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The Analysis of Students' Understanding of Electricity Fundamental Concepts

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ABSTRACT
The aim of this research was to analyze students' understanding of electricity fundamental concepts. The research of subjects are 86 students in physics department of UNG who are taking lectures of Fundamental Physics I in 2021/2022 academic year. Data analysis was conducted based on combination of multiple-choice test results Certainty of Response Index scores. The results show the students' understanding of electricity fundamental concepts which includes sub topics: conduction and induction, relation of electrostatic force and distance, electrostatic force resultant, electric field and electric potential, relation of voltage and electric current in conductor, series and parallel circuit, and placement of ammeter and voltmeter in electrical circuits, are still weak by most students, even many students who choose the false answer but are very sure of the answer. The research recommended further research to examine more intensely and more factually about the causes of student failure in solving fundamental problems of electricity, for example using Predict-Observe-Explain model or structured clinical interviews.

INTRODUCTION

Fundamental physics lecturers should deliver students a complete, thorough, and profound understanding of physics fundamental concepts to students, allowing the students to implement the science in different problem-solving and technology products. Conceptual understanding constitutes an ability to understand the meaning of information, including the ability to translate, interpret, and extrapolate the information [1]. Accordingly, a conceptual understanding is the ability to re-narrate, interpret, and draw a conclusion from information using the concerned individuals' narration and, as such, based on their characters. A naive, incorrect conceptual understanding which deviates from the correct meaning may lead to a misconception [1] [2] [3] [4] [5] [6] [7] [8].

In the last decades, physics researchers are striving to enhance conceptual students' understandings and decrease their misconceptions associated with the fundamentals of physics. For instance, in the mechanic field, we can find a vast amount of research on endeavors combating student difficulties in apprehending fundamentals of cinematics and dynamics [9] [10] [11] [12] [13] [14] [15] [16]. Previous researchers have analyzed students' conceptual understandings and misconceptions of the fundamentals of kinematics and dynamics using a diagnostic test instrument they develop [12] [17] [18] [19] [20], fundamentals of temperature and heat [21] [22], fundamentals of waves [23][24] [25] [26], and fundamentals of an electric circuit [4] [27] [28] [29] [30] [31].

There are some backdrops elucidating why there is abundant physics education research on escalating students' conceptual understandings and de-escalating their misconceptions bearing on the mechanics sub-field (kinematics and dynamics). Among the backdrops is the idea that by mastering the fundamentals of mechanics completely, thoroughly, and profoundly, there will be no hardship in learning other physics subfields [19].

On the contrary, studies of conceptual understandings and misconceptions of electricity fundamental concepts are less in number when a complete, thorough, and profound understanding of the concepts is pivotal because the fourth industrial revolution (modern/digital technology) is advocated by ever-varying electric circuit components and types. And yet, basic components for building electronic equipment, e.g., resistors, capacitors, inductors, diodes, transistors, transformers, and integrated circuits (IC) are still used. People are ignorant in terms of the functions of the basic components. A capacitor (condenser) stores and releases energy or electric charge, and an inductor (coil) serves as a frequency regulator, filter, or connector. A diode orients electric current in one direction and blocks electric current from the opposite direction, converts AC into DC, and limits voltage for both small and large currents. A transistor (transfer resistor) acts as a current amplifier, circuit breaker and switcher, voltage modulator, signal modulator, and rectifier. A transformer transfers electric energy from one circuit to another through an electromagnetic induction process. Finally, an integrated circuit (IC) is a combination of hundreds or even thousands of resistors, capacitors, transistors, and diodes in a small shape and size and functions as a signal and power amplifier.

Notwithstanding researchers' low motivation in the field of physics education field, especially concerning conceptual understandings and misconceptions of electricity fundamental concepts, some researchers have significantly contributed to electricity-related literature. Pesman builds a three-tier test instrument to examine misconceptions about simple electric circuit topics [27]. Dupin & Jhosua observe French students' conception of electric circuits [29]. Kucukozer & Kocahkulah investigate high school student misconceptions of simple electric circuit topics [28]. Mursalin remediates students' misconceptions using a PhET (Physics Education Technology) simulation approach [30]. Mursalin detracts from senior high school students' misconception of electric circuits using POE (Predict-Observe-Explain) learning [31].

In physics, we have the terms basic quantities and derived quantities. A basic quantity brings about a relationship between a physics quantity and other physics quantities. Accordingly, research on conceptual understandings of the relationship between physics quantities is popular among researchers. As such, the relationship between a physics quantity and other quantities should be completely, thoroughly, and profoundly apprehended by students. And yet, the relationship between physics quantities is frequently incorrectly conceptualized by most students or teachers. For instance, students or teachers may describe Coulomb's law quickly and correctly but may be baffled when having to answer the relationship between the law and physics quantities. In this article, physics basic and derive quantities (the relationship) are demonstrated in the forms of figures or charts to reveal students' understanding of electricity fundamental concepts.

Building on the background, we are aimed to unravel students' understandings of electricity fundamental concepts, notably the subtopics of conduction and induction, the nature of the charges, the relationship between electrostatic force and the distance between charges, resultant electrostatic force, electric field and electric potential, the relationship between voltage and electric current in a conducted, series, and parallel (lamp) resistance circuits, and the placement of ammeters and voltmeters in electric circuits.

METHOD

Students at the Physics Department Faculty of Mathematics and Natural Science Universitas Negeri Gorontalo (UNG) who are taking Fundamental Physics I odd semester academic year of 2021/2002 are engaged in this research. As stated in the curricula set by the Physics Department Faculty of Mathematics and Natural Science UNG, among the lecture topics/materials of Fundamental Physics 1 is electricity, primarily addressing its qualitative aspects, and hence the mathematic equations are only ascribed as a tool to unveil the relationship between two physics quantities germane to the topic of electricity, either in a directly proportional or inversely proportional relationship.

Eighty-six students from the Physics Department Faculty of Mathematics and Natural Science UNG act as the research samples. They are taking either a bachelor's degree in physics, physics education, or natural science education. Fundamental Physics 1 in each major is taught by a different teacher team within the last three years. Before beginning lecturing activities, all teacher teams carry out a meeting to discuss lecturing materials and objectives, strategies, models, methods, approaches, and references used. After the discussion, Giancoli's book [32] is decided as the prime reference, whereas Tipler & Mosca's [33] and other books which support lecturing are decided as additional references. Lecturing materials, objectives, and assessment instruments are all the same; while learning strategies, models, methods, and approaches may differ by the teaching style of the lecturer concerned. For instance, on the topic of electricity, lecturers use a PhET simulation animation program to present the effect of electric charge properties or to explain the relationship between two physic quantities.

The instrument used is a multiple-choice test containing 11 question items on the topic of electricity, particularly conduction and induction, the nature of charges, Coulomb's law, electric fields, electric potentials, Ohm's law, electric resistance circuits, ammeter, and voltmeter. The test is presented in a pictorial and/or chart form. The test is given after the topic of electricity is completely discussed. In answering each question item in the multiple-choice test, students should give the Certainty of Response Index (CRI) scored from 0-5 [34], the scores of which are exhibited in Table 1. Score 0 indicates a prediction-based answer to the question item in the multiple-choice test given (not sure), score 5 indicates a highly certain answer (certain), and scores 1-4 indicate the degree of certainty and correctness of the answer is between the two ideal scores (0 and 5).

Table 1. The Degree of Students' Confidence in Answering Each Question Given

CRI Score	Degree of Students' Certainty in Answering Question Tests
0	100% guessing (totally guessing answer)
1	75%-99% guessing (almost guessing)
2	50%-74% guessing (not sure)
3	25%-49% guessing (sure)
4	1%-24% guessing (almost)
5	Not guessing (certain)

The data on the levels of students' understanding of electricity fundamental concepts are collected by combining students' answers to each question item and the degree of confidence/certainty in the answers. For example, an incorrect answer with the category of the degree of certainty of "not guessing, 5, or certain" indicates a misconception. However, a correct answer with the category of the degree of certainty of "not guessing, 5, or certain" is indicative of a good, complete, thorough, and profound understanding. This way or method to determine the category of students' understanding levels is called a two-tier. Potgieter et al. [35], Sutopo [23], and Chang et al. [36] use the method to investigate students' understandings of physics fundamentals. Table 2 points out the rubric of the degree of students' understanding based on the combination of answer correctness and levels of certainty in each answer.

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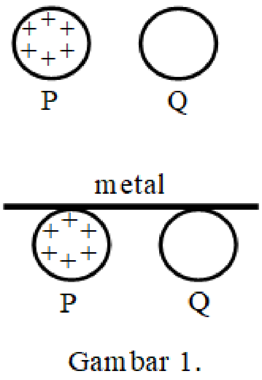
Table 2. The Rubric of The Levels of Students' Understandings Based on Certainty Scores [23] [35] [36]

Answer	Category of Students' Understanding Based on Certainty Scores			
	5	**4**	**3**	**2 – 0**
Correct	Very good	Good	Poor	Weak
Incorrect	Misconception	Weak	Weak	

RESULTS AND DISCUSSIONS

Students' Understanding of Electric Conduction

Figure 1 points out the question item to reveal students' understandings of electric conduction, and Table 3 presents the distribution of students' answers and understanding levels. As pointed out in Table 3, more than 48% of 86 respondent students answer correctly (E*), 14% come with a very good understanding (complete, thorough, and profound), 22% show a good understanding, and 12% show a poor one. Other students, above 33%, answer incorrectly and have a weak understanding, and 17% also answer incorrectly and point out misconceptions.



See Figure 1.
Top: Two identical metal spheres P and Q (with the same material and size).
Sphere P is given six positive charges and sphere Q is neutral.
Bottom: When spheres P and Q are making a contact with (connected with) the metal bar, then ….
A. P has six positive charges and Q is neutral.
B. P is neutral and Q has six positive charges.
C. P has six positive charges and Q has six positive charges.
D. P has six positive charges and Q has six negative charges.
E. P has three positive charges and Q has three positive charges.
F. P has three negative charges and Q has three positive charges.

Fig 1. *Question Item to Disclose Students' Understanding of Electric Conduction*

Table 3. Distribution Of Students' Answers and Understanding Levels Based on The Question in Figure 1

Distribution of Students' Answers					**Distribution of Students' Understanding Levels**		
Option	**Total**		**Misconception**		**Category**	**N**	**%**
	N	**%**	**N**	**%**			
A	7	8.1	2	2.3	Very good	12	14.0
B	12	14.0	4	4.6	Good	19	22.1
C	6	7.0	1	1.2	Poor	11	12.8
D	5	5.8	2	2.3	Weak	29	33.7
E*	42	48.8	-	-	Misconception	15	17.4
F	14	16.3	6	7.0			
Total	86	100	15	17.4		86	100

**: Key answer*

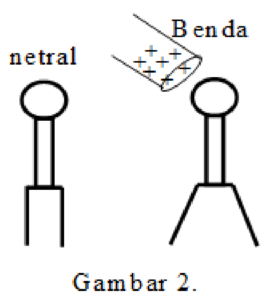
To answer the question item in Figure 1 certainly, students should apprehend and implement the atomic theory and principles of analogy. **Firstly:** Several electrons can move freely and rapidly in a conductor but cannot leave it easily. These free electrons are often called conducting electrons. When a positively charged object is brought near or in contact with a conductor, free electrons in the conductor are attracted by the positively charged and move rapidly (approaching the positively charged object). On the contrary, if a negatively charged object is brought near or in contact with a conductor, free electrons in the conductor will move against the object rapidly [32] [33]. **Secondly:** When a physics situation is hard to understand or the solution is unconscionable, it can be analogized with another more real one [37] [38].

The question item in Figure 1 addresses the phenomenon of electric conduction pertinent to electric current and electric voltage (potential difference). Electric current and voltage are basic electric quantities which are invisible and difficult to understand and learn. Accordingly, (1) electric current can be analogized with water current (flow), and (2) electric voltage can be analogous to the difference in water level. Analysis results demonstrate that water moves (flows) from a higher surface (higher potential energy) to a lower surface (lower potential energy) and will stops (calm water) when achieving a state of equilibrium (the same level of the surface). And yet, free electrons in a conductor act differently from water, which flows from a higher to lower surface, instead, they move (flow) from a lower to higher potential and stop when the potential difference is zero.

Students answering incorrectly: A, C, or D are exhibiting a weak understanding and may not apprehend the concept, even ±2% of them are certain of their answers, indicating misconceptions. Students answering B (an incorrect answer) allegedly comprehend the transfer of free electrons from neutral metal sphere Q (a low potential) to metal sphere P (a high potential) but fail to figure out when the transfer stops or how many electrons should be transferred in order that a state of equilibrium is attained. 4% of the students are certain of their answer. Other students, who answer B, allegedly understand the transfer of three electrons from neutral metal sphere Q to metal sphere P. However, they assume that there are excess electrons in metal sphere P and accordingly, conclude that metal sphere P has three negative electrons. 4% of them are certain of their answer.

Students' Understanding of Electric Induction

The question item to investigate students' understandings of electric induction is pointed out in Figure 2. The distribution of students' answers and understanding levels are presented in Table 4. In Table 4, more than 39% of 86 respondent students choose the correct answer (E*), and more than 19% of the students showcase a good conceptual understanding (complete, thorough, and profound) of electric induction, 14% show off a good understanding, and 6% demonstrate a poor one. Half of the total respondent students (50%) answer incorrectly and exhibit a weak understanding, and 10% answer incorrectly as well and indicate misconceptions.



See Figure 2.
Left: A neutral electroscope.
Right: When a positively charged object is brought near the head of the electroscope, the leaves will spread apart. This means that ….
A. The head of the electroscope is negatively charged.
B. The electroscope is charged.
C. The leaves of the electroscope are positively charged.
D. A, B, and C are correct.
E. A and C are correct, but B is incorrect.
F. A and B are incorrect, but B is correct.

Fig 2. *Question Item to Disclose Students' Understanding of Electric Induction*

Table 4. Distribution Of Students' Answers and Understanding Levels Based on The Question in Figure 2

Distribution of Students' Answers					Distribution of Students' Understanding Levels		
Option	**Total**		**Misconception**		**Category**	**N**	**%**
	N	**%**	**N**	**%**			
A	10	11.6	-	-	Very good	17	19.8
B	20	23.3	7	8.1	Good	12	14.0
C	14	16.3	-	-	Poor	5	5.8
D	5	5.8	2	2.3	Weak	43	50.0
E*	34	39.5	-	-	Misconception	9	10.4
F	3	3.5	-	-			
Total	86	100	9	10.4		86	100

**: Key answer*

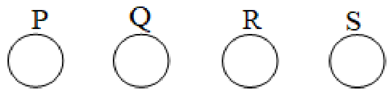
To answer the question item in Figure 2 certainly and correctly, students should apprehend and apply the atomic theory in the conductor as previously explained. Additionally, students should comprehend the question item as a phenomenon of electric induction with these two stipulations: **firstly**: a positively charged object and the electroscope are not in contact (connected) either directly or indirectly, and **secondly**: when a positively charged object is brought near the head of the electroscope, electrons in the electroscope move towards the positively charged object and leads to the head of the electroscope, whereas positive charges in the electroscope move against the positively charged object and lead to the leaves of the electroscope [32] [33].

Students selecting either A or C demonstrate a partial understanding (a weak understanding) of the phenomenon of electric induction. Both A and B suggest the object is charged with electricity (negative and positive) as long as the positively charged object is near the head of the electroscope. 20 students (above 23%) choose the incorrect answer B (a charged electroscope), and seven of them (above 8%) exhibit misconceptions. Meanwhile, 6% of the total students opt for another incorrect answer B, and 2% of them indicate misconceptions. Students' failure at certainly answering correctly is because **firstly**, they implement the concept of electron movement in the phenomenon of electric induction in exactly the same manner as that in the phenomenon of electric condition, and **secondly**, they incorrectly comprehend the physical meaning or definition of electric induction as a phenomenon of the separation of negative charges (electrons) and positive charges in a conductor as a result of the placement of charged objects near the conductor, and this separation process is not followed by electron transfer from the conductor to a charged object or vice versa.

Students' Understanding of the Nature of the Charge in An Object

The question item afforded to reveal students' understandings of how to determine types of the charge of an object based on the nature of electric charges is indicated in Figure 3. The distribution of students' answers and understanding levels are pointed out in Table 5. As presented in Table 5, 54 (63%) of 86 respondent students answer correctly (E*), 43% of them show a very good understanding (complete, thorough, and profound), and 13% and 7% showcase good and poor understandings, respectively. Moreover, above 27% of the total students answer incorrectly and show off a weak understanding, and above 9% answer incorrectly too and demonstrate misconceptions.

To confer the right answer on the question item in Figure 3 certainly, students should apprehend and apply their knowledge about the nature of electric charges based on Coulomb's law and describe the non-contact force (electrostatic force) as a vector quantity acting on an electric charge.



Gambar 3.

Neutral metal spheres P, Q, R, and S are placed inline (Figure 3). When the spheres are electrically charged, and electrostatic forces only occur between two adjacent ones, the correct order of the types of charges are ....

A. P positive, Q negative, R negative, and S positive.
B. P negative, Q negative, R positive, and S positive.
C. P positive, Q positive, R negative, and S negative.
D. P positive Q positive, R negative, dan S positive.
E. A, B, and C are correct, but D is incorrect.
F. A, B, C, and D are correct.

Fig 3. *Question Item to Unravel Students' Understandings of How to Determine Types of Charge in An Object Based on The Nature of Electric Charges and Direction of Electrostatic Forces*

Table 5. Distribution Of Students' Answers and Understanding Levels Based on The Question in Figure 3

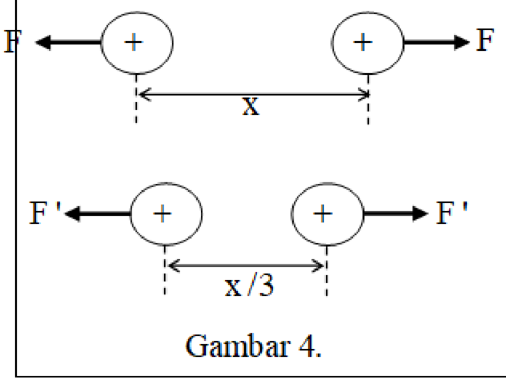
Distribution of Students' Answers					**Distribution of Students' Understanding Levels**		
Option	**Total**		**Misconception**		**Category**	**N**	**%**
	N	**%**	**N**	**%**			
A	3	3.5	-	-	Very good	37	43.0
B	8	9.3	2	2.3	Good	11	12.8
C	9	10.5	1	1.2	Poor	6	7.0
D	5	5.8	2	2.3	Weak	24	27.9
E*	54	62.8	-	-	Misconception	8	9.3
F	7	8.1	3	3.5			
Total	86	100	8	9.3		86	100

**: Key answer*

Students choosing either A, B, or C demonstrate a weak understanding (a partial understanding). In addition, they cannot generalize or conclude that the three answers are correct. 4% (three) of the students certainly opt for B and C (exhibiting a misconception). A, B, and C are correct as the options abide by Coulomb's law if the directions of electric force are drawn with directed lines/arrows towards spheres P, Q, R, and S. Students answering incorrectly (D and F) indicate a weak understanding or even no understanding of the concept. 6% (five) of them are certain of their answer. D is a wrong option as sphere S is positively charged and if the directions of electric forces are drawn with directed lines towards spheres P, Q, R, and S, Coulomb's law is not fulfilled. More than 9% of the students with option D are certain of their answers.

Students' Understanding of Electrostatic Force

The question item delivered to unveil students' understandings of the relationship between electrostatic forces and the distance between two electric forces is demonstrated in Figure 4. The distribution of students' answers and understanding levels are exhibited in Table 6. As indicated in Table 6, 32 (above 37%) of 86 respondent students answer correctly (E*), above 22% show a very good understanding, 12 show a good understanding, and 4% show a poor one. Other students, above 38% and 24% answer incorrectly and show a weak understanding and misconceptions, respectively.



See Figure 4.
Top: Two positive electric charges in a line are in a distance apart x and experience the electrostatic force F.
Bottom: If the distance between both charges is x/3, the electrostatic F' is ....
A. F B. 1/3 F C. 1/9 F D. 3 F E. 9 F
F. A, B, C, D, and E are incorrect.

Fig 4. *Question item to untangle students' understandings of the relationship between electrostatic force and distance between two electric charges*

Table 6. Distribution of students' answers and understanding levels based on the question in Figure 4

Distribution of Students' Answers					**Distribution of Students' Understanding Levels**		
Option	**Total**		**Misconception**		**Category**	**N**	**%**
	N	**%**	**N**	**%**			
A	2	2.3	-	-	Very good	19	22.1
B	9	10.5	5	5.8	Good	10	11.6
C	6	7.0	3	3.5	Poor	3	3.5
D	34	39.5	13	15.1	Weak	33	38.4
E*	32	37.2	-	-	Misconception	21	24.4
F	3	3.5	-	-			
Total	86	100	21	24.4		86	100

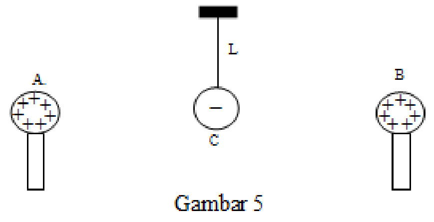
**: Key answer*

To answer the question item in Figure 4 correctly and certainly, students should comprehend the physical meaning of an inversely proportional relationship and the square of the distance as stipulated in Coulomb's law and apply it to solve electrostatic force-related problems. As pointed out in Table 6, 37 students answer correctly, and only 3/2 (more than 22%) are certain. 24 students answer incorrectly and show a misconception.

Students choosing the incorrect option A showcase a poor or even no understanding of the concept. Students opting for two other incorrect answers B and C show off no understanding of the physical definition of an inversely proportional relationship or are unable to solve fraction division problems. Above 9% (eight) of the students selecting B or C are certain of their answer and accordingly, demonstrate a misconception. The incorrect answer is mostly D (34 or 40% of 86 students). 15% (13) of the students are certain of their answer. As such, the majority of the students only apprehend the electrostatic force which is inversely proportional to the distance between two electric charges, while Ohm's law stipulates that the electrostatic force between two electric charges is proportional to the result of the multiplication of both charges and is inversely proportional to the square of the distance.

Students' Understanding of Resultant Electrostatic Force

The question item to identify students' understanding of resultant electrostatic force is pointed out in Figure 5. The distribution of students' answers and understanding levels are demonstrated in Table 7. Building on Table 7, 18 (21%) of 86 students choose the correct answer E*. 13% of them exhibit a very good understanding, and more than 8% have a poor one. 68 students (70%) answer incorrectly, and more than 31% and 4% indicate a weak understanding and misconception, respectively.



Conducting spheres A, B, and C are placed in line. Spheres A and B are permanently placed, whereas sphere C is suspended using a neutral string between A and B (see Figure 5). After the three spheres are charged, the correct statement is ….
A. Sphere C vibrates.
B. Sphere C moves from A to B repeatedly.
C. Sphere C moves towards sphere A.
D. Sphere C moves towards sphere B.
E. Sphere C remains static.
F. A, B, C, D, and E are incorrect.

Fig 5. *Question item to examine students' understanding of resultant electrostatic force in a charge due to the other two electric charges*

Table 7. Distribution of students' answers and understanding levels based on the question in Figure 5

Distribution of Students' Answers					Distribution of Students' Understanding Levels		
Option	Total		Misconception		Category	N	%
	N	%	N	%			
A	1	1.2	-	-	Very good	11	12.8
B	45	52.3	32	37.2	Good	7	8.1
C	9	10.5	3	3.5	Poor	-	-
D	11	12.8	6	7.0	Weak	27	31.4
E*	18	20.9	-	-	Misconception	41	47.7
F	2	2.3	-	-			
Total	86	100	41	47.7		86	100

: Key answer

To deliver the right answer to the question item in Figure 5 certainly, students should be able to determine the magnitude and direction of electrostatic force in a charge (sphere C) due to the effect of two other charges (spheres A and B) and able to determine the magnitude of the resultant force and its physical definition.

As in Table 7, of 21% of students who answer correctly, only 3/2 are certain of their answer. Meanwhile, 48% of students show misconceptions and their answers are incorrect. Most students who answer incorrectly choose option B (45 of 86 students, or more than 52%), and 32 or more than 37% are certain of their answer. This showcases that most of the students assume that the resultant electrostatic acting on metal sphere C is not equal to zero and becomes the restoring force so that metal sphere C moves from A to B continuously and will stop when the restoring force vanishes (zero). The two other incorrect answers mostly chosen by students are D and C, even those choosing either of the two incorrect answers (7% and 3%, respectively) are certain of them. In other words, they cannot conclude that in metal sphere C, there are two electrostatic forces of attraction which are equal and move in an opposite direction and the resultant of these two forces is equal to zero, or metal sphere C is static.

Students' Understanding of Electric Fields and Electric Potential in Charged Conducting Spheres

The question item proposed to investigate students' understandings of electric fields and electric potential in a charged conducting sphere is conveyed in Figure 6. The distribution of students' answers and understanding levels are demonstrated in Table 8. The correct answer to this question item is C. As in Table 8, 17 (above 19%) of 86 students opt for the incorrect answer (C*), and above 10% and 7% have a very good understanding and a poor one, respectively. Meanwhile, 69 or above 80% answer incorrectly, above 24% and 55% of them have a weak understanding and exhibit a

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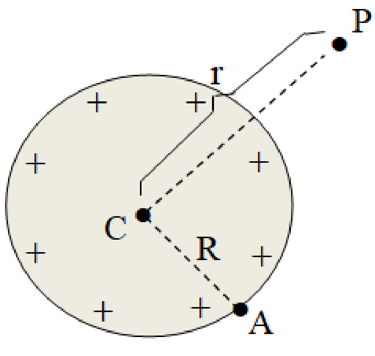
misconception, respectively.



Gambar 6

See Figure 6.
In a conducting sphere with radius R and center C, positive electric charges are uniformly distributed over the surface of the sphere.
(1) The electric field strength at point C is minimum/zero.
(2) The electric field strength at point P is 1/r.
(3) The electric field strength at point A is maximum.
(4) Electric potential at points C and A is equal and maximum.
(5) Electric potential at point P is $1/r^2$.
The correct statement is:
A. (2) and (5)
B. (2), (3), and (4)
C. (1), (3), and (4)
D. (1), (2), (3), and (4)
E. (1), (3), (4), and (5)
F. (1), (2), (3), (4), and (5)

Fig 6. *Question item to find out students' understanding of electric fields and electric potential in a conducting sphere with electric charges*

Table 8. Distribution of students' answers and understandings levels based on the question in Figure 6

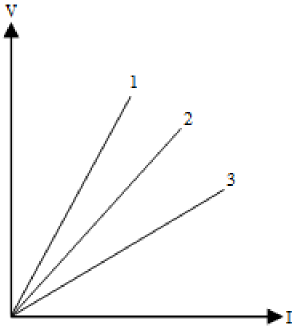
Distribution of Students' Answers					**Distribution of Students' Understanding Levels**		
Option	**Total**		**Misconception**		**Category**	**N**	**%**
	N	**%**	**N**	**N**			
A	44	51.2	36	41.9	Very good	9	10.5
B	10	11.6	6	7.0	Good	6	7.0
C*	17	19.8	-	-	Poor	2	2.3
D	5	5.8	3	3.5	Weak	18	20.9
E	5	5.8	2	2.3	Misconception	51	59.3
F	5	5.8	4	4.6			
Total	86	100	51	59.3		86	100

To answer the question item in Figure 6 correctly and certainly, students should apprehend (1) the definition of electric field strength as a force per test charge unit, (2) the electric field strength, by this definition, is inversely proportional to the square of the distance from the source charge, (3) electric field strength is a vector quantity delineated as imaginary lines (electric field lines) which come from a positive charge leading to and ending up to a negative chare, (4) the definition of electric potential as electric potential energy per test charge unit, (5) electric potential strength, by this definition, is inversely proportional to the distance from the source charge, (6) if a conducting sphere is given electric charges and all charges disperse to the sphere surface, then: (i) electric field strength in the sphere is equal to zero, (ii) electric field strength on the sphere surface is maximum, (iii) electric field strength outside the sphere is proportional to $1/r^2$, (iv) electric potential in the sphere is equal to electric potential on the sphere surface (the equipotential field) and maximum, and (v) electric potential outside the sphere is proportional to 1/r.

The incorrect answer mostly opted by students is the option A (44 or above 51% of 86 students). 36 or 42% of them are certain of the answer. This attests to that most of the students fail to comprehend the definition or concept of electric field strength and potential at a point as a result of the source charge. Another incorrect answer mostly opted by students is the option B (ten or 12% of 86 students), and six or 7% of them are certain of the answer. This exhibits their success in understanding that electric field strength at a point on the surface of the conducting sphere is maximum, and that electric potential inside and on the surface of the conducting sphere is the same and maximum. Meanwhile, the options D, E, and F, each is selected by 5 or 6% of the total students, and nine or more than 10% of them are certain of their answers.

Students' Understanding of Resistance in Graph V-I

The question item used to examine students' understandings of the relationship between voltage V and electric current strength I by Ohm's law is indicated in Figure 7. The distribution of students' answers and understanding levels are pointed out in Table 9. The right answer to the question item is B. In Table 9, 30 (35%) of 86 students select the right answer (B*) to this question, and a half or above 17% of them have a good understanding, above 14% and 4% have good and poor understandings, respectively. Meanwhile, 56 or more than 65% of the total students answer incorrectly, above 25% and 40% have a weak understanding category and a misconception, respectively.



Gambar 7.

The data of the results of the measurements of voltage V and current I on a resistance circuit are presented in Figure 7. From the data, we can conclude that the resistance ....

A. $R_1 = R_2 = R_3$
B. $R_1 > R_2 > R_3$
C. $R_1 < R_2 < R_3$
D. $R_1 = R_2 \neq R_3$
E. $R_1 \neq R_2 = R_3$
F. A, B, C, D, and E are wrong.

Fig 7. *Question item to investigate students' understandings of the magnitude of resistance through the chart of a voltage-current relationship*

Table 9. Distribution of students' answers and understandings levels based on the question in Figure

Distribution of Students' Answers					**Distribution of Students' Understanding Levels**		
Option	**Total**		**Misconception**		**Category**	**N**	**%**
	N	**%**	**N**	**N**			
A	12	14.0	5	5.8	Very good	15	17.4
B*	30	34.9	-	-	Good	12	14.0
C	32	37.2	24	27.9	Poor	3	3.5
D	3	3.5	1	1.2	Weak	22	25.6
E	2	2.3	-	-	Misconception	34	39.5
F	7	8.1	4	4.6			
Total	86	100	34	39.5		86	100

To certainly accord the correct answer to the question item in Figure 7, students should be able to (1) read the chart of the relationship between voltage V and electric current strength I in a conductor and (2) determine and conclude the magnitude of the resistance of several conductors through chart V-1 by drawing a horizontal line parallel to axis I or a vertical line parallel to axis V as a tool.

The incorrect answer the majority of the students choose is the option C. Students opting for C probably do not use the recommended tool, which is either a horizontal line parallel to axis I or a vertical line parallel to axis V to determine and conclude the magnitude of resistance in chart V-I. This assumption is supported by the evidence that of 32 or above 37% of 86 students, 24 of 28% are certain of their answers. Accordingly, most students fail to use the tool by drawing either a horizontal line parallel to axis I or a vertical line parallel to axis V in chart V-I to determine and conclude the magnitude of resistance of some different conductors predicated chart V-I. The same assumption is also applicable to other incorrect answers selected by students. And yet, students choosing the incorrect answer A probably use their misleading instinct that the magnitude of resistance of several

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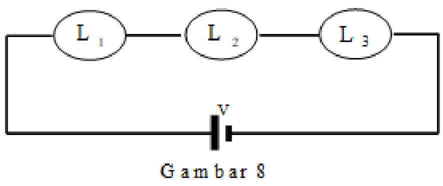
conductors is the same and that voltage V and electric current I or V and I are proportional by Ohm's law in connection with conductors.

Students' Understanding of Series Resistance Circuits



Three non-identical lamps L_1, L_2, and L_3 are in series and in connection with an ideal voltage source (V), as in Figure 8. The correct statement to this circuit is ….
A. The three lamps' light is not equally bright.
B. The three lamps' voltage is the same.
C. The circuit resistance grows larger.
D. A and B are correct but C is incorrect.
E. A and C are correct but B is incorrect.
F. A, B, and C are correct.

Fig 8. *Question item to study students' understandings of the nature of series lamp resistance circuits*

The question to disclose students' understandings of series (lamp) resistance circuits is shown in Figure 8. The distribution of students' answers and understanding levels are shown off in Table 10. The correct answer is C. In Table 10, of 33 (more than 38%) of 86 students who answer this question item correctly, 20% have a very good understanding, and above 16% and above 2% have good and poor understandings, respectively. 53 (62%) other students answer incorrectly, above 24% and even above 37% of them showcase a weak understanding and a misconception, respectively.

Table 10. Distribution of students' answers and understandings levels based on the question in Figure 8

Distribution of Students' Answers					**Distribution of Students' Understanding Levels**		
Option	**Total**		**Misconception**		**Category**	**N**	**%**
	N	**%**	**N**	**N**			
A	27	31.4	22	25.6	Very good	17	19.8
B	3	3.5	-	-	Good	14	16.3
C*	33	38.4	-	-	Poor	2	2.3
D	5	5.8	2	2.3	Weak	21	24.4
E	10	11.6	5	5.8	Misconception	32	37.2
F	8	9.3	3	3.5			
Total	86	100	32	37.2		86	100

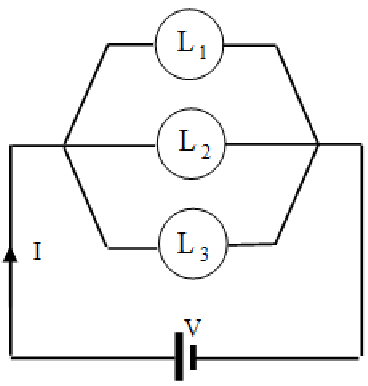
To confer the right answer to the question item in Figure 8 certainly, students should be able to understand and implement the nature of series (lamp) resistance circuits. As in Table 10, more than 38% of students answer correctly but only half (more than 19%) are certain of their answers. More than 37% answer incorrectly and show off a misconception.

The incorrect option A is mostly opted by students who answer incorrectly (27 or above 31% of 86 students), and 22 or above 25% of the students are certain of their answer. As such, most of the students may assume that the magnitude of electric current will always decrease after passing through each (lamp) resistance in a series circuit. They also assume that electric current is partially absorbed (attenuation model) by each circuit component and that electric current close to the positive pole of the voltage resource is higher than that close to the negative pole of the same voltage resource. Finally, they probably also analogize a series circuit to downstream current on a water embankment. These attenuation model and downstream model assumptions have been revealed by a misconception researcher, Van den Berg [4] who carry out an analysis on senior high school students, physics education students, and physics teachers in Indonesia. Three other incorrect answers which are mostly opted by students, in consecutive order from the most to least selected, are E, F, and D. Ten of 23 students who choose the answers are certain of them, and as such, demonstrate a weak understanding and even a misconception.

Students' Understanding of Parallel Resistance Circuits

The question item to unveil students' understandings of parallel (lamp) resistance circuits consists of two questions which (1) the nature of parallel resistance circuits and (2) the effect of the change in resistance values on electric current strength. To answer both question items correctly, students should be able to apprehend and apply their knowledge correctly. The knowledge intended is that (1) an ideal battery means that the resistance source (battery) is assumed to be without internal resistance, (2) an identic lamp means that the lamp power and voltage are the same, (3) identical resistance means that the resistance value is the same, (4) the algebraic sum of electric current strength flowing (incoming) to the junction is equal to that of electric current strength coming out of the junction (Kirchoff's first law), and (5) the circuit resistance value becomes smaller.

Question Item on the Nature of Parallel Resistance Circuits



Gambar 9

Three non-identical lamps L_1, L_2, and L_3 are in parallel and in connection with an ideal voltage source V, as in Figure 9. The correct statement to this circuit is ....

A. The three lamps' light is not equally bright.
B. The voltage of each lamp is the same.
C. The circuit resistance is R/3.
D. A and B are correct but C is incorrect.
E. B is correct but A and C are incorrect.
F. A, B, and C are correct.

Fig 9. *Question item to untangle students' understandings of the nature of parallel (lamp) resistance circuits*

Table 11. Distribution of students' answers and understandings levels based on the question in Figure 9

Distribution of Students' Answers					**Distribution of Students' Understanding Levels**		
Option	**Total**		**Misconception**		**Category**	**N**	**%**
	N	**%**	**N**	**N**			
A	7	8.1	4	4.7	Very good	23	26.7
B	21	24.4	17	19.7	Good	9	10.5
C	15	17.5	11	12.8	Poor	3	3.5
D	3	3.5	-	-	Weak	16	18.6
E	5	5.8	3	3.5	Misconception	35	40.7
F*	35	40.7	-	-			
Jumlah	86	100	35	40.7		86	100

The question item to examine students' understanding of the nature of parallel (lamp) resistance circuits is demonstrated in Figure 9. The distribution of students' answers and understanding levels are exhibited in Table 11. The correct answer to this question item is F. In Table 11, of 35 (41%) of 86 students answering correctly to this question item, 23 (27%) have a good understanding, and more than 10% and more than 3% indicate good and poor understandings, respectively. 51 (more than 59%)

other students answer incorrectly, 16 (more than 18%) and 35 (41) of whom have a weak understanding and a misconception, respectively.

The option B is the incorrect answer mostly selected by students. Of 21 (above 24%) of 86 students who answer B, 17 (20%) are certain of their answer. Furthermore, the option C is the second incorrect answer mostly chosen by students. Of 15 (above 17%) of students who answer C, 11 (13%) are certain of their answer. The option A is the third incorrect answer mostly opted by students. Of seven (above 8%) of students who answer A, four (5%) are certain of their answer. Students answering either A, B, or C have weak or partial understandings. We can conclude so as in this question item, students are categorized as having a very good understanding (A, B, and C) if and only if they can choose all of the three options (A, B, and C) as the correct answers. This is proven by: (1) when the electric current passing through the three identic lamps is measured using an ammeter, if the ammeter needle points the same number, the three lamps' light is the same, (2) when the voltage of the three lamps is measured, if the voltameter needle points the same number, the voltage of the three lamps is the same, and (3) in identic lamps, resistance R of the three lamps is the same, and circuit voltage is R/3/

Question Item on the Effect of Resistance Values on Electric Current Strength

If one of the lamps is disconnected/broken in Figure 9, then ….
A. The lamp's light is unchanged.
B. The circuit current strength becomes smaller.
C. The circuit resistance grows larger.
E. B is correct but A and C are incorrect.
F. A, B, and C are correct.

Fig 10. *Question item to untangle students' understandings of the Effect of Resistance Values on Electric Current Strength*

The question is to examine students' understanding of the effect of resistance values (one of the lamps is disconnected or broken) in Figure 9 on electric current strength. The distribution of students' answers and understanding levels are demonstrated in Table 12. The correct answer is F. In Table 12, of 37 (43%) students who answer correctly to this question item, 21 (above 24%) exhibit a very good understanding and above 1% exhibit a poor one. 49 or 57% answer incorrectly, 15 or above 17% of them indicate a weak understanding and 34 or 40% indicate a misconception.

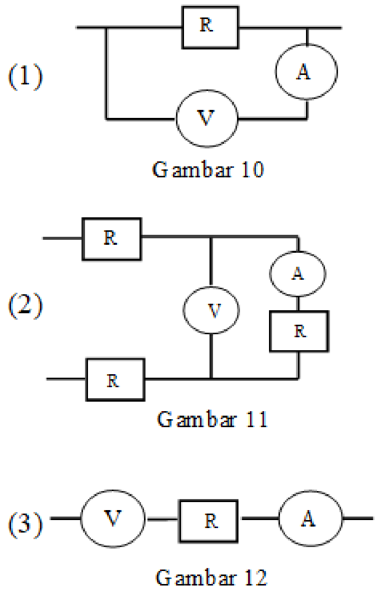
Table 12. Distribution of students' answers and understanding levels based on the question in Figure 9 if one of the lamps is disconnected/broken

Distribution of Students' Answers					**Distribution of Students' Understanding Levels**		
Option	**Total**		**Misconception**		**Category**	**N**	**%**
	N	**%**	**N**	**N**			
A	5	5.8	3	3.5	Very good	21	24.4
B	11	12.8	7	8.1	Good	15	17.4
C	29	33.7	23	26.7	Poor	1	1.2
D	1	1.2	-	-	Weak	15	17.4
E	3	3.5	1	1.2	Misconception	34	39.5
F*	37	43.0	-	-			
Total	86	100	34	39.5		86	100

The option C is the incorrect answer mostly chosen by students who answer incorrectly. Of 29 (34%) of 86 students who opt for the answer, 23 (above 26%) are certain of their answer. The option B is the second incorrect answer mostly chosen by students who answer incorrectly. Of 11 (12%) students who opt for the answer, seven (above 8%) are certain of their answer. The option A is the second incorrect answer mostly chosen by students who answer incorrectly. Of five (6%) students who choose the option, three (4%) are certain of it. Those who opt either the option A, B, or C have a weak or partial understanding as students with a complete, thorough, or profound (very good) understanding of this question item are those who can combine the options A, B, and C as correct answers. This can be exhibited as follows: Before lamps are disconnected/broken (one of the lamps): circuit resistance = R/3 and circuit electric current strength = 3V/R means that the electric current strength flowing through each lam is V/R, after lamps are disconnected/broken: circuit resistance becoming R/2 and circuit electric current strength becoming 2V/R means that electric current strength flowing through two lamps is V/R each. Accordingly, we can conclude that the lamp brightness does not alter before and after one of the lamps is disconnected/broken (the option A is correct, (2) The circuit electric current strength before one of the lamps is disconnected is 3V/R, and that after one of the lamps is disconnected is 2V/R. It means that the circuit current strength becomes smaller (the option B is current), and (3) The circuit resistance before the lamps are disconnected is R/3 and becomes R/2 after the lamps are disconnected. In other words, circuit resistance grows larger after one of the lamps is disconnected (the option C is correct). As such, the correct answer to this question item is F.

Students' Understanding of Ammeter and Voltmeter Placement

The question item used to identify students' understandings of the position/placement of two measurement tools ammeter (A) and voltmeter (V) when they are used in an electric circuit is indicated in Figures 10-12. The distribution of students' answers and understanding levels are pointed out in Table 13. The correct answer to this question item is the option D. As in Table 3, of above 24% of 86 students who answer correctly, 14% present a very good (complete, thorough, and profound) understanding of ammeter and voltmeter position when they are in use, and above 8% and 2% show good and poor understandings, respectively. of 75% of the students who answer incorrectly, 34% and 42% show a weak understanding and a misconception, respectively.



Correct ammeter (A) and voltmeter (V) position or placement when they are used on an electric circuit is ....
A. (1)
B. (2)
C. (3)
D. (1) and (2)
E. (2) and (3)
F. (1), (2), and (3)

Fig 11. *Question item to investigate students' understandings of correct ammeter and voltmeter positi on on an electric circuit*

Table 13. Distribution of students' answers and understanding levels based on the question in Figures 11

Distribution of Students' Answers					Distribution of Students' Understanding Levels		
Option	**Total**		**Misconception**		**Category**	**N**	**%**
	N	**%**	**N**	**%**			
A	23	26.7	14	16.3	Very good	12	14.0
B	22	25.6	15	17.4	Good	7	8.1
C	9	10.5	3	3.5	Poor	2	2.3
D*	21	24.4	-	-	Weak	29	33.7
E	5	5.8	1	1.2	Misconception	36	41.9
F	6	7.0	3	3.5			
Total	86	100	36	41.9		86	100

To answer this question item correctly, students should be able to apprehend the characteristics of and how to use an ammeter and voltmeter on an electric circuit. (1) An ammeter (ammeter) measures electric current strength (DC or AC) in an electric circuit. It has very small resistance in order that: (i) all electric currents measured can pass through it and (ii) very small resistance will breed a low voltage drop. Hence, an ammeter can only be placed or installed in series with an electric circuit component whose electric current strength will be measured, and (2) A voltmeter measures the potential difference (voltage) between two points or electromotive force. It has a very large resistance to avert electric current to pass through when it is in use. Therefore, a voltameter is placed or installed in parallel (between two points) with the electric circuit component whose voltage will be measured (Daryanto, 2008).

65 (3/4 or 76%) of 86 students who answer incorrectly, 34% show off a weak understanding, and even 42% of them are certain of their answers. Those who select the incorrect option A or B cannot draw the conclusion that the ammeter and voltmeter placement on both electric circuits (Figures 10 and 11) is correct. Meanwhile, those who choose other incorrect answers (either C, E, or F) signal a weak understanding or even a misconception.

CONCLUSION AND SUGGESTION

Building on the results and discussion, we can draw some following conclusions: (1) Electric fundamental concepts in the question items inquiring the topics of electric conduction and induction, electric charges, the relationship between electrostatic force and charge distance, resultant electrostatic force, electric field and electric potential, the relationship between voltage and electric current on a conductor, parallel series (lamp) resistance circuit, and ammeter and voltmeter placement in an electric circuit are still understandable and unapplicable for most students when they are confronting different physics conceptual issues in terms of electricity, (2) Although physics students have started learning fundamental concepts of static electricity and dynamic electricity since elementary or high schools, many of them still exhibit lack or poor understandings and even misconceptions, (3) Several causes which lead to students' failure at solving various physics conceptual problems of electricity as aforementioned in point (1) are that: (i) their comprehension of a concept is correct according to them but incorrect according to experts, (ii) they have a poor and weak or no conceptual understanding, and only hinge on their instincts when facing physics conceptual issues of electricity, (iii) they have understood all basic concepts pertaining to each question item to be solved but fail to choose and implement which the most suitable concept to a certain question item is. For example, they have built an apprehension that in a conductor, there are free electrons (conduction electrons) which can move freely from low to high potentials but fail to execute that, electrons are transferred from low to high potentials and stop when a state of equilibrium is reached, and (iv) most of them only apply electric fundamental concepts partially to each question item but fail to carry out generalization or draw correct conclusions.

This article elucidates the results of the analysis of students' understandings of electric fundamental concepts. The analysis is conducted predicated on the combination of student answers (correct options and incorrect answers/detractors) to each multiple-choice question and CRI (Certainty of Response Index) scores. Thus, we recommend a more serious observation through a structural clinical interview (diSessa, 2007; Russ et al., 2012), where the cardinal causes of students' failure at comprehending different fundamental issues of electric phenomena completely, thoroughly, and profoundly are studied.

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