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Why we need better pedagogical approach physics education in Korea : A case study of in-service teachers' difficulties in electricity

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This paper explores the development of a tutorial emphasizing movement of charges, and analyzes the changes of teachers' conceptual understanding from implementation of the tutorial. We conducted preliminary study to determine elementary teachers' specific difficulties and misconceptions about electrical current. In applying the results from preliminary study data we developed and implemented a tutorial for in-service teachers. Multiple-choice questionnaires on the concept were given before and after completing the tutorial. The contribution of the tutorial to teachers' scientific conception of electrical current can thereby be evaluated. To better observe some of the specific changes in teachers' understanding, all activities of the tutorial were recorded and transcribed. We strived to analyze teachers' change in conceptual understanding through the tutorial qualitatively as well as quantitatively.

Keywords: Charge movement, Conceptual understanding, Electricity, Misconception, Tutorial.

I. Introduction

The concept of electrical current is taught repeatedly at all levels of education, from general science classes in elementary school to university physics courses[1]. However, there is a lack of uniform understanding of electrical current among students, and many students have misconceptions[2-5]. Previous studies have analyzed student misconceptions and sought to address the lack of understanding of the concept of current through pedagogical approaches. Notably, pre-service teachers have similar misconceptions about electrical current[6-8]. To address this problem, new approaches and methods are needed to promote educators' conceptual understanding of this key physical concept.

The typical curriculum of electricity in physics courses begins with charges, and the definitions of a charge, electric field created by charges, electrical potential created by charges, Gauss' law, capacitance, etc follow. All conceptions that are taught revolve around charges, before teaching the concepts pertaining to current and then circuits[9]. These facts suggest that emphasizing charges and their interaction is crucial for understanding currents.

How do elementary school teachers presently learn about current? Notwithstanding small changes, the established curriculum begins teaching electricity in 7^{th} or 8^{th} grade with the topic of electrostatics[1]. Students should have been introduced to electrostatics to solidify their concept of charges, which is then used to understand the concept of currents. However, students do not reach full conceptualizations of electrical currents because they tend to understand these two concepts independently. This results in failed association between experimentation of electrostatics and observation of related phenomena[10], as well as unsuccessful understanding of the interactions between electrons in a simple circuit[11]. In prior research, it was reported that pre-service elementary school teachers complained of a lack of basic knowledge and concepts and an inability to respond to unexpected student questions. They had insufficient basic conceptual understanding of electricity and magnetism, and lacked confidence in related scientific knowledge[12].

How then can their persistent misconceptions about electricity be changed to form a solid scientific conception? The Tutorials in Introductory Physics[13] is one example of an alternative method for instruction. Tutorials target students' conceptual difficulties. If tutorials do indeed help students deal specifically with the concepts that continually foil them in normal classes[14], then they should also assist elementary school teachers to understand the concept of electrical current. Hence, viable means of improving elementary school teachers understanding of electrical current would be contents emphasizing the interaction of charges through the usage of tutorials. In the present study we have developed a tutorial to effectively change misconceptions of in-service teachers. We refer to it simply as ‘Tutorial’ from the University of Washington for above purpose even though it does not include homework. This paper describes the details of the tutorial and implementation for in-service teachers. In particular, we aim at improving teachers’ performance by implementing the tutorial and present both quantitative data, based on teachers’ written responses to conceptual questions, and qualitative data, based on interviews with teachers.

This paper is organized as follows. In Section Ⅱ we briefly address the methods of investigation and present a description of the data collection and analysis. In Section Ⅲ we describe the program for in-service teachers that are implemented. The impact of the program was examined during the implementation. Section Ⅳ includes our conclusion and implications for instruction and future studies.

II. Methods of investigation and data analysis

The purpose of this study was to develop a tutorial emphasizing movement of charges, and to analyze the changes in teachers’ conceptualization upon implementation of the tutorial. We conducted preliminary research to determine elementary teachers’ specific difficulties and misconceptions about electrical currents. Previous studies focused on the elementary students’ difficulties with electricity, but few studies examined elementary teachers’ conceptual understanding. We identified difficulties facing elementary school teachers and misconceptions. In the following results from preliminary research data we developed tutorial and implemented for in-service teachers. Table 1 shows the procedure of this study.

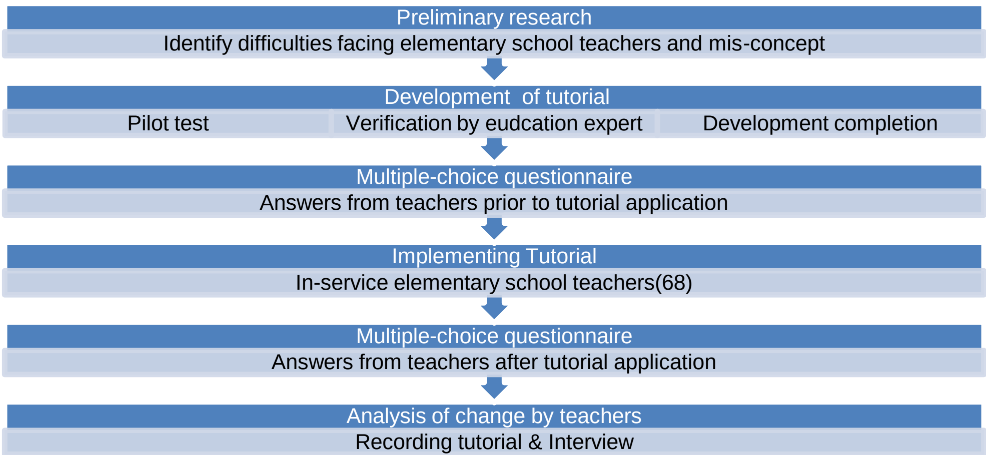


FIG. 1. Research procedure

This section describes data collection and analysis(“Development of tutorial” and “Implementing tutorial”) components of this study.

A. Development of tutorial

Elementary school teachers teach the concept of electrical currents in fourth and fifth grade in the Korea national curriculum. We requested teachers to notate the difficulties encountered while teaching these courses. 73 elementary teachers were selected to participate in a preliminary study. There were 13 questions in this part. One question allowed for a free description of the difficulties teachers experience teaching about electrical current and the remaining 12 questions are related to a concept test about electricity. Only one question given from our previous research[15] and another one question from McDermott’s[13].

We analyzed teachers' conceptions and modified existing curriculum for teachers. After making decision of large and small categories in tutorial, we developed small scale laboratory and activity for each category. Tutorial has been examined by physicists and physics educators.
Figure 2 shows the procedure for developing the tutorial.

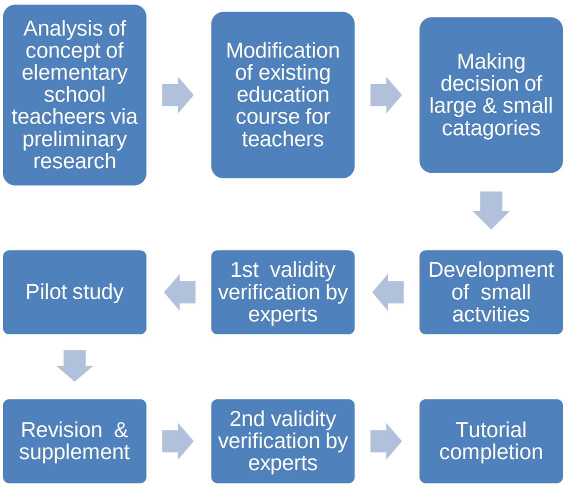


FIG. 2. Procedure for developing tutorial

B. Observed teachers' activities

In the study there were 68 in-service teachers from 60 different elementary schools in various regions in Korea. Their age ranged their age between 26 to 51 years old and experience in teaching from 3 to 26 years (see table 1).

TABLE 1. Information of attendees' teaching career(N=68)

	Teaching experiences (year)				
	1-5	6-10	11-15	16-20	More than 21
Male	1	7	7	3	1
Female	15	28	2	3	1
Total	16	35	9	6	2

The tutorial was implemented as a workshop within a training program for in-service teachers. First, teachers were asked multiple-choice questions about electricity before the tutorial. We analyzed teachers' responses to the multiple-choice questions and all activities of the tutorial were also recorded. The recorded conversations were analyzed to assess the reasoning and arguments used by the teachers. The study was focused on assessing the contribution of the tutorial to change participating teachers' understanding of electrical current. Multiple-choice questions were therefore posed to teachers after the tutorial again. All 8 multiple-choice questions are taken from DIRECT and ECCE[16,17]. Although these questions do not directly inquire about the movement of charges, it was believed that this concept test was developed to determine teachers' ideas about electricity. To the obtained data can thus provide information for an objective comparison and analysis of the teachers' understanding of the concepts before and after the tutorial. The multiple-choice questions are given in the appendix.

III. Analysis and results

A. Description of the tutorial

In the preliminary study, 73 elementary teachers described difficulties experienced with teaching concepts related to electricity in their classroom. The most frequent response was a challenge in dealing with a lack of basic knowledge in teaching electricity and related courses. They stated that it was difficult to answer students' questions because they did not understand the scientific concept. Also, teachers acknowledged that they were able to answer textbook questions but did not necessarily know the reasoning behind them. Thus, the teachers resorted to teaching students to memorize facts.

A plastic is rubbing with a fur. And connect to a circuit in below. Is a bulb bright?

	Before rubbing	After rubbing
Plastic plate		
fur		

What is the reason?

FIG. 1. Preliminary study question(conductor and insulator)

Textbooks state that when connecting a material to a circuit, the material is considered conductive if the bulb lights up, and insular if the bulb does not light up. Since this concept is commonly explored in elementary school, and is a crucial first step for students to learn about conductors and insulators, it is important for teachers to correctly conceive this concept. A familiar experiment is to connect fur and plastic plate to a circuit before and after rubbing them, in order to learn about conductors and insulators(Fig. 1). Only 29% teachers responded that the circuit tester will not light up before or after rubbing the insular materials. However, while some teachers had valid scientific reasons, others held the misconception that there needs to be electromagnetic induction or an anode or cathode in order for current to flow. 27 teachers responded that there is no light before friction but there is light after friction. A common justification was that friction made an insulator into a conductor, while others mentioned electron transport and electric power. Fourth grade textbooks demonstrate the connection of various materials to the circuit but do not mention the effects of charged insulators. Although the teachers understood that plastic and fur are insulators, the responses that these materials become conductors, through rubbing, as well as other forms of reasoning behind their answers, show that they do not have correct conceptual understanding regarding conductors and insulators. In particular, they are confused between "charged" and "conductive". Charged insulators are not conductive.

Another question involved voltage in a closed circuit with a battery and light bulbs(Fig. 2).

Write down the voltage (potential difference) between each point on the electric circuit with a brief reason.

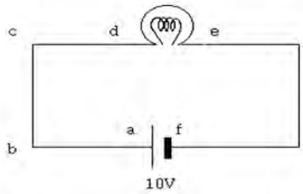


FIG. 2. Preliminary study question(voltage in closed circuit)

The teachers were instructed to write down the voltage at each connection and their reasoning. These voltage questions may be unfamiliar to elementary school teachers, but elementary textbooks contain descriptions and explanations regarding appropriate batteries to use for each bulb. Additionally, teachers are asked what happens when a bulb is attached to a battery with unsuitable voltage; hence, it is important to explore the educators' concept of voltage. For a closed circuit, the majority (33 teachers) answered that the circuit and both ends of the battery and the bulb have 10V because the current is the same in all parts of a series.

As seen in previous studies, elementary instructors believed that current is the highest priority in learning about circuits, and many responded that the current is constant in a circuit regardless of loads. The battery is most frequently discussed in the fourth grade electricity unit, but teachers were found to have insufficient knowledge about voltaic batteries. This lack of a basic conceptual understanding hinders their ability to teach about serial and parallel circuitry, and hence they rely on memorization to convey the knowledge.

1. Designing the lessons

The movement of charges is emphasized by a tutorial that is made up of two major categories, covering the electrostatic and the current. The tutorial deals with the electrostatic charge which is an existing component of the curriculum. However, because the curriculum does not consider the movement of charges, it requires a revised tutorial that complements the perspective of the movement of charges. In development and application of teaching materials for changes in concepts about voltage and electric grounding in teaching and learning resources using open circuits and grounding, students have difficulties in distinguishing between open circuits and closed circuits, resulting in a tendency to use Ohm's Law in an open circuit, according to Lee[18]. Because an open circuit does not contain any movement of charges, it can be referred to as an electrostatic situation, and this fails to properly apply the concepts of electrostatics. Many students could not differentiate between an electrostatic situation and a static current situation, and they were not aware of the fact that conductors carrying current remain at a neutral state corresponding with the state before current flowed. In order to understand a situation where there is no constant flow of current, such as in a case very similar to the phenomenon of electrostatic induction, we suggest that considering the electric force between charges facilitate learning. Therefore, there is a need for a concept that would serve as a bridge from the electrostatic to current. From the two previous studies cited above, it was decided that an open circuit would be introduced as a bridging concept that would link electrostatic and current as shown below(Fig. 3), and the concept of transient current used be in this study.

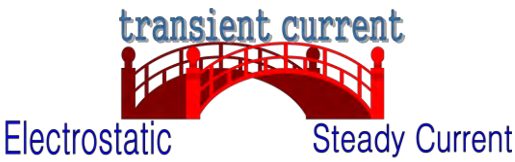


FIG. 3. Role bridging transient current between electrostatic and steady current

Electrostatic, which is a major category, was divided into two minor categories for the formation of the concept of transient current. The first minor category is conductors and insulators. The second minor category enabled the understanding of the concept of transient current by selecting the learning content related to open circuits. The study of current, which is also a major category, was also constructed by being divided into two minor categories(see Fig. 4). Given the salient misconception identified in a previous study that current will be consumed from the electric bulb, understanding current through the force between charges in a closed circuit was determined to be a crucial point. This is because we can proceed to the serial connection and parallel connection of the bulb only after strengthening this concept. A pre-test was conducted for each of the major categories of the electrostatic section and current section before entering them, and a post-test was conducted at the end of the major category.

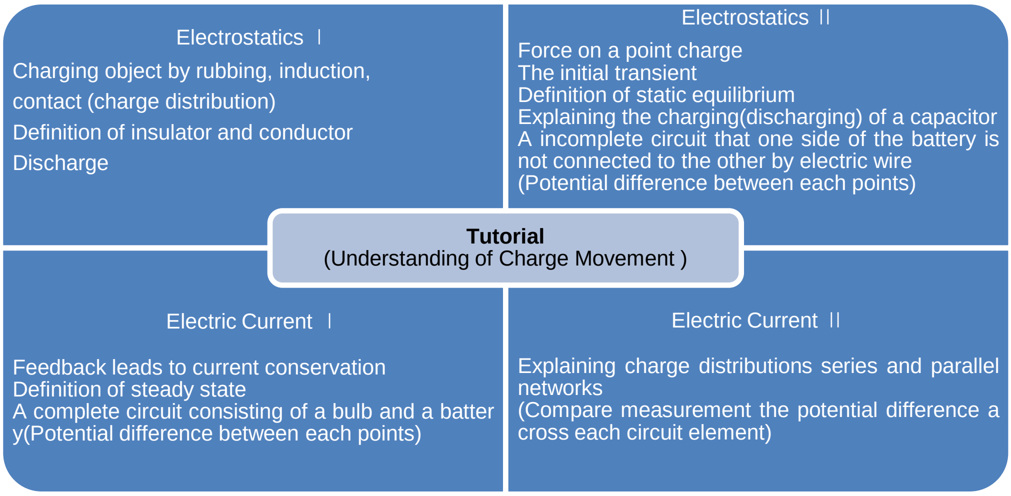


FIG. 4. Contents of developed tutorial

2. How was the movement of charges emphasized?

The overall experiment and activity of open circuit, which is the second category in the tutorial, is presented in Table 1 and is comprised of six experiments and activities. To bring an understanding of voltage by considering the force between charges we introduce the concept that net force acts on the charge whenever a charge is located in a voltage, where the potential difference between two points exists. This approach is quite useful because the teachers are accustomed to considering the voltage of a flow.

Teachers are asked whether voltage between two points of a metal ball is induced with opposite sign charges (see Fig. 5). Also, in the same situation, the second question is whether there is a net force on the electron located at the center of the ball. The situation for the third question is similar to that described in the previous problems, with the exception there is a charged insulator rod located near the metal ball. Contents of the questions are the same as those for voltage and net force. The teachers are asked about the forces at three different points of the inside ball. Teachers should write their reasoning for each response. In fact, the situation for the first two questions can be made from the situation with a charged insulator. After the metal ball is induced by the charged rod, if the rod suddenly is removed, the first situation can be produced experimentally.

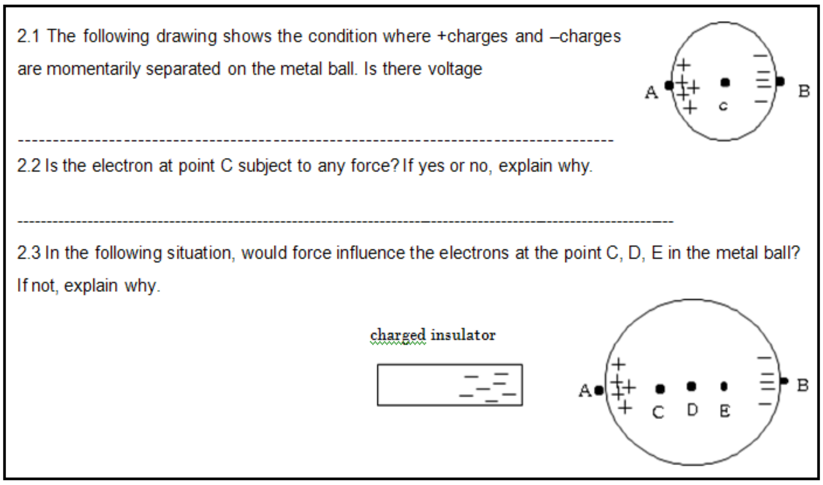


FIG. 5. Electric force in electrostatic induction

The previous situation is relatively easy to understand as it is conventional and intuitive. However, the second situation presents many difficulties to teachers. When the negatively charged insulator is brought near the metal ball, the electrons inside the metal ball receive force and are pushed to the right side. Many electrons are initially driven, but there is a limit to this due to the repulsive force by electrons accumulated at the right side. Charges are very quickly redistributed in order for the force to be zero at all points inside the metal ball, which means there is no voltage or electric potential difference between any two points of the ball. As a result, the electrons inside the conductor no longer move. Thus, all points of the conductor reach to an equipotential state when the conductor reaches an electrostatic situation. Most students and teachers think there is a potential between A and B points because they only look at charges induced at the surface. Because the charges are opposite, it resembles a battery. They are not thinking about the impact of the negative charges of the charged insulator. This content was included in the tutorial, which emphasized the movement of charges.

Tutorial emphasizes the temporal movement of charges within the wire even though the circuit is incomplete(see Fig. 6). It consists of a short wire and a battery.

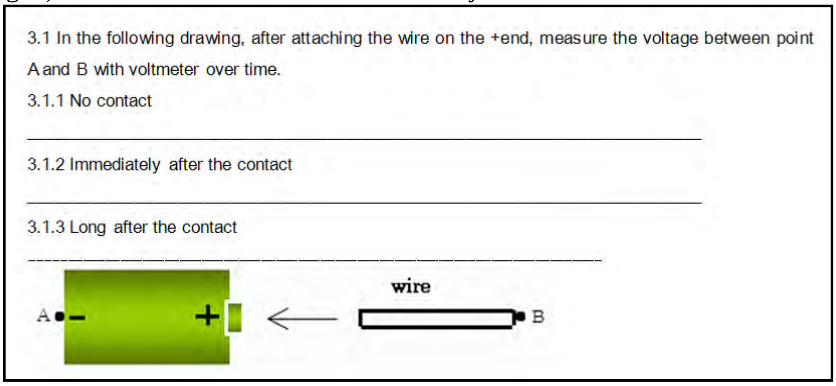


FIG. 6. Charge movement with time within the wire

Teachers are asked to predict the voltage before the contact of the leading wire to the terminals of the battery, immediately after the contact, and then over an elapsed time after the contact and then measure the voltages. Before making contact with the battery, electrons inside the wire cannot move. This is because the electric field inside the wire by the battery is almost zero. However, the situation differs when the leading wire is touched to the battery. The voltage between the negative side of the battery and the end of the right side of the leading wire must equal to the voltage of the battery. In order to make this happen, the battery causes electrons inside the wire to move. In other words, the charges move in the wire so that transient current flows. The charges will move until the leading wire reaches the same potential as the positive electrode of the battery. The whole wire becomes equi-potential. It was helpful for the teachers to comprehend the transient current in the second minor category of the electrostatic, and it is important to consider the movement of charges in the concept of a transient current.

The content of the tutorial that facilitates the understanding of the distribution of charges and entails measurement of the voltage in an open circuit is illustrated(Fig. 7). First, after predicting the voltage between points in the open circuit, a voltmeter is used. For explaining the reason for the measured voltage, the distribution of charges must be used. We also asked the teachers to explain the reason for points where the voltage was 0, by making a connection with the distribution of charges.

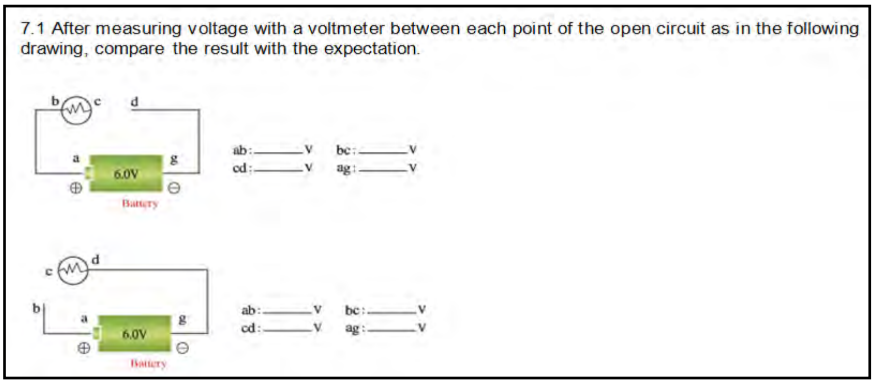


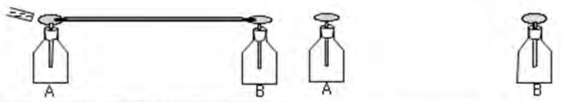
FIG. 7. Measurement of the voltage in open circuit

Through the results of a preliminary study, we found that many teachers thought the voltage was 0 between all points because current does not flow if the middle portion of the circuit is disconnected. Through this approach, we were able to succeed in changing their misconceptions into scientific conceptions. Also, voltage is introduced as a kind of force acting on the charge, which is an important part of the tutorial. This plays a crucial role in breaking the ongoing misconceptions that the ultimate result of current is voltage. Teachers used to think that voltage is generated by current. They are confused between cause and effect. Voltage is cause and current is result when the wire is connected to two points with electric potential difference.

The tutorial contents are offered in the figure, indicating it is a battery that makes electrons continuously move in a circuit. Connect two electroscopes with copper wire and bring an electrified nonconductor closer to one electroscope. Observe the movement of the metal foils at both sides and eliminate the copper wire in the middle. Finally, conduct a test by removing the electrically charged nonconductor. Observe the movements of each metal foil for the two electroscopes, under each situation and explain the movement of the charges.

If an electrified nonconductor is brought near electroscope A, negative charges would tend to situate at a location farthest from the nonconductor. When the two electroscopes are connected with a copper wire, they can be regarded as a single metal. Some negative charges may move to the metal foil of electroscope A but most will move to electroscope B. Thus, approaching the electrified nonconductor, the metal foils of both electroscope A and B will become open. At this time, if the copper wire is removed, the two electroscopes will be separated and there will be no movement of charges between the two electroscopes. Finally, if the electrically charged nonconductor close to electroscope A is eliminated, the metal foil of electroscope A will close and then open again. The metal foil of electroscope A has a portion of negative charges. However, it does not rise until the electrified nonconductor is removed. It then rises when the electrified nonconductor is eliminated, and accordingly appears to shrink. However, electroscope A has positive charges due to insufficient negative charges. This is verified by the phenomenon that the foil shrinks when the electrified nonconductor is eliminated and then expands again. In the end, electroscope A is electrified with positive charges and electroscope B with negative charges. This can be confirmed by placing the copper wire between the two electroscopes. When two electroscopes are linked with the copper wire, the metal foils of both electroscopes close, thus becoming neutral. At this time, a question should be postulated, asking how to cause continuous movement of charges between the two electroscopes. It is indicated that a battery is required to make charges move continuously. The role of charges can then be understandable from the perspective of the battery. In conclusion, the tutorial contents are organized in a way to provide insight to the role of the battery by emphasizing the movement of charges, which is the most critical in understanding the role of the battery, by using two electroscopes(Fig. 8)[15].

1.1 Observe the movement of two metal foils and draw metal foils in electroscope



(1) Put wires on the two netural electroscopes. At this time, the copper wires inside the sheath of a cable should contact the metal plate. Bring an ebonite rubbed with fur closer to electroscope A.

(2) Under the situation of (1), first remove the cable and then keep the ebonite at a distance.

1.2 What kind of charges do the two electroscopes have after (2)? Make a picture of electrified charges on the above metal foils.

Electroscope A (   ), Electroscope B (   )

What is the reason?

1.3 What forces are working between the charges electrified on electroscope A?

1.4 What forces are working between the charges electrified on electroscope B?

1.5 How will the metal foils be affected if the electrified electroscopes A and B are connected with a cable?

What is the reason?

1.6 Connect electroscopes A and B electrified by different charges. Among (+)positive charges and (-)negative charges electrified to the electroscopes, which move?

FIG. 8. Understanding the role of the battery from charge movement

B. Implementing tutorial

1. What kinds of changes were observed in teachers within the process of applying the tutorial?

(1) Thoughts about the conductor and insulator

There are an electrically neutral plastic ball and a metal ball. If 3 electrons are added to the ball as indicated in the drawing, what would happen to the movement of electrons? Select the below list.

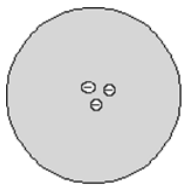
In the case of Plastic Ball ________________

In case the case of Metal Ball ________________

① Stays the same ② Spread evenly on the outer

③ Spread evenly on the outer surface of the ball

④ Roaming inside of the ball with active movement



What is the reason?

FIG. 9. Pre-test question from [Electrostatics]

Figure 9 shows pre-test question about conductor and insulator in developed tutorial. Only 36.5% of the teachers gave a correct response. Even the teachers, who provided the correct answers, gave incorrect reasons. This is because of the electrical energy that is generated by friction. The reason for this is that active electrons move freely in metals, but electrons spread as they do in plastic (as insulators), etc. There are some misconceptions about the atomic model. In order to correct such misconceptions by replacing them with scientific conceptions, the process of the tutorial includes the following experiment(Fig.10)[15]. The experiment was executed to observe the movement of charges under the context where the metal ball is being inducted and contacted by the charged insulator. In this drawing, as a part of a worksheet, we had the participant draw electrons at the moment of contact.

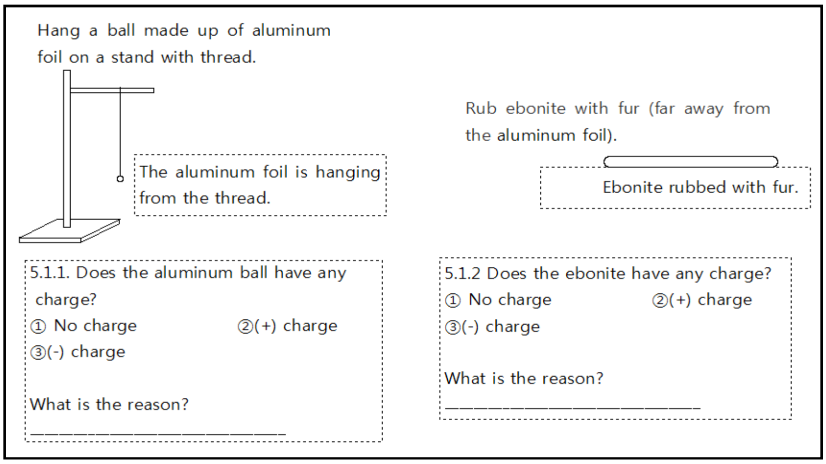


FIG. 10. Charge movement in case of induction and contact

The following is a conversation between teachers during the tutorial process.

T1: (As the stick approaches the ball) the plus charge is in the condition of being induced. While on the opposite side, the -charge is in the condition of being induced, and was contact made. Therefore, the -charge jumped from the ebonite to the ball.
T2: I thought the charge moving towards the ball from the ebonite. Since minus charge is arranged towards the ball where the bar touched and there is still a lot of –charge in the bar, it is the same sign, so it pushes…

We were able to confirm that teachers had an increasingly concrete perspective that the metal ball is a conductor, and that the ebonite rod is an insulator even though they are charged. The rate of a correct answers obtained in a reexamination of the pre-test question(in Fig. 9) after the tutorial is 91%. Also, teachers were worried about the phrase 'after a while' in the question because of the consideration of the time until the inside of the metal became neutral. We can see that they thought much more deeply than what the question was actually asking, which was about the movement of charges in the conductor and the interaction of charges.

(2) The belief that the cause of voltage is the current

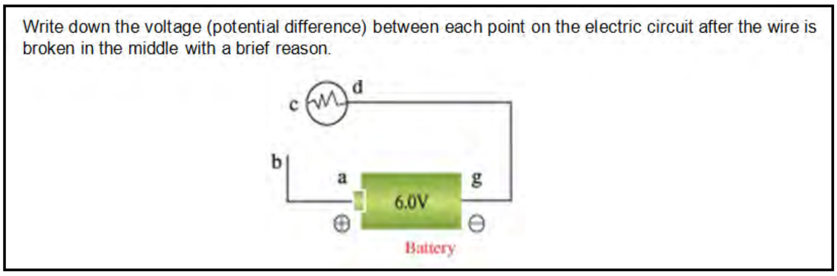


FIG. 11. Pre-test question [Electrostatics]

31 teachers responded as all 0v in pre-test(Fig. 11), while describing the reason as, 'current is not flowing because of a disconnection' and 'a potential difference doesn't originate if the circuit is not connected.' As in the results of pre-test, it has been confirmed that there is a typical misconception of considering voltage as the result of current.

In order to correct this misconception, the tutorial included contents such as experience using a circuit connecting capacitors, batteries, and light bulbs, along with measurement and explanation of the voltage in an open circuit, which is introduced in the Mcdermott's introductory physics tutorial[13]. We added a simple context as below(Fig. 12) and wanted make teachers can explain the charging of a capacitor.

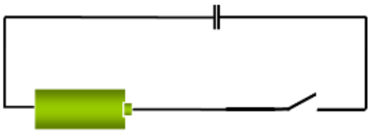


Fig. 12. Explaining the charging of a capacitor

Since the experiment using a capacitor was not very familiar, the elementary school teacher initially felt somewhat confused. However, as the experiment progressed, gradual changes in the teachers' conceptualization were observed. The teachers, who answered in the pre-test that there is not any voltage because current does not flow, were able to consider the distribution of charges by verifying the results of the experiment shown in the drawing. They were then able to connect this situation and the capacitor. During the application process of the tutorial, the teachers' dialogue was as follows.

T1: If both ends of the electrodes are at this point, the charges are in the state of being distributed as (+)charges in the positive side of the battery and (–)charges at the negative side of the battery, aren't they? Then, the negative side of the wire should have a distribution of (–)charges as well, right?

T2: If voltage is being measured from the broken parts, then… the capacitor is also the same way. Can this possibly be the same as the capacitors?

After finishing the tutorial, the correct answers in a re-examination of the pre-test increased from 4% to 87%. The first thing the teachers mentioned about lighting up the bulb in the circuit is the current. As shown in the results of previous research[19], they had a tendency to consider current as the main concept of the circuit analysis. However, after the tutorial, the respondents were able to explain the concept of voltage as the interaction of charges as well. From the tutorial emphasizing the movement of charges, the misconception of 'current being the cause of voltage' has been replaced with a scientific concept.

(3) The belief that current is 'used up' in the circuit

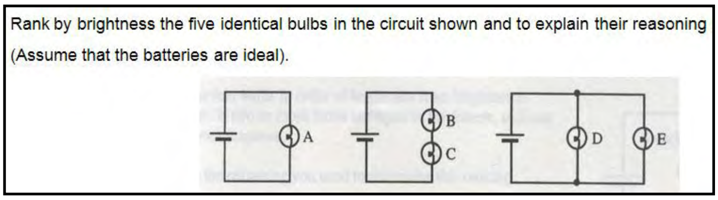


FIG. 13. Pre-test question [Electric current] originated from McDermott's

In the pre-test, 28 percent of teachers answered that A is the brightest since there is only one light bulb in the circuit. This is the misconception of a 'consumable model' type in an electric circuit which leads to the belief that voltage is consumed when it passes though the light bulb. In order to correct this misconception, the tutorial involved the following information. In a closed circuit, after measuring the voltage between each point, we had the participants estimate and explain the results of the distribution of charges.

The following is an excerpt from a conversation with the teachers during the process of the tutorial.

T1: Initially, I wonder if an electron disappears magically, but you know it is not possible. Why are the C and A parts equi-potential? There must be an electron passing through the light bulb.... If there are charges remaining outside…

T2: Accelerated by the following (-) electrons continuously being pushed out… The number of electrons passing through each section is equal. The number of electrons constantly passes through with the same speed. (Because of the same potential difference)

T3: The electron has constant velocity motion at A and C. B and D take the force of the voltage and they speed up according to the amount of its force. Therefore, the current is the same everywhere.

T4: At point B, the speed goes up since there are a small number of electrons that can pass through.

T1 teacher describes the reason for the potential difference becoming 0 at both ends of the wire as follows. 'The idea of the charge being accumulated at each end of the light bulb came from understanding the potential difference being 0 in the situation where charges are not being forced through the prior tutorial of the

electrostatic area.’ This can be seen as the critical moment of correcting the typical misconception of the current being consumed at the circuit or being consumed while passing through the light bulb. When interpreting the current and voltage in the circuit, explaining it in terms of the movement of charge is an important solution to correct the constant misconception of teachers.
After finishing the tutorial, the correct answers in a re-examination of the pre-test increased from 15% to 93%.

(4) The belief that the battery exports constant current
The following question is a question that was asked in a preliminary study before the development of the tutorial(see Fig. 14)[13]. It asks about the current flowing in the circuit, and about the brightness of the bulb when the brightness of the bulb and switch are closed in a case where the switch is open and the serial and parallel of the electric bulb are mixed in the circuit.

The circuit shown has four identical light bulbs, an ideal battery and a switch.
When the switch is opened: Rank the brightness of the bulbs. Explain

When the switch is closed: Rank the brightness of the bulbs.

If switch is closed, does the brightness bulb A?
① Increase ② decrease ③ the same
Explain your reasoning.

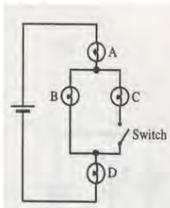


FIG. 14. Preliminary study question

51% of the teachers responded that there is no change in the brightness of bulb A when closing the switch. Among all the reasons, the most common response was that ‘because there is no change in the current.’ The elementary school teachers have a misconception that ‘the battery exports a constant current regardless of connections of loads.’ We included the following information in order to correct these kinds of misconceptions. When questioned about the conception of the distribution of charges after measuring the voltage in a serial connection of the electric bulb, teachers intentionally drew charges at contacting cross-sections of the wire and the resistor. Eventually these charges produce forces to move electrons inside the resistors. There is a strong tendency to draw half of the number of charges of the end of the two bulb ends in a serial connection. They drew the same number of charges because two electric bulbs are measured as having the same voltage as the battery in the parallel connection. In this part, the teachers start to conceive of the movement of charges that pass the battery. The following is an excerpt from a teacher’s interview.

T1: The battery works selectively depending on how the circuit is arranged. The ability of the electrons to move in this way is similar to V, where it is slowly exported in a situation where depending on the case of the passing wire that can cause it to be delayed, and in the situation where it can move quickly (plenty) it moves fast (many).

Through the results from a battery-like voltage in two electric bulbs, it was explained that in a parallel connection, it becomes twice the amount of work that the battery does. Teachers were able to consider the movement of charges by connecting the works of the battery, and they were also able to explain that the battery does different things depending on the circuit. It can be said that the tutorial played an important role in correcting the misconception that ‘the battery exports constant current.’ An example of the distribution of charges that teachers drew is presented in the figure.

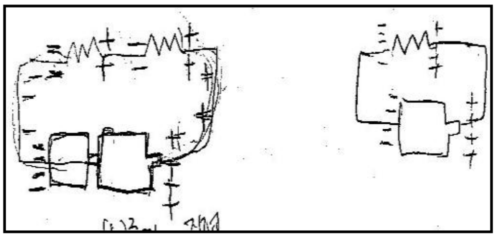


FIG. 15. Diagrams drawn by teachers to show distribution of charges in series

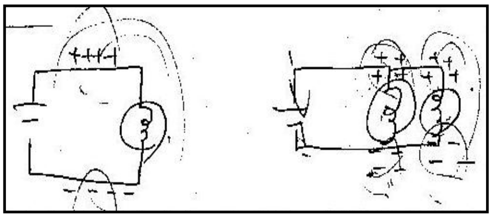


FIG. 16. Diagrams drawn by teachers to show distribution of charges in parallel

2. Results of answers to multiple-choice questionnaire before and after implementing the tutorial

After applying the tutorial, we observed the degree of changes of the teachers' conceptualization by comparing the results of answers to an optional questionnaire before applying the tutorial(Fig. 17).

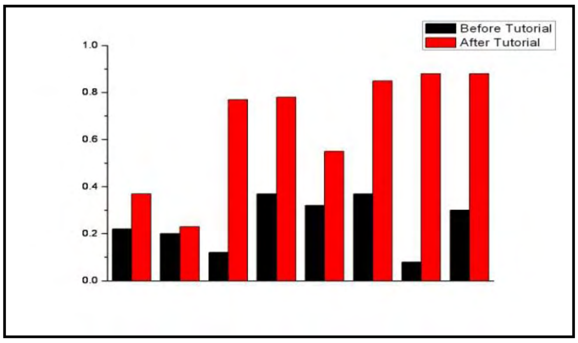


FIG. 17. Pre and Post Tutorial results for multiple choice questionnaires

The question with the lowest rate of correct answer asks about the brightness of a bulb in a situation with a mixed circuit of the serial and parallel connection. The following is a summary of the teachers' interviews.

Q: Which point in this problem's situation is difficult?
T1: I think the battery will move the charges faster (more) if the switch is closed. But I wonder about the charges that are passing the B bulb…
T2: The movement of charges that pass the A and B bulbs when the switch is open will create a C bulb… I also think the movement of charges that pass A might become slower…

The explanation of the voltage that depends on each bulb through the distribution of charges in the single connection of serial and parallel circuits was understood, but we can see that there was difficulty in applying this concept to a mixed circuit. There is a need to reinforce the content of the tutorial in order to apply it to a mixed circuit by consideration of the movement of charges in serial and parallel circuits.

IV. Conclusions and Implications for Teaching

This study developed tutorials for elementary school teachers emphasizing the movement of charges. We attempted to fix persistent misconceptions that remained despite years of teaching experience. We obtained these conclusions after analyzing the changes in their conceptualization of electricity.

When the educators understood the characteristics of conductors and insulators, they were able to explain friction, induction, and the movement of charges at contact points. This ended the confusion between electric charge and current. Though many teachers responded that there was no voltage while current did not flow in an open circuit, their understanding of voltage and the movement of charges was enhanced through the tutorial. These tutorials played an important role in correcting the misconception that voltage is the same as current. By emphasizing the interaction of charges in a closed circuit, the teachers understood that current was not consumed but remained constant. Also, the tutorials corrected the misconception that the battery produces constant current in all situations; instead, the teachers began thinking in terms of the movement of charges through a battery in a series and a parallel circuit.

We bring up the following suggestions based on our experimental results and conclusions.

First, there will be implications from studying only one method in developing an elementary school educational curriculum. Physics education for elementary school teacher-in-training will differ from a physics professor's curriculum. There is a need for a curriculum that emphasizes conceptual understanding, rather than practicing quantitative problem-solving. Therefore, we believe the tutorial suggested in this study will be useful for would-be elementary instructors in teaching electricity-related units in the elementary school situations.

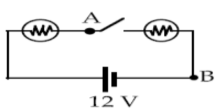
Second, our resultant tutorial can be used as a refresher material for re-educating current elementary educators. The tutorial emphasizing movement of charge was developed based on the difficulties that instructors face in teaching electricity-related units. Also, the tutorial covers detailed content focusing on addresses these difficulties; thus, we anticipate that it will be valuable in retraining elementary teachers. We confirmed the enhanced conceptual understanding of the participating elementary teachers, and we foresee that teachers' understanding will lead to improved students' understanding as well.

Third, future study is needed to observe teachers who have a solid conceptual understanding of currents as a result of participating in tutorials focused on the movement of charges as well as the effects of their conceptual understanding in their teaching.

APPENDIX : MULTIFUL CHOICE QUESTIONNAIRES

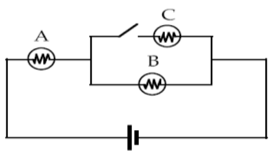
1. What is the potential difference between points A and B?

1) 0V
2) 3V
3) 6V
4) 12V
5) None of the above

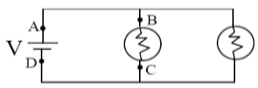


2. What happens to the brightness of bulbs A and B when the switch is closed?

1) A stays the same, B dims
2) A brighter, B dims
3) A and B increase
4) A and B decrease
5) A and B remain the same



※ Questions 3-4 refer to the circuit below.



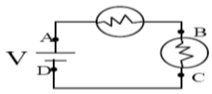
3. Compare the current at A now to the current at A before with only one bulb (Battery is ideal and they have no internal resistance).

1) The current at A is now twice as large as before
2) The current at A is now larger than before but not twice as large

3) The current at A is the same as before
4) The current at A is now half as large as before
5) The current at A is now smaller than before but not half as large

4. Compare the current through the bulb connected between B and C now to the current through it before when there was only one bulb.
1) The current is larger than it was before
2) The current is the same as before
3) The current is smaller than it was before

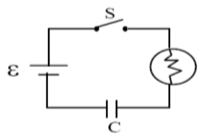
※ Questions 5-6 refer to the circuit below.



5. Compare the current at A now to the current at A with only one bulb (Battery is ideal and they have no internal resistance).
1) The current at A is now twice as large as before
2) The current at A is now larger than before but not twice as large
3) The current at A is the same as before
4) The current at A is now half as large as before
5) The current at A is now smaller than before but not half as large

6. Compare the potential difference across the bulb, V_{BC}, now to what it was before when there was only one bulb.
1) The potential difference is now twice as large as before
2) The potential difference is now larger than before but not twice as large
3) The potential difference is the same as before
4) The potential difference is now half as large as before
5) The potential difference is now smaller than before but not half as large

※ Questions 7-8 refer to the circuit below.



7. Which correctly describes what happens to the bulb when the switch is closed?
1) The bulb is dim and remains dim.
2) At first the bulb is dim and it gets brighter and brighter until its brightness levels off.
3) The bulb is bright and remains bright.
4) At first the bulb is bright and it gets dimmer and dimmer until it goes off.
5) None of these is correct.

8. Which correctly describes what happens after the switch has remained closed for a long time?
1) The bulb continues to shine brightly.
2) The bulb no longer shines.
3) The potential difference across the capacitor is steady and much smaller than ε.
4) The current in the circuit is steady and large.
5) None of these is correct.

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