). Meanwhile, the expected level is 4 (minimum mistakes) and 5(accurate and complete). Most of the students presented better scores in the series and series-parallel question (level 4), followed by the parallel circuit question (level 5) and double loop question (level 3). The participants' incomplete or incorrect description reflects their inability to properly illustrate the problem solvency in a figure. Especially in the double loop question item, the participants were unable to write down the direction of current for every hindrance, the source of voltage, and the direction of the loop. Meanwhile, in the series circuit, the participants faced issues in determining the I direction of the electric current (where the question used two batteries with their poles in the opposite direction). Previous studies also reported students' difficulties in working on problem-solving questions in the form of graphics and figures (De Cock, 2012), along with issues in constructing and drawing electrical circuits (Kock et al., 2013). Contrarily, figures are essential in physics learning as it aids students in organizing their knowledge and constructing understanding which later equips them to resolve a problem (Namdar & Shen, 2016). Our finding indicated that generally, the physics education study program students have relatively good problem-solving skills (average score of 3). Our participants have mostly provided useful descriptions during the problem-solving process, although they have some mistakes or missing concepts.

In the category of physics approach, the participants have relatively good problem-solving processes (problem-solving skills level ranging from 3 to 5) on the series, parallel, and series-parallel electric circuits Topic. However, the double loop circuits attain problem-solving levels of 2 (37.8%) and 3 (35.2%). In this category, the participants scored better in the series electrical circuit question item (relatively high people in levels 4 and 5) and parallel circuit (level 3). Most of the participants' mistakes or incomplete answers are caused by their non-comprehensive physical approach to solving the problems. Further, our data collection instrument used relatively complex questions, with two intercorrelated questions in every item. For instance, in the double loop circuits, most participants used Kirchoff II laws, while some used Kirchoff I and II laws, with only one using Kirchoff I, Kirchoff II, and Ohm laws. The 10.8% of the participants even used no physic approach, signifying a low conceptual understanding. Another physics approach rarely used by the participants is the P or electric power that is commonly used to determine the lamp brightness in a series circuit and I strong electric current in parallel circuit with lamp specification in Watt. Further, in this category, we observed the highest number of participants providing no answers or no physics approach (18.9%), but most participants present great ability in using the suitable physic approach based on the question item. Another study in electromagnetic Topic also reported similar findings (Docktor et al., 2016). Besides, this category serves as the fundamental element in solving specific physic problems.

The third category is a specific application of physics, in which the participants present low problem-solving levels (levels 2 and 3) in the series, series-parallel, and double-loop electrical circuit Topic. The participants have higher problem-solving skills in the parallel circuits question item (ranging from 2 to 5 levels). The majority of students attained problem-solving level 2 in the series electrical circuit (46.0%), series-parallel circuit (40.5%), and double loop circuit (54.1%). Meanwhile, 32.5% of participants have level 5 problem-solving in the parallel circuit question item, indicating their accurate and comprehensive answers. In this category, the participants' mistakes primarily circulate around inaccurate usage of the physic approach and physics quantities or variables based on the variations of figures and non-comprehensive analysis of the provided formation of the electrical circuit. These findings are similar to those reported by previous studies (Engelhardt and Beichner 2004; Karpudewan, Ahmad, and Chandrasegaran 2017), in which the physics problems on simple electrical circuits mostly correlate with the figure of the electrical circuit. Besides, another study uncovered students' problems in resolving problems in the form of figures (Kock et al., 2013).

As shown in Figure 1, most of the college students in the physics education program encounter problems in determining the direction of the electrical current I, although they are capable of calculating the loop's direction. In using the Kirchoff II Law ($\sum \varepsilon + \sum IR = 0$) following the selected direction of the loop (clockwise or anticlockwise), the participants do not determine the symbol + and – correctly and accurately in crossing the voltage source and R resistor. Even many of the participants perceived the current surrounding resistor as the same. They were not aware of the mistaken ideas that became the source of misconception in the double-loop electrical circuit due to their frail understanding of physics laws and concepts (Ceberio, Almudí, and Franco 2016; Riantoni et al. 2017). Further, their misunderstanding can also be caused by their lack of exercise and reflections on their previous mistakes. It is bothersome as these college students are prospective novice physics teachers. In a previous study, novice students are reported to use inaccurate procedural frameworks with no sufficient training and exercises (Ryan et al., 2016). The same results are also observed from students who have a minimum reflection from their previous problem-solving process since this process has been confirmed to facilitate students enhance their problem-solving skills (Safadi and Yerushalmi 2014; Tsovaltzi et al. 2010).

In addition, most participants also gave incorrect answers about the lamp's brightness level (in the series circuit) and in the form of a circuit once its component is broken off (in the series-parallel circuit). Consequently, these participants cannot decide the I electrical current direction, as reported in previous studies (Karpudewan et al., 2017) (Peşman & Eryilmaz, 2010). Besides, the participants' failure in finding the lamp's brightness is induced by their incomprehension that the electrical power impacts the brightness ($P = V.I = \frac{V^2}{R} = I^2.R$) and a change of component within the circuit affects the amount of I electrical current or V potential different within the newly formed circuit. These issues require immediate solution from the future researchers.

In the fourth category, mathematical procedures, our analysis results suggested that the participants have similar performance as in the category of the specific application of physics, primarily in the series, parallel-series, and double-loop electrical circuits. The participants mostly have level 2 of problem-solving with missing or incorrect mathematical procedures. In detail, 48.7, 43.4, and 54.1% of them have level 2 problem-solving skills in the series, series-parallel, and double loop circuits, respectively. Contrastingly, 32.5% of participants performed better in the parallel circuit, in which their answer showed level 5 problem-solving skills with complete and accurate problem-solving. Fundamentally, they have minimum mistakes in the mathematical operation, but they performed poorly in the further process of the specific application of physics. In other words, their incomplete specific application of the physics process results in a low mathematic procedures process. Their deficient mathematic procedure process is also caused by their incomplete, unwritten, and incorrect mathematic operations. For instance, in calculating the equivalent obstacles in the parallel circuit and the electrical current, the participants' mistakes were in the multiplication and division operation (one for each participant). These findings indicate participants' non-poor mathematic procedures, but they cannot apply the specific physic operation. Linearly, a previous study discovered that students face no issues in using mathematic operations and formulas in the problem-solving process (Ceberio et al., 2016), but they have difficulties in implementing the physics concept during the problem-solving process(Yuliati et al., 2018).

In the last category of logical progression, the participants have levels 1 and 2 of problem-solving in the series and series-parallel electrical circuit, while their problem-solving in the parallel circuits ranges from levels 1, 4, and 5. Meanwhile, most of the participants have level 1 problem-solving in the double loop circuits. The majority of participants presented not-focus and non-consistent solutions, so 37.8, 27.1, and 75.7% of them have level one problem-solving in the series, parallel, and double loop electrical circuits, respectively. In the series-parallel circuit, 35.2% of the participants have level 1 and 2 problem-solving, with all or most of their solutions unclear, not focused, and inconsistent. Overall, the participants have the lowest problem-solving abilities in this category in comparison to the other four categories, as presented in Figure 7. As reported in (Docktor et al., 2016), students scored the lowest in the logical progression category. This finding is contrary to the nature and characteristics of physics, as this field of science investigates natural phenomena in daily life that necessitate clear and logically connected physical problem-solving.

Our findings show that our studies offer no comprehensive solution for the low problem-solving skills, primarily on the simple electrical circuit Topic. However, this study enriches the references serving as the fundamental sources for future studies investigating comprehensive and accurate solutions for this issue. Future studies are expected to find a procedure to enhance students' problem-solving skills through physics courses (Maries 2023; De Cock 2012), primarily for the college students taking physics education study programs.

CONCLUSION

Our analysis results indicated that the problem-solving process of college students in the physics education department (prospective physics teachers) could be identified through the five problem-solving categories. Our participants present sufficient problem-solving skills in the categories of useful description and physics approach but poor performance in the categories of the specific application of physics and logical progression. Their low skills are even higher in the double-loop electrical circuit Topic. For the mistakes in the problem-solving process, we observed that the participants gave an incomplete picture of an electrical circuit (especially in I direction and index or label of components within the circuit). They also have feeble ability to decide the appropriate physics concepts, laws, and principles during the problem-solving process. In the series-parallel and double-loop circuits, many participants used V on voltage sources to determine the magnitude of the electric current I on R resistance. Besides, most of them are also incapable of correctly using the + and – symbols in every source of voltage and (R) obstacles, during the implementation of Kirchhoff II law, following the selected loop direction within the double loop circuit.

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