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Promoting in solving electric circuit problems via voltage tracking and division

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Abstract :
Despite a tremendous success in boosting students learn electrical analogies for science education, it remains a challenge to extend such strategy for formally constructing equations related to the Ohm's law in order to solve electrical problems based on series and parallel circuits. Unlike most traditional works of teaching technique that focus mainly on the current, an alternative approach with highlighted voltage is served as a guidance to help students solve the problems and develop a better understanding of direct circuits. To this end, we present a design of teaching method so-called voltage tracking and division. We report results from a study in which we used a set of pretest, posttest, and delayed posttest to evaluate the change in 35 sophomore students, major in general science of education, as a result of their participation in the electricity and energy course that comprised a 4-hours intensive class and 1-month follow-up examination. Through the employment of our method, students showed significant gains from pretest to posttest as well as that on the delayed posttest compared to the pretest. These results suggested that voltage tracking and division method facilitated the development of students' ability in solving electric circuit problems and also provided the persistence of such understanding. We envisage that our findings would evoke teaching tools that benefit from emphasizing voltage via the voltage tracking and division method to enhance the deepen understanding of students in solving circuit problems.

Keywords: Science teaching, Physics teaching, voltage tracking and division, problem solving, electric circuits

Introduction

Encouraging students learn scientifically analogies are remedial strategies for science education (Weller, 1970; Dagher, 1995; Treagust et al., 1998; Aubusson, 2009). Despite their widespread applications in physics (Jonāne, 2015; Fortman 1993; Cruz-Hastenreiter, 2015; Parappilly et al., 2018), particularly in electricity (Stocklmayer and Treagust, 1996; Sengupta and Wilensky, 2016; Ugur et al., 2012; Oh et al., 2012), the use of analogies has been demonstrated only with limited success (Brown and Salter, 2010; Goris, 2016). For example, some analogies such as the water, gravitational, or anthropomorphic models are introduced to the students as the alternative approaches to provide the basic formal tuition in the topic of electrical circuitry while they do little to foster deep developing technical expertise in calculation (Stocklmayer and Treagust, 1996). Accordingly, an extended work to formally construct the understanding of the nature of electricity thus remains challenging.

Unlike most traditional works of teaching technique that concentrate mainly the current in introductory electricity (Young et al., 2016; Engelhardt and Beichner, 2004), an alternative approach so-called an emphasis on voltage helps students develop a better understanding of direct circuits than traditional method (Rosenthal and Henderson, 2006). This notion is supported with an observation of understanding failure to explain the effect of adding cells in single or multiple loops, as students tends to use reasoning based on current and resistance where reasoning based on voltage is a necessary (Smith and Kampen, 2011). Consequently, teaching method with highlighted voltage aimed at providing guidance to students is essential (Millar and Beh, 1993).

Toward this end, our work focuses specifically on the development of teaching method - voltage tracking and division to solve electric circuit problems related to serial and parallel connection. To measure the development of students' knowledge, we performed the pretest, posttest, and delayed posttest to a group of 35 sophomore students major in general science of education who registered the electricity and energy course at Bansomdejchaopraya Rajabhat University. After conducting the pretest, we began the teaching hours with introduction of voltage tracking method to students and then measured the increase of students' ability to solve the circuit problems using posttest. Our voltage tracking method comprises (i) observing of cell's positive and negative charges on the move, (ii) giving to the maintenance of a constant difference in electric potential between two positions across resistors, (iii) providing a flow of electric current from higher to lower potentials, and (iv) writing equation regarding the ohm's law. In addition, we further provided our help to misconstrued students using the voltage division strategy to clarify why the current keep constant for serial circuit whereas it is inversely proportional to the resistance for parallel circuit. After a month of teaching, the delayed posttest was allocated to all participants. The results from tests display that not only the voltage tracking and division considerably improved student ability to solve electric circuit problems, but it also became effective to change misconceptions in solving equations and created permanent conceptual changes in students' ideas. We envisage that our method would be a guidance methodology for the students to solve electric circuit problems and enhance their deepened understanding.

Curriculum related to the voltage tracking and division

Throughout the curriculum, we introduce a model as the voltage tracking for analyzing the electrical circuit based on the serial and parallel connections (figure 1). The step begins with charge distribution: the positively and negatively charges virtually move from cell to two ends of resistors in opposite direction (figure. 1a). The upon step is followed the definition of voltage which is the potential difference or P.D.: as cell gives the P.D. of E volt, the P.D. across two ends of resistors is equally (figure. 1b). The next step is to construct the current flow from higher to lower electric potential (figure. 1c). And the last step is using the Ohm's law, P.D. = Current I × Resistance R, to present the corresponding equations: (i) $E = I(R_1 + R_2)$ in serial presents the flow of a current through R_1 and R_2 while $E = I_1 R_1 = I_2 R_2$ in parallel shows the different amount of current passing through, and (ii) $E = P.D._{1} + P.D._{2}$ with $P.D._{1} = IR_1$ and $P.D._{2} = IR_2$ in serial presents the voltage division (figure. 1d). Notably, as seen by both connections, our voltage tracking helps students to understand the relationship between P.D., I, and R.

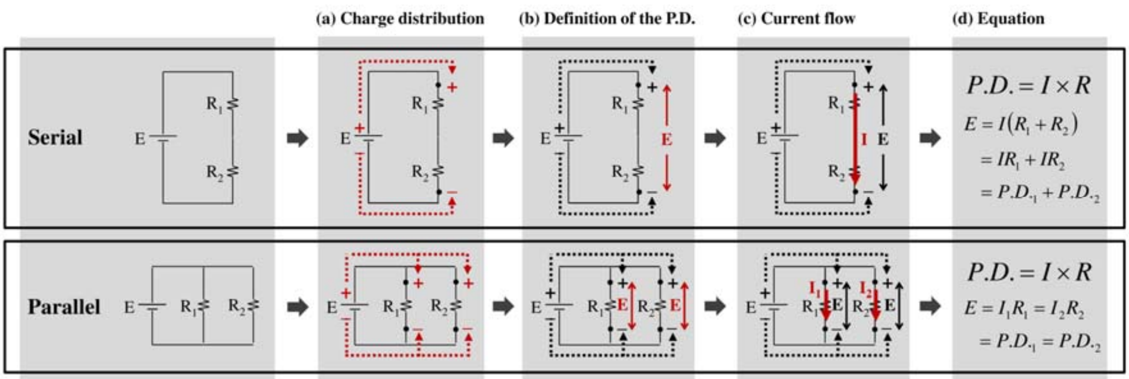


Figure 1. Procedure of the voltage tracking method used for analyzing the electrical circuit based on the serial and parallel connections composes of (a) charge distribution, (b) definition of the P.D., (c) current flow, and (d) corresponding equation.

With students who are still in trouble and struggle to clearly understand our voltage tracking model, we suggest the voltage division model as the supported strategy (figure 2). According to P.D. = I × R, the P.D. is directly proportional to R when I keeps constant (serial shown in figure 2a) whereas the I is inversely proportional to R when P.D. keeps constant (parallel shown in figure 2b). Consequently, the mathematical ratio is simply used to provide the solution for electrical circuit problem (Young et al., 2016; Kipnis, 2009).

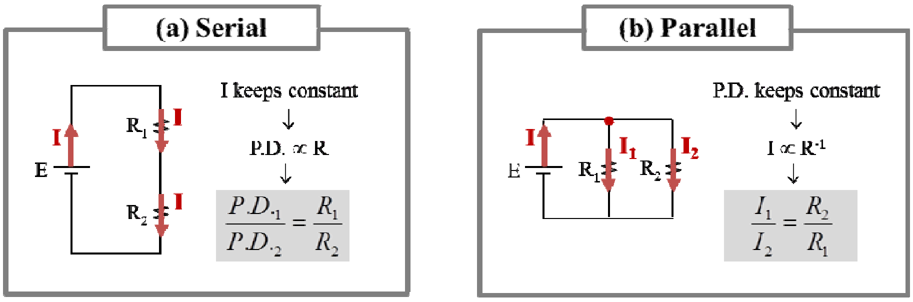


Figure 2. The voltage division as the supported strategy for analyzing the electrical circuit based on the (a) serial and (b) parallel connections.

Method

The voltage tracking and division are used to help the students' solving of electrical circuit problems regarding either serial or parallel connections (figure 3). In classroom, our framework involved three following steps which were (i) addressing the students' ability to solve the electric problems through pretest, (ii) repairing the students' misunderstanding using the voltage tracking, and (iii) administering the students' understanding through posttest. Moreover, with some students who still had a difficulty in posttest solving, we provided our help by introducing the voltage division strategy. Finally, we then rechecked the students' solving for validation of their knowledge through a delayed posttest after a month of teaching. We noted that this study conducted a group of 35 sophomore undergraduate students who registered the electricity and energy course, major in program of general science, faculty of education, Bansomdejchaopraya Rajabhat University as the participants.

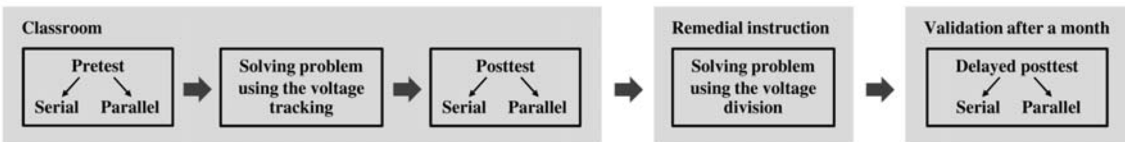


Figure 3. Our framework accompanied by the voltage tracking and division is used as strategies to help the students' solving of electrical circuit problems regarding either serial or parallel connections.

Three sets of questions based on serial and parallel circuits were given to the students for their pretest, posttest, and delayed posttest (figure 4). For all questions, we asked them to write down and briefly explain their answers in order to calculate the current released from cell (I_{cell}), the current flow through each resistor (I_n), as well as the P.D. across each resistor ($P.D._n$); where n was the number of resistors. Note that the questions from posttest and delayed posttest were modified to challenge the students for their deepen understanding.

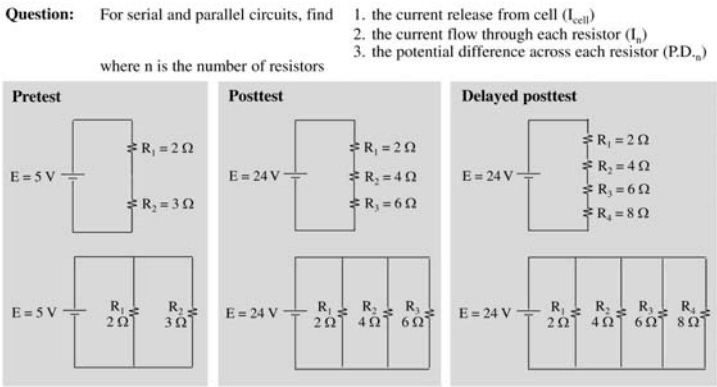
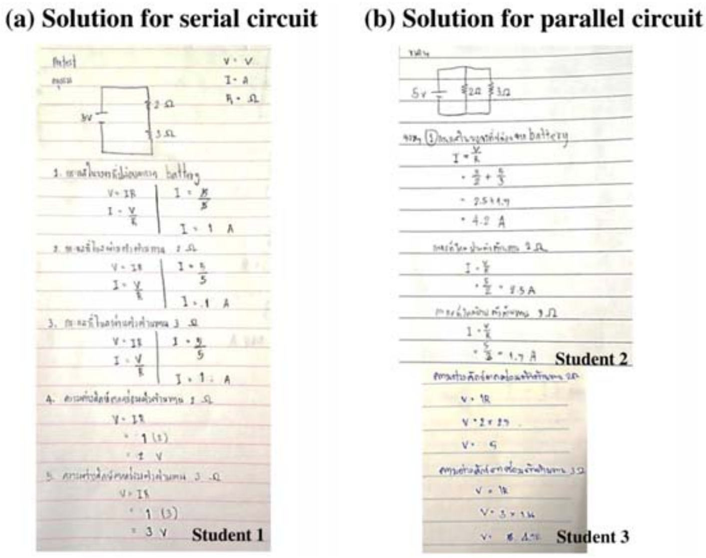


Figure 4. The pretest, posttest, and delayed posttest given to students.

Result and discussion

To determine pre-existing electricity knowledge, we performed the pretest at beginning of course and its result was shown in figure 5. The correct solutions of pretests for either serial (figure 5a) or parallel (figure 5b) circuit problems were derived from a few students who could not answer all the questions correctly. In particular, only a little more than half of all students had a fairly thorough understanding of finding the current released from the cell in the serial circuit whereas less than a quarter of that had a right calculation of the remaining issues (figure 5c). This result recognizes that the background knowledge upon which calculation was drawn will be regarded inferior for all students. Accordingly, to establish a concept knowledge baseline of solving electric circuit problems is necessary.



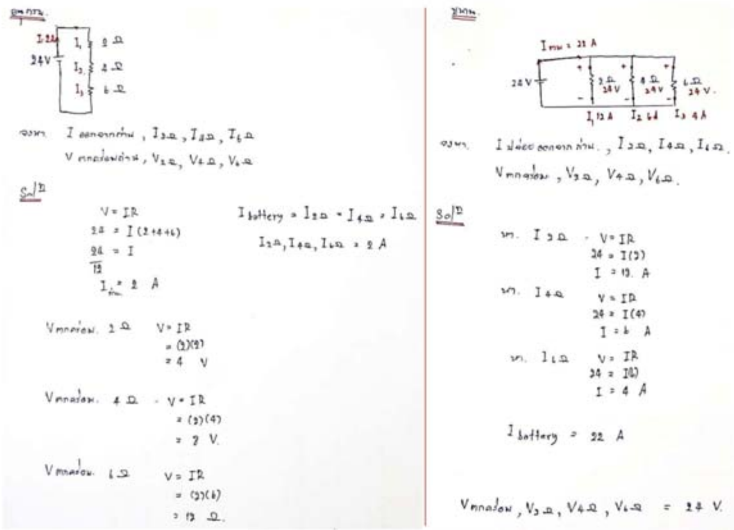
(c) Percentage of correct answers

% Correct	Serial	Parallel
I_{cell}	**54**	**20**
I_1	11	23
I_2	11	23
$P.D._1$	23	9
$P.D._2$	23	11
$\bar{I}$	**11**	**23**
$\overline{P.D.}$	**23**	**10**

Figure 5. The pretest solutions for either (a) serial or (b) parallel circuit problems together with (c) the percentage of correct answers.

As the first treatment, we established the voltage tracking model to help the students' solving of electrical circuit problems regarding both serial and parallel connections. To address the effectiveness of this treatment, the posttest was conducted with the same participants after introducing our model. Figure 6 presents the results: the pattern of solutions to determine the related variables were illustrated through the implement of our method (figure 6a) and more than three quarter of students were able to calculate all variables correctly (figure 6b). Remarkably, 97% of students correctly calculated all variables in parallel circuit problem, along with 94% of that gave the right calculation on I_{cell} and all P.D. in serial circuit problem (figure 6b). This result suggests that the voltage tracking considerably improves student ability to solve electric circuit problems.

(a) Solution for serial and parallel circuits



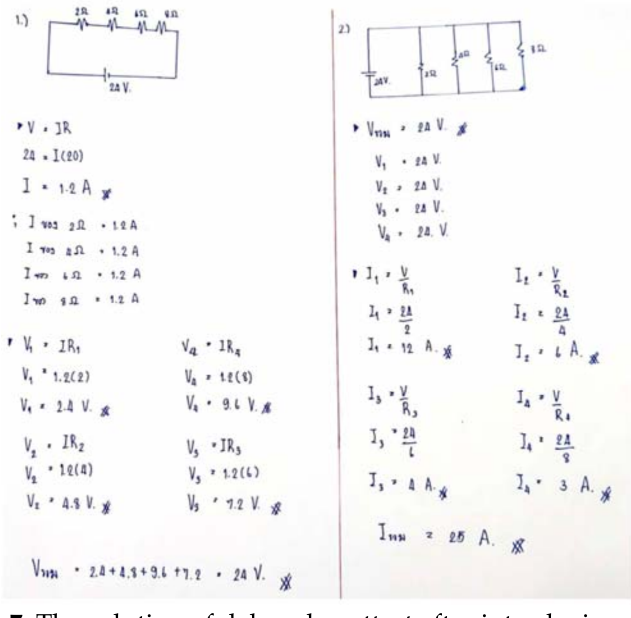
(b) Percentage of correct answers

% Correct	Serial	Parallel
I_{cell}	**94**	**97**
I_1	77	97
I_2	77	97
I_3	77	97
P.D.$_1$	94	97
P.D.$_2$	94	97
P.D.$_3$	94	97
$\overline{I}$	**77**	**97**
$\overline{P.D.}$	**94**	**97**

Figure 6. The posttest solutions after introducing voltage tracking technique: (a) pattern of solutions to determine the related variable in either serial or parallel circuit problems together with (b) the percentage of correct answers.

As the second treatment for some students who still had a difficulty in posttest solving, we provided our help by teaching them to learn the voltage division strategy at the remedial hours. To address the question of whether learning gains resulted from our strategy as well as to check the stability of students' learning, the delayed posttest was performed to all participants. Figure 7 displayed the results: the pattern of calculation to solve electric circuit problems from all students tended to be the same (figure 7a) with 86% of students who gave all answers correctly (figure 7b). Especially, it was found that 100% of students correctly identify all variables, except the value of current flow through each resistor in serial circuit and the current release from the cell in parallel circuit (figure 7b).

(a) Solution for serial and parallel circuits



(b) Percentage of correct answers

% Correct	Serial	Parallel
I_{cell}	**100**	**86**
I_1	97	100
I_2	97	100
I_3	97	100
I_4	97	100
P.D.$_1$	100	100
P.D.$_2$	100	100
P.D.$_3$	100	100
P.D.$_4$	100	100
$\overline{I}$	**97**	**100**
$\overline{P.D.}$	**100**	**100**

Figure 7. The solution of delayed posttest after introducing voltage tracking and division techniques: (a) pattern of solutions to determine the related variable in either serial or parallel circuit problems together with (b) the percentage of correct answers.

In order to compare the significant enhancement of electricity knowledge through the employment of the voltage tracking and division, we further plotted the conceptual change on each of the instructional objectives. Figure 8 summarized a comparison of the percentage of correct answers determined with the pretest (white bars), posttest (grey bars), and delayed posttest (pattern bars). The result showed that the percentage of correct answers increased significantly after introducing the voltage tracking (posttest vs. pretest); likewise, the increase of the percentage of correct answers was profound after the voltage division was engaged (delayed posttest vs. posttest). This result indicates that the voltage tracking and division play a key role in the enhancement of the students' ability to solve the electric circuit problems. Furthermore, in term of the validation of students' knowledge, the results from posttest and delayed posttest were comparable and greater than the pretest. Accordingly, this result displays the persistence of student knowledge to solve electric circuit problems.

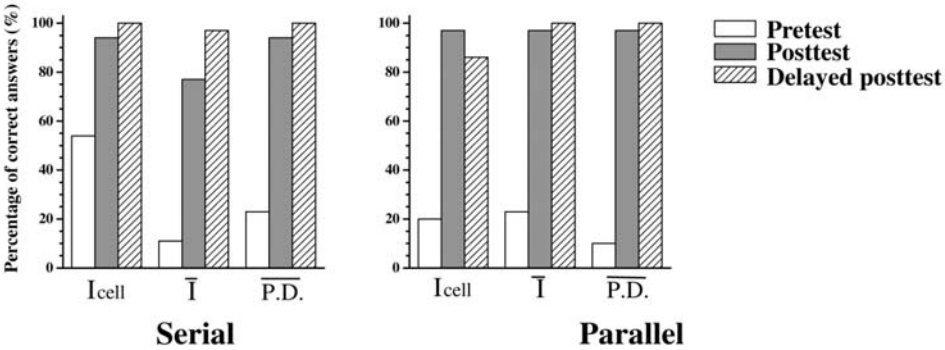


Figure 8. Comparison of the percentage of correct answers determined with the pretest (white bars), posttest (grey bars), and delayed posttest (pattern bars).

In addition to the above validation, we also worked through the incorrect answers from the delayed posttest. The result exhibited the misconceptions of students about electric current as shown in figure 9. For the serial circuit (figure 9a), since the current flows across each resistor with the same magnitude as the current releases from cell, each current is hence equal 1.2 A (wrong answers in dash block). For the parallel circuit (figure 9b), as the current released from cell is simply calculated by the summation of all currents, the current released from cell thus became 25 A (wrong answers in dash block). These two erroneous results reflected the common mistake of students in solving electric circuit problems (Engelhardt and Beichner, 2004; Küçüközer and Kocakülah, 2008; Gaigher 2014).

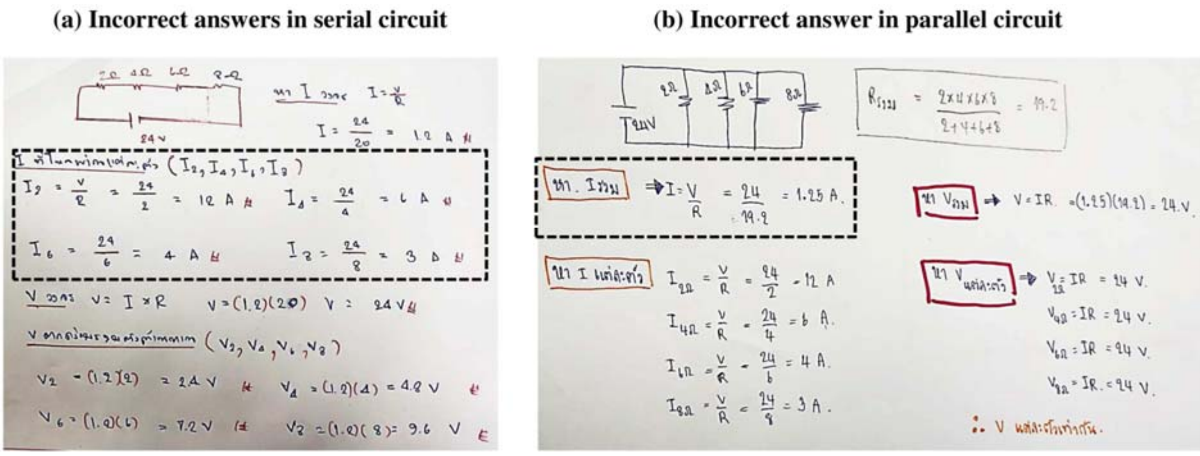


Figure 9. The misconceptions of students about electric current in both (a) serial and (b) parallel circuits.

Conclusion

As electric circuit problems related to serial and parallel connection are the important parts of the science curricula, it is crucial for teachers to develop coherent method that allows students to be able to understand and find the correct solutions. Furthermore, as the difficulties experienced by students in solving problems persist for a long period of time, it is incumbent upon teacher to overcome these obstacles. To this end, we develop the teaching method so-called voltage tracking and division. In a set of pretest, posttest, and delayed posttest demonstrated significant gains on measures of content knowledge. Our result indicates that the voltage tracking and division play a key role in the enhancement of the students' ability and be responsible for the persistence of student knowledge to solve electric circuit problems.

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