The improvement of electrical circuit problem-solving ability through 5E learning based on knowledge integration

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ABSTRACT

Introduction. The development of global learning and education in the last five years has undergone a significant transformation driven by the demands of 21st century abilities. There is an increasing focus on the development of abilities relevant to the modern job market such as problem-solving. One of the paradigm shifts in higher education has been how to prepare students who are ready to compete in the world of work by improving problem-solving abilities. This improvement can be done by implementing learning that is in accordance with the concepts that students must understand. This also what engineering students must have. In line with that, problem-solving abilities are raised as competencies in the Electronic Engineering study program. Therefore, solving electrical circuit problems is very important for Electronic Engineering students. This study discusses the improvement of electrical circuit problem-solving abilities through 5E learning based on knowledge integration.

Study participants and methods. The research instrument used in this study was essay questions given to 22 Electronic Engineering students of Universitas Nusantara PGRI Kediri to obtain data on problem-solving abilities. These questions are two questions on the concept of Ohm's law and two questions on Kirchoff's law, which are conceptual materials of electrical circuits. The data analysis techniques used in the study were quantitative and qualitative data analysis. Quantitative data were obtained from integrated tests analyzed from problem-solving ability identification scores. Problem-solving abilities increased as indicated by conducting an n-gain value analysis. N-gain was obtained from pretest-posttest scores both globally and for each component. Problem-solving data were analyzed qualitatively, focusing on shifts in the distribution of each ability component and supplemented by students' thinking methods.

Results. First, the median n-gain of problem-solving ability globally is 0.310 in the lower medium category and IQR=0.612-0.290. This indicates that the impact of 5E learning based on knowledge integration increased n-gain global problem-solving ability. 5E learning based on knowledge integration improves students' ability to solve electrical circuit problems globally and in each component. Second, the problem-solving ability consists of four levels from the best to the lowest, namely Level A (doing all problem-solving steps), level B (doing 50% of problem-solving steps), level C (doing 25% of problem-solving steps) and level D (not solving the problem). Each level indicates the level of quality of students' problem-solving ability.

Conclusion. This study shows that 5E learning based on knowledge integration has improved students' electrical circuit problem-solving abilities. However, the concepts of Ohm's law and Kirchoff's law still have challenges, so they require consistent practice. So ideally, in the future, more exercises are needed in 5E learning based on knowledge integration to further improve the problem-solving skills of Ohm's law and Kirchoff's law. In addition, this research is limited to analyzing electrical circuit problem-solving capabilities, so it can be carried out further on other concepts.

KEYWORDS

problem-solving ability, 5E learning, knowledge integration, electrical circuit, Ohm's law, Kirchoff's law, understanding

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INTRODUCTION

The development of global learning and education in the last five years has undergone a significant transformation driven by the demands of 21st century abilities. This indicates that global education faces significant challenges but also shows hope for progress. There is an increasing focus on the development of abilities relevant to the modern job market such as problem-solving. According to the Council of Europe, education must equip students with abilities relevant to the ever changing world of work, including problem-solving abilities. This is in line with one of the pillars developed by UNESCO, learning to know. This pillar emphasizes the importance of developing students' knowledge, skills and abilities, encouraging them to actively solve problems. Therefore, good problem-solving abilities in higher education are essential for students to compete in the world of work [1]. This is demonstrated by one of the competencies of Electronic Engineering study program. The Electronic Engineering study program develops electrical circuit problem-solving abilities as a form of competency that students must possess. To solve electrical circuit problems, students must have a strong conceptual understanding of the scientific or physics ideas in electrical circuit problems. However, students still have naive ideas that will interfere with the problem-solving process.

Naive ideas are conceptual ideas that students adopt based on their daily experiences, but do not yet match the concepts understood by scientists [2]. These naive ideas will interfere with students' problem-solving. So naive ideas must be remediated towards the central idea. An example of a student's naive idea related to electrical circuits is that students in solving electrical circuit material problems only use the surface attributes of the problem [3]. Analyses from various researchers reveal several common misunderstandings among students regarding electric current, voltage, and resistors [4], basic electrical circuits [5], series [6], parallel circuits [7], Ohm's law [8], Kirchoff's law [9], a complex series [10]. In addition, based on the results of observations, students use the plug-and-chug or recursive plug-and-chug problem-solving strategy. Students adopt the plug-and-chug problem-solving strategy, directly applying a remembered formula and inserting numbers without verifying their suitability. Students also understand the voltage of a resistor, in which V is the same as the battery voltage or voltage source, and R is the resistance being discussed. This causes the root of the error in understanding V, I, and R which should not be. Meanwhile, students who use the recursive plug and chug problem-solving strategy use several formulas but with a mathematical thinking process alone without physics. When students face the problem of replacing resistance from a series-parallel resistance circuit, they misunderstand the series circuit as a parallel circuit, so the following problem-solving process is wrong. This shows that students only see the physical appearance of the circuit or problem. Based on the description of the naive ideas held by the students, it can be concluded that students have not succeeded in solving electrical circuit problems. The findings of this study indicate that errors in problem-solving come from students' inability to build and understand relationships between concepts [11] and factors that influence naive ideas are students' personal experiences [12] and not building central ideas in the problem-solving process [13].

Success in solving electrical circuit problems depends on students' conceptual understanding. A strong conceptual understanding is needed to solve electrical circuit problems [14]. The problem-solving process requires a conceptual understanding structure that students have. Building a strong conceptual understanding structure helps students integrate conceptual and problem-solving aspects [15]. Students need support to develop a strong knowledge structure to solve various physics concept problems. Students cannot make connections and develop a strong conceptual knowledge structure without this. Students need to build relationships from ideas to help students develop an integrated and deep knowledge structure. However, students still have a low conceptual understanding, so effective learning is necessary for conceptual understanding. Effective learning is believed to be able to overcome students' naive ideas [16]. The effectiveness of instruction depends on students' active involvement, particularly in problem-solving activities. A student-centered approach impacts student behavior and problem-solving in a collaborative learning environment. However, an in-depth analysis is still needed to identify problem-solving abilities and student difficulties by implementing collaborative learning [17]. Collaborative learning allows students to exchange ideas to improve their abilities [18].

One of the most efficient collaborative learning methods is 5E learning. 5E learning empowers students to construct their knowledge and express their ideas so that they are motivated to be active in learning [19]. Each step of the 5E cycle of learning reflects the interaction between students and teachers, as well as interactions between students. 5E learning can be a better alternative to improve students' understanding of concepts [20]. However, using 5E learning alone is insufficient to improve students' abilities [21]. This is because 5E learning can only improve understanding of electrical circuits. Understanding the concept alone is insufficient to help students solve electrical circuit problems. So, it is necessary to develop 5E learning that can further improve the ability to solve electrical circuit problems, namely 5E integrated learning.

5E integrated learning helps students understand learning well to understand concepts well [22]. Integrated learning is learning that accustoms students to have a deeper understanding of concepts from various perspectives and trains students to think systematically. Integrated learning can improve students' ability to solve problems [23]. Learning that is believed to enhance student development is meaningful learning that provides sufficient space for students to represent problem-solving abilities that involve maximum diagram representation, namely 5E learning based on knowledge integration. 5E learning based on knowledge integration has an elaboration stage dedicated to problem-solving while strengthening conceptual understanding of the central idea of electrical circuits. Although theoretically, 5E learning based on knowledge integration is believed to be successful, it needs to be tested empirically.

THEORETICAL BACKGROUND

Problem-solving is a complex process in learning physics where performance depends on the complexity of the given problem [24]. Problem-solving helps students identify and apply relevant principles to reach solutions [25]. Successful problem-solving requires the ability to: understand the problem, apply and synthesize knowledge, make decisions about how to proceed, access actions taken in resolution processing, and analyze results [26]. Students' problem categorization ability stems from their experiences with and beliefs about physics problem-solving [27].

Problem-solving according to John Dewey, George Polya, Stephen Krulik, and Jesse Rudnick can be grouped and presented in Table 1 [28].

Table 1

Problem-Solving according to John Dewey, George Polya, and Stephen Krulik

Steps in Problems-Solving		
John Dewey	George Polya	Stephen Krulik and Jesse Rudnick
Facing problems	Understanding the problem	Reading problems
Diagnosing or defining the problem	Making a plan	Investigating the problem
Determining multiple solutions	Executing the plan	Choosing a strategy
Determining the expected consequences of the solution	Looking back	Solving the problem
Testing the consequences		Reviewing and expanding solutions.

Physics problem-solving has so far been too focused on single-concept problems [29]. This is due to the inability of students to break down the given situation and make predictions by connecting the physics concepts they have learned. Concept identification is an obstacle for students to solve physics problems. Meanwhile, physics problem-solving requires the application of various concepts and various mathematical applications. This problem-solving process contributes to students' problem-solving abilities, which depend on the wealth of previous knowledge and experience [30]. Problem-solving abilities consist of the process and results of students in solving the problems. Students' problem-solving abilities are measured by their demonstrated ability levels which is categorized into ability components. The components of problem-solving abilities developed by Docktor [31] and the components of electrical circuit problem-solving abilities formulated in this study are presented in Table 2.

Table 2

Components of Problem-Solving Ability

Jennifer Docktor & Ken Heller	Electrical Circuit Problem-Solving Ability Formulated in this Research
1. Useful description 2. Physics approach 3. Specific applications of physics 4. Exact mathematics 5. Development of logic	1. Analyze the circuit to formulate problem-solving steps 2. The accuracy of the concepts/equations applied 3. Accuracy of mathematical use 4. Problem-solving evaluation

Problem-solving ability in this study is the level of students' ability to describe and explain all ideas, and information through the thinking process when solving the problems of electrical circuit material concepts. Problem-solving ability refers to students' capacity to describe and explain ideas and information through their thought processes while solving electrical circuit problems using diagram representations and involving structured knowledge integration based on the level of student understanding of the concept. The problem-solving ability of each student is different depending on the level of each component. Students' problem-solving ability can determine students' ability to master the concept.

RESEARCH METHODS

The learning used in this study was 5E learning based on knowledge integration. The stages of 5E learning based on knowledge integration are packaged in student worksheets. Worksheets are instruction sheets in discussions containing everyday electrical circuit problems that students must solve. The stages of 5E learning based on knowledge integration consist of exploring, explaining, elaborating, and evaluating. The initial stage of implementing 5E learning based on knowledge integration is engagement in where lecturers and students conduct demonstrations with simple electrical circuits to discover the ideas students understand. The next stage is to explore; students perform experiments to prove the validity of Ohm's and Kirchoff's laws in various electrical circuits and collect ideas about student understanding. Furthermore, in the explain stage, students formulate the experiment results to build the central idea of Ohm's and Kirchoff's laws. The fourth stage of 5E learning based on knowledge integration is elaborate where students use the understanding of the central idea of Ohm's law and Kirchoff's law built in the explain stage to solve electrical circuit problems and strengthen the understanding of the central idea in a new context. The last stage is evaluation, an assessment of the understanding of the central idea of Ohm's law and Kirchoff's law. At the evaluation stage, the lecturer gives a quiz consisting of 2 different concepts adjusted to the concept material being studied, namely the concept of Ohm's and Kirchoff's laws.

The research instrument used in this study was essay questions given to 22 Electronic Engineering students to obtain data on problem-solving abilities. These questions are two questions on the concept of Ohm's law and two questions on Kirchoff's law, which are conceptual materials of electrical circuits. Problem-solving ability data were obtained from the problem-solving ability identification score using the Table 3 rubric. The problem-solving ability level consists of 4 levels from the best to the lowest: level A, level B, level C, and level D. Each level states the level of quality of the student's problem-solving ability.

The results of the validity test of the problem-solving ability research instrument show that $r_{xy}>r_{tabel}$ so that question items number 1 to question number 4 are declared valid. The reliability test results using Cohen Kappa Statistics show that the interpretation of problem-solving ability is .79, which means substantial agreement.

The data analysis techniques used in the study were quantitative and qualitative data analysis. Quantitative data were obtained from integrated tests analyzed from problem-solving ability identification scores. Problem-solving ability increased as indicated by conducting an n-gain value analysis. N-gain was obtained from pretest-posttest scores both globally and for each component. The n-gain score criteria were adapted from the development of Sutopo & Waldrip [33]. For n-gain to be meaningful, it is necessary to see the difference test between pretest-posttest scores and the nonparametric Wilcoxon test. Furthermore, an n-gain difference test was carried out between problem-solving ability components using a paired samples test. Problem-solving ability data were analyzed qualitatively in the form of a shift in the distribution of levels of each problem-solving ability component and supplemented with students' thinking methods using stages adapted from Creswell [33].

Table 3

Identification Score Rubric and Problem-Solving Ability Level Category

Component Problem-Solving Abilties	Category	Score
1. Analyze the circuit to formulate problem-solving steps a. Determining the replacement resistance (completed using diagrammatic representation) b. Determining I and V for each obstacle.	Level A: Analyze the circuit to formulate all complete problem-solving steps	3
	Level B: Analyze the circuit to formulate 50% of the problem-solving steps	2
	Level C: Analyze circuits to formulate 25% of the solution steps.	1
	Level D: Does not formulate problem-solving procedures	0
2. The accuracy of the concept/equation applied a. Applying the concept of Ohm's law and Kirchoff's law b. Applying Ohm's law and Kirchoff's law equations	Level A: Using concepts/equations that are appropriate and applicable to determining the solution to the given problem	3
	Level B: Uses concepts/equations that are appropriate and do not apply to determining the solution to the given problem	2
	Level C: Using concepts/equations that are inappropriate and do not apply to determining the solution to the given problem	1
	Level D: Does not use concepts/equations	0
3. Accuracy of mathematical use a. Applying mathematical numbers to the solution of Ohm's law and Kirchoff's law problems b. Applying mathematical operations to the solution of Ohm's law and/or Kirchoff's law problems	Level A: Using mathematical numbers and mathematical operations appropriately and precisely for the given problems.	3
	Level B: Using mathematical numbers and mathematical operations that are less appropriate and less precise for the given problem.	2
	Level C: Using mathematical numbers and operations that are inappropriate or inappropriate for the given problem.	1
	Level D: Does not use mathematical numbers and mathematical operations	0
4. Problem-solving evaluation a. Explains the circuit solution b. Explaining the solution to Ohm's law and/or Kirchoff's law problems	Level A: Provides an explanation of the solution to the series/problem that is appropriate and precise in describing the solution to the problem.	3
	Level B: Provides an explanation of part of the solution to the series/ problem that is appropriate and precise in describing the solution to the problem.	2
	Level C: Does not explain the solution to the series/problem that is appropriate and precise in describing the solution to the problem.	1
	Level D: Does not evaluate problem-solving	0

STUDY RESULTS

1. Problem-Solving Abilities

The increase in problem-solving ability is expressed by n-gain from pretest to posttest. Since n-gain is calculated from the difference in posttest scores to the pretest, the differences between the pretest and post-test were tested statistically to ensure their significance. The results showed significant differences between pretest and posttest scores globally and per component. The n-gain of problem-solving ability globally and per component are presented in sequence in Table 4. The median n-gain of problem-solving ability globally is .310 in the lower medium category and IQR=.612-.290 <Table 4>. Meanwhile, the n-gain of each component in the sequence is a mean of

.461 in the upper medium category and sd=.284 (for component 1), a mean of .422 in the lower medium category and sd=.162 (for component 2), a mean of .264 in the lower medium category and sd=.375 (for component 3), and a mean of .384 in the lower medium category and sd=.222 (for component 4). The results of the n-gain difference test of problem-solving ability component pairs showed that component pairs 1 and 3 and component pairs 2 and 3 were significantly different Table 5. This indicates that the impact of 5E learning based on knowledge integration increased n-gain global problem-solving ability. The stages of 5E learning based on knowledge integration used during learning are presented in Figure 1.

Table 4

N-gain of Problem-Solving Ability (PSA) Globally and Each Component

Statistics	Component				Global
	PSA 1	PSA 2	PSA 3	PSA 4	
Q1	.330	.330	0	.200	.290
Q2 (Median)	.415	.330	0	.330	.310
Q3	.750	.500	.627	.607	.612
Mean	.461	.422	.264	.384	.404
Sd	.284	.162	.375	.222	.185
Skewness	.225	.968	.915	-.006	1,304
Information:					
PSA 1: Analyze the circuit to formulate problem-solving steps					
PSA 2: Accuracy of applied concepts/equations					
PSA 3: Accuracy of mathematical use					
PSA 4: Problem-solving evaluation.					

Figure 1 The Stages of 5E Learning based on Knowledge Integration

Table 5

Component Pair	PSA 1 & PSA 2	PSA 1 & PSA 3	PSA 1 & PSA 4	PSA 2 & PSA 3	PSA 2 & PSA 4	PSA 3 & PSA 4
p (significance)	.482	0	.294	.025	.201	.100
t	.716	4,134	1,076	2,412	1,319	-1,721

Table 6

Shift in Problem-Solving Ability of Each Component

Problem-Solving Ability Components	Shifting Ways Students Solve Problems		Solution
	Ohm's Law	Kirchoff's Law	
1. Analyze the circuit to formulate problem-solving steps	All students move to level A (Students analyze the circuit to formulate all the steps complete troubleshooting)	Some students are stuck at level B (Students analyze circuits to formulate 50% of the steps) solution to the problem)	Students analyze the circuit to formulate problem-solving steps for Kirchoff's laws with four steps, namely: 1. determine the direction of the loop and the direction of the current, 2. determine Ieach branch, 3. determine Ieach obstacle, 4. determine Veach obstacle.
2. The accuracy of the concepts/ equations applied.	Some students move to level A (Students use appropriate and applicable concepts/equations). Determination of the solution to the given problem)	Some students shifted from level C (Students use inappropriate and irrelevant concepts/equations) applies to determining the solution to the given problem) to level B (Students use appropriate concepts/equations and do not apply in determining the solution to the given problem)	Students apply concepts/equations by combining two steps, namely: 1. applying the concept/equation of Kirchoff's first law 2. applying the concept/equation of Kirchoff's II law and then determining each branch and Vhhe resistance.
3. Accuracy of mathematical use	All students move to level A (Students use mathematical numbers and mathematical operations) appropriate and precise to the given problem)	Some students are stuck at level B (Students use mathematical numbers and mathematical operations that are not suitable and not appropriate to the problem given)	The mathematical numbers and operations are adjusted to the equations for solving Kirchoff's law problems.
4. Problem-solving evaluation	Some students move to level A (Students provide explanations of solutions to series/problems that appropriate and precise in describing the solution to the problem)	Some students shifted from level C (Students did not explain the solution to the series/problem) which is appropriate and precise in describing the solution to the problem) to level B (Students provide part of the solution to the series/problems that appropriate and accurate in describing the solution to the problem)	Students evaluate the solution to Kirchoff's laws by following the way students analyze circuits and use concepts/equations.

2. Shift in How Students Solve Problems from Pretest to Posttest based on Problem-Solving Ability Components

The way students solve problems is categorized into level A, level B, level C, and level D based on their problem-solving abilities. Each level is categorized based on each component of problem-solving abilities and each problem question. Where the components of problem-solving abilities Figure 2 include: (1) Analyzing the series to formulate problem-solving steps, (2) Accuracy of the concept/ equation applied, (3) Accuracy of the use of mathematics, and (4) Evaluation of problem-solving. Levels A, B, C, and D are quality levels that state students' problem-solving abilities. The analysis results of the shift in problem-solving abilities of each component are presented in Table 6.

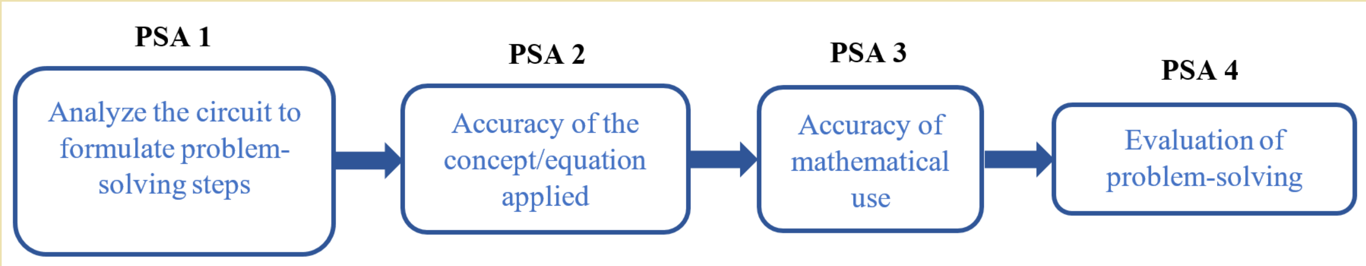

Figure 2 Problem-Solving Ability (PSA) Scheme

DISCUSSION

The analysis results show that 5E learning based on knowledge integration improves students' ability to solve electrical circuit problems globally and in each component. 5E learning based on knowledge integration empowers students to responsibly construct their knowledge and express their ideas so that they are motivated to be active in learning in line with research by Susanti et al. [19]. Each step of the 5E learning based on knowledge integration reflects the interaction between students and teachers, as well as interactions between students. Especially at the explanation stage, students communicate the results of their observations and understanding of electrical circuits, especially in the concept of Ohm's law and Kirchoff's law. This shows that 5E learning based on knowledge integration effectively improves electrical circuit problem-solving abilities. 5E learning based on knowledge integration is meaningful integrated learning. To obtain meaningful learning, conceptual understanding needs to be supported by problem-solving [34]. Problem-solving abilities are based on understanding, planning, solving, and re-evaluating [35]. 5E learning based on knowledge integration is in line with Sengul's integrated learning [36] which can increase student involvement in developing conceptual understanding. In addition, 5E learning based on knowledge integration contributes to improving student abilities which has an impact on their learning outcomes in line with research by [37]. In addition, 5E learning based on knowledge integration can assess conceptual understanding according to the level of ability, as in the research conducted by Duran [38] and Campbell [39]. 5E learning based on knowledge integration is a 5E learning that helps students develop knowledge integration to improve problem-solving abilities and diagram representation abilities to provide solutions to electrical circuit problems with the right concept. This shows that 5E learning based on knowledge integration has advantages that other learning does not have.

Meanwhile, the component pair difference test analysis results show several problem-solving ability components differ. This difference indicates process limitations to identifying each element of problem-solving ability, but there is still a relationship between the components. This problem-solving process contributes to students' problem-solving abilities which depend on the wealth of knowledge and experience possessed by students [40]. Problem-solving abilities consist of the process and results of students in solving problems. Students' problem-solving abilities are in the form of results expressed in the problem-solving ability level, categorized into ability components.

5E learning based on knowledge integration brings success in students' problem-solving abilities, shifting to level A in solving Ohm's law problems. However, students' problem-solving abilities are stuck at level B and shift from level C to level B in solving Kirchoff's law problems. This happens because there are differences in the content of Ohm's law and Kirchoff's law problems. The content of Ohm's law problems only contains one voltage source; in Kirchoff's law problems, there is more than one voltage source. So, analyzing Kirchoff's law problem circuit requires a more difficult analysis than analyzing Ohm's law problem circuit. Students also have difficulty analyzing, explaining, and interpreting the phenomenon of Kirchoff's law concept in electrical circuits [41].This shows that students have the same pattern of learning difficulties in understanding the concept of Kirchoff's law in electrical circuits as shown by Khwanda & Kriek [42]. Especially in terms of understanding the relationship between voltage and electric current [14]. This study shows that the lack of understanding of electrical circuits possessed by students is in line with research conducted by Siong et al. [43]. Students often solve problems that are commonly solved but tend to have difficulty solving new problems that require a deeper understanding of concepts [12] as is the case in this study. In line with that, Kirchoff's law is considered a more complex concept [44] so it requires problem-solving abilities and a deeper understanding than Ohm's law.

Complex circuit concepts such as Kirchoff's laws require a learning environment that improves students' conceptual understanding of electrical circuits [46]. Students also need to build a well-organized knowledge integration structure around the central idea as stated by Liu et al. [12]. This emphasizes that understanding and applying the central idea during teaching can help develop a more integrated knowledge structure and gain a deeper conceptual understanding [46], and a conceptual framework approach is needed [47]. The conceptual framework approach is promising in guiding knowledge integration assessment in physics education and can facilitate the development of effective instruction to encourage deep conceptual learning. The conceptual framework and assessment results are then used to inform the development of new instruction that explicitly emphasizes teaching the conceptual framework's central idea and making connections to the central idea in students' knowledge structure [46]. The conceptual framework is built with a central idea emphasizing strengths [48]. So, when students do not have adequate basic knowledge and have not integrated the necessary concepts, the conceptual framework created is inappropriate [49].

Learning electrical circuits ideally requires the ability to solve Ohm's law and Kirchoff's law problems. Understanding the concept alone is not enough for problem-solving; it also requires problem-solving experience. Exercises that are packaged into 5E learning based on knowledge integration are needed to improve problem-solving abilities. 5E learning based on knowledge integration provides exercises with various forms of circuits to provide students with experience in solving electrical circuit problems consistently. This experience in 5E learning based on knowledge integration will help students solve various Ohm's and Kirchoff law problems.

CONCLUSION

The impact of 5E learning based on knowledge integration improves global problem-solving abilities and individual components. N-gain global problem-solving abilities, component 2, component 3, and component 4 are in the lower medium category while component 1 is in the upper medium category. 5E learning based on knowledge integration brings a shift in the way students better solve electrical circuit problems. Overall, 5E learning based on knowledge integration significantly improves the problem-solving abilities of Ohm's law and Kirchoff's law. This shows that 5E learning based on knowledge integration has been empirically tested to improve problem-solving abilities. However, 5E learning based on knowledge integration can only bring the level of students' problem-solving abilities to level A in Ohm's law and from level C to level B in Kirchoff's law. However, the concepts of Ohm's law and Kirchoff's law still have challenges, so they require consistent practice. So ideally, in the future, more exercises are needed in 5E learning based on knowledge integration to further improve the problem-solving abilities of Ohm's law and Kirchoff's law. In addition, this research is limited to analyzing electrical circuit problem-solving capabilities, so it can be carried out further on other concepts.

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