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Physics Students' Conceptual Understanding of Electricity and Magnetism in Nine Years Basic Education in Rwanda

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Abstract: We investigate students' misconceptions in electrostatics, direct current (DC) and magnetism which are important in electricity and magnetism. We developed and administered a multiple-choice questionnaire test to reveal students' misconceptions related to charged bodies, lightning, electric fields, electric potential, forces, DC resistive electric circuits and magnets. This test aimed at obtaining quantitative information about misconceptions and was administered to 380 senior two students from Nine Year Basic Education (9YBE) Schools. The selected students have some experience with the new Rwandan secondary physics Competence Based Curriculum (CBC) that is currently under implementation. We find that senior two students have several common misconceptions related to these concepts. The data indicate that although students have some backgrounds on the subject matter, they still seem to believe that if the two charges are separated by a distance, a large-charged object exerts a greater force of attraction or repulsion on the small one. Considerable number of participated students held the misconception of considering current consumption in the resistor/bulb or the electrical devices in the circuits. They also believed that the battery was a continuous current source. The findings also revealed that students held a misconception that a bar magnet when broken into pieces, it is demagnetized. Moreover, a considerable number of participants hold the misconception that all metals are attracted by a magnet. Our study also revealed some of the statistically significant differences in terms of either gender or location of schools for some items.

Keywords: *Electric current, electricity, electrostatics, magnetism, students' misconceptions.*

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Introduction

In Rwanda, at lower secondary school education, physics is among core subjects from S1 to S3. Despite the importance of physics for the development of Rwanda, there are some challenges that physics education is facing including the students' claim that physics is a difficult subject and the low performance in the subject matter. Some abstract physics topics have been reported among topics making students to feel that physics is very difficult. Moreover, these abstract topics have several concepts where students develop misconceptions (Hermita et al., 2017; Li, 2012; Mboniyirivuze et al., 2019; Turgut et al., 2011). The feeling that physics is very difficult leads some students not to pursue physics related options at advanced level as well as at tertiary education. The students' low conceptual understanding of physics concepts was reported among reasons leading to the problem of low performance of secondary school physics students. Literature highlighted that students' performance in physics is largely affected by their initial knowledge that may include some misconceptions (Halloun & Hestenes, 1985; Hermita et al., 2017; Mboniyirivuze et al., 2019; Uwizeyimana et al., 2018). For four decades, research has revealed that the students' initial common senses beliefs or preconceptions is the major determinant of what students learn in the course and largely affect performance in physics (Halloun & Hestenes, 1985; Li & Singh, 2017; Uwizeyimana et al., 2018). Students' preconceptions in physics cannot be determined without careful research (Halloun & Hestenes, 1985). The assessment of students' prior knowledge plays a paramount role while carrying out investigation related to science instruction design (Heller & Finley, 1992). Several researches on students' conceptual understanding and their misconceptions have become a central issue in physics due to their effect on students' learning and performance from the past four decades (Çepni & Keleş, 2006; Goldberg & McDermott, 1987;

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Halloun & Hestenes, 1985; Lemmer et al., 2020; Li, 2012; Li & Singh, 2017; Maloney et al., 2001; Masson et al., 2014; McColgan et al., 2017). While the word alternate conception has a more neutral sense, it emphasizes what students already know rather than what they don't, the term misconception emphasizes the incorrect knowledge structure occurring repeatedly and explicitly (Lemmer et al., 2020). In this paper, the term misconception has been chosen to be used due to the emphasis of the incorrect students' knowledge structure.

Electricity and magnetism (EM) are key topics in physics and science curricula for elementary school, secondary as well as tertiary levels of education (Gunstone et al., 2009). They are also one of the fundamental areas and topics in physics, with numerous applications that touch on many aspects of our daily lives. Despite the importance of EM, the abstraction and complexity in some of their related concepts are mainly problematic that make their understanding difficult for students (Arnold & Millar, 1987; Mboniyiryivuze et al., 2019; Mioković et al., 2012; Mulhall et al., 2001). Electricity has been reported among topics extremely difficult that conventional teaching methods do not allow student to make sense of it easily (Dega et al., 2013; diSessa, 2006). In previous studies the EM has been described as one of the fields of physics with recurrent misconceptions and discrepancies in understanding by using research instruments including interview schedules and tests (Arnold & Millar, 1987; Çepni & Keleş, 2006; Engelhardt, 1997; Maloney et al., 2001; Mboniyiryivuze et al., 2019; McColgan et al., 2017; Ndiokubwayo & Nkundabakura, 2019; Ndiokubwayo et al., 2020). Despite the availability of several tests, the design and applicability of these existing tests to a general audience are limited. In Rwandan context, there is no standard diagnostic test available in electricity and magnetism. Therefore, to determine whether students have misconceptions about electricity and magnetism in Rwandan Nine Years Basic Education, we used Conceptual Understanding Test for Electricity and Magnetism (CUTEM). The CUTEM instrument aligned with senior two secondary school physics syllabus and physics students' book was designed by the authors. The authors were motivated to design the new conceptual understanding test because existing tests like Electricity and Magnetism Conceptual Assessment (EMCA) (McColgan et al., 2017), MCS (Li, 2012; Li & Singh, 2017) and BEMA (Ding et al., 2006); Conceptual Survey of Electricity and Magnetism (CSEM) (Maloney et al., 2001) are different with the senior two Rwandan lower secondary schools' topics level and content depth. The advantage of a written test is mainly that it could administer to a large sample of big classes. This instrument aligned with senior two Rwandan secondary school physics syllabus and physics students' book was designed in incorporating students' misconceptions of electricity and magnetism reported in literature about those concepts into the distracters. CUTEM is suitable to use for high school students. This test can be used as a screening tool to see what misconceptions students have or as an evaluation tool to see how new students are learning. In this study, participated students were considered to have misconceptions when they choose an answer as specific incorrect responses option for multiple choice item differing from scientifically accepted concepts as reported in literature review (Mboniyiryivuze et al., 2019). To determine students' conceptual problems before and/or after instruction, this instrument would be useful. Teachers may use CUTEM to assess their instructional approaches, as well as their students' conceptual understanding challenges. The same instrument may be used to evaluate physics curriculum especially in electricity and magnetism. It may also be used to assess the efficacy of other supplemental materials in helping students overcome their conceptual understanding difficulties. This paper aims at reporting about the obtained findings while investigating 9YBE students' conceptual understanding of electricity and magnetism in Rwanda by using CUTEM and proposes some recommendations to improve students' performance in physics from early stage.

Literature Review

Students construct their own mental representations of understanding inferred from their formal schooling as well as their experiences and impressions of the world irrespective of the teaching style of the teacher (Moynihan, 2018; Neidorf et al., 2020). These students' representations of the world may sometimes be scientifically inaccurate. Students have relied on these representations which may contain misconceptions to explain the world before entering classrooms (Halloun & Hestenes, 1985). Misconceptions contradict scientific explanations given during formal training, and if not addressed early, they can be difficult to change (Mboniyiryivuze et al., 2019; Neidorf et al., 2020). To overcome students' misconceptions and reach to a successful conceptual change (diSessa, 2006), a conflict between the student's mental representation and the scientific representation must take place to multiple times before the change (Çakır, 2008; Moynihan, 2018; Posner et al., 1982). Over the past four decades, studies of students' misconceptions have become a dominant issue in physics education due to their effect on students' learning (Afra et al., 2009; Christensen et al., 2011; Clement, 1982; Goldberg & McDermott, 1987; Halloun & Hestenes, 1985; Lemmer et al., 2020; Mboniyiryivuze et al., 2019; Turgut et al., 2011). Different misconceptions reported in literature are common among students from different countries, different backgrounds, and different educational levels and systems (Afra et al., 2009; Bilal & Erol, 2009; Duit & von Rhöneck, 1997; McDermott & Shaffer, 1992). Both pre-service and in-service physics teachers were reported to hold misconceptions (Afra et al., 2009; Gunstone et al., 2009; Mboniyiryivuze et al., 2019). Therefore, physics teachers are recommended to identify students' misconceptions before the introduction of new concepts, helping them to prepare and design instructional materials and using methods helping students to overcome their misconceptions (Mboniyiryivuze et al., 2019).

Electricity and magnetism (EM) constitute a significant part of physics concepts and it is considered as very elemental part in the study of physics. While studying EM, the student is rapidly immersed in a universe where nearly all quantities are unobservable. which makes the subject matter difficult. Some concepts of EM are either microscopic such as electrons

or abstracts such as field, flux, and potential (Chabay & Sherwood, 2006). Moreover, the research has reported that teaching electricity at any instructional level is challenging due to the abstract nature of this knowledge. Students examine and attempt to explain macroscopic phenomena that occur from tiny processes that are not directly visible or perceptible (Mulhall et al., 2001). The instruction of electricity is highly challenged due to the absence of direct perception allowing students to construct mental models of complex phenomena that are involved in macroscopic observations (Azaiza et al., 2012). It was claimed that one could imagine that one bulb presents less resistance than two bulbs connected in series, but one cannot observe, using senses, electrical current or the processes causing resistance as it can be experienced for the case of the movement of balls and their collisions (Azaiza et al., 2012).

In Rwanda, lower secondary school students study physics course which consists of several electricity and magnetism chapters from Senior one to Senior three. Despite its importance, EM is one of the areas of physics where earlier study has discovered persistent misconceptions and gaps in understanding (Arnold & Millar, 1987; Çepni & Keleş, 2006; Engelhardt, 1997; Maloney et al., 2001; Mboniyirivuze et al., 2019; McColgan et al., 2017; Ndiokubwayo et al., 2020). Even though students understand the theory of electricity and magnetism, they are unable to apply Coulomb's law (Maloney et al., 2001). It was found that the most serious conceptual difficulties of students are conservation of current (in steady state) and the concept of potential (Arnold & Millar, 1987; Dega et al., 2013). The study conducted on North American university students to explore their conceptual difficulties regarding simple direct current circuits revealed that many students enter college engineering departments without a clear knowledge of circuit models (Akarsu, 2010; Fredette & Lochhead, 1980). Investigations into students' understanding of direct current (DC) resistive electric circuits showed that students develop a set of models to explain current. Research indicates two prominent misconceptions about DC resistive electric circuits: (a) current is consumed within the circuit and (b) the battery is a constant current source (Çepni & Keleş, 2006; Engelhardt, 1997;). In fact, students reason sequentially or locally in making predictions about circuits rather than considering the whole circuit. These findings apply not only to American students but to those in other countries as well (Engelhardt, 1997). These misconceptions are very resistant to change with some even held by graduate students who have had years of additional instruction (Engelhardt, 1997). It was reported that it is generally accepted by science teachers that electric current is a difficult topic to teach effectively in the early years of secondary school (Arnold & Millar, 1987). In fact, the outcomes of programme of instruction, however well-structured and sequenced, are often disappointing in terms of both short- and long-term gains in conceptual understanding (Arnold & Millar, 1987). Arnold and Millar (1987) reported that the main reason for electric current topic to be difficult to teach effectively in the early years of secondary school appear to arise from the fact that the major concepts which map out the domain (current, voltage, resistance) correspond to properties which cannot be directly observed by senses.

Some common misconceptions related to magnetism have been reported including the confusion of magnetic poles with electric charges or that some parts of a magnet are positively charged while others are negatively charged (Lemmer et al., 2020; Sederberg & Bryan, 2009). There is also another misconception that the magnetization process comprises transfer of charges (Sederberg & Bryan, 2009). The similarity between magnetic and electric phenomena was also reported while comparing magnet with the earth. Some students believe that magnet and earth are similar not because the earth may also orientate compasses but because they both attract things (Bradamante & Viennot, 2007). The misconception that magnet attract only metals was also reported (Lemmer et al., 2020; Sederberg & Bryan, 2009).

While coming in classroom, students bring different misconceptions related to electricity and magnetism (Dega et al., 2013; Mboniyirivuze et al., 2019; Raduta, n.d.). Therefore, physics teachers are recommended to identify those misconceptions before the introduction of new concepts helping them to prepare and design instructional materials and using methods helping students to overcome their misconceptions (Mboniyirivuze et al., 2019). The use of a multiple-choice test is one method of diagnosing misconceptions, and most students are acquainted with the format. It's easy to rate and gives an insight into how students learn and what they appreciate. Unfortunately, it is not capable of probing as thoroughly as interviews. Combining the two techniques to take advantage of their strengths while minimizing their shortcomings might be a better option (Beichner, 1994; Engelhardt, 1997). One can gain the depth of information desired from the interviews and utilize the speed and objectivity of the multiple-choice exam (Engelhardt, 1997). However, this requires trained teachers to arrange interviews and it is time consuming. Beichner (1994) said that the ability to statistically analyze data from large number of participants for objectively graded multiple-choice exams may allow greater generalizability of the findings.

Methodology

To conduct this research, a descriptive survey research design was chosen. A descriptive research design is a basic research design that examines the situation, as it exists in its current state (Williams, 2007). The design method was adopted for this study as its purpose was to describe and analyse the existing conditions of students' understanding of EM physics concepts in Nine Year Basic Education (9YBE) in Rwanda. We developed and administered a multiple-choice questionnaire to reveal students' misconceptions related to charged bodies, lightning, electric fields, electric potential, forces, DC resistive electric circuits and magnets to obtain quantitative information about misconceptions from senior two students from 9YBE Schools. The used designed questionnaire was called Conceptual Understanding Test for Electricity and Magnetism (CUTEM).

The development of CUTEM was based mainly on a critical review of existing studies on common alternative conceptions of students in electricity and magnetism, but also on authors' understanding of Rwandan students' learning difficulties and incorrect answers based on teaching and administering some questionnaires in their classes.

This instrument aligned with senior two secondary school physics syllabus and physics students' book was designed by the researchers. As multiple-choice tests are tests which can be easily graded and analyzed quantitatively, they were useful to collect data from many students in some 9YBE classes. Although the students' understanding may not be investigated fully by a multiple-choice test answer alone, asking students to explain their responses after each question or/and with in-depth interviews of a subset of students, multiple choice test can be very helpful in identifying students' difficulties and misconceptions (Beichner, 1994; Engelhardt, 1997). This paper focuses on quantitative data collected in using one-tier test to identify the students' misconceptions in electricity and magnetism as reported in literature review. The used test was mainly preferred for this study due to its quality of being easily and quickly graded. Moreover, this test is good for students who know their subject matter but are poor writers (in our case participants are from S2) and it permits coverage of a wide range of topics in a relatively short time (Kaltakci Gurel et al., 2015).

The reliability analysis from data obtained from a pilot study and validation was carried out before administering the questionnaire. The randomly chosen S2 class of a 9YBE school was involved in the pilot study and it was not among the schools participated in the study. Participants in pilot study were 28 students in which 22 students were males while 6 students were females. The piloted instrument had twenty-one items with four choices each. The instrument reliability test was carried out by using Cronbach's alpha method by using data obtained from the responses of twenty-eight students. From the reliability analysis, the reliability coefficient reached at Cronbach alpha of 0.658. The used questionnaire contained demographic data including school location, sex, and age. For content validity, experts in physics education helped to examine the questionnaire. The content validity was done in the following two main steps including development stage and judgement stage. The development stage started with identifying content domain which were electrostatics, electric current and magnetism. These domains were identified under the guidance of senior 2 physics curriculum, physic students' book as well as experts' views. Then different items were constructed from those three identified contents domain and validated by experts. Table 1 reports findings about item analysis for content validity.

Table 1. Result of Item Analysis

Item	Total correct answers	Correct answers Upper (n = 7)	Correct answers Lower (n = 7)	Difficulty level	Discrimination index
1.	3	1	0	0.11	0.14
2.	14	5	3	0.50	0.29
3.	6	2	1	0.21	0.14
4.	10	5	1	0.36	0.57
5.	12	4	1	0.43	0.43
6.	11	3	3	0.39	0.00
7.	4	2	1	0.14	0.14
8.	7	3	0	0.25	0.43
9.	12	5	0	0.43	0.71
10.	20	6	3	0.71	0.43
11.	6	2	1	0.21	0.14
12.	9	3	1	0.32	0.29
13.	8	4	2	0.29	0.29
14.	13	3	3	0.46	0.00
15.	14	6	0	0.50	0.86
16.	15	5	5	0.54	0.00
17.	7	4	2	0.25	0.29
18.	15	6	2	0.54	0.57
19.	7	0	2	0.25	-0.29
20.	5	1	0	0.18	0.14
21.	7	3	2	0.25	0.14

Item analysis results in terms of difficult level and item discriminating indexes are shown in Table 1. Items 6, 14, 16, and 19 were found to be poor items with discriminating indexes below 0.1 while 1, 3, 7, 11, 20 and 21 items were found marginal items with discriminating index varying from 0.10 to 0.19. Items 2, 12, 13, 17 and 19 were moderately discriminating items with discriminating indexes from 0.20 to 0.29 while items 4, 5, 8, 9, 10, 15 and 18 were found to be

very good items with discrimination index above 0.4. Related to items difficult level, all items were moderate with difficulty indexes varying between 0.25-0.75 with only 5 items 1, 3, 7, 11, and 20 considered as difficult. Despite the diversity of discrimination indexes and difficult levels, authors have decided to keep these items as all of them have passed through a tough selection by experts at development and judgement stages under guidance of both senior two physics curriculum and physics student books. While selection of items, the inclusion of main concepts was considered as per domains

Sample and Data Collection

The population of the study was 801 students composed of all senior two students from eighty schools from two districts from Eastern Province (Kayonza District) and Kigali city (Gasabo District). The sample for the study was three hundred ninety-five (395) students drawn from these eight 9YBE schools. However, the non-considered fifteen (15) participants were unclassified as they did not show their gender. The selected students have some experience with the new Rwandan secondary physics Competence Based Curriculum (CBC) that is currently under implementation. The considered three hundred eighty (380) students have successfully responded to the test and indicated their gender. A slim majority of the participants were from urban representing 53.2% ($n = 202$) while 46.8% ($n = 178$) participants were from rural area. The distribution of respondents according to gender and districts is shown in Table 2.

Table 2. The Overall Sample of the Study

Location	Female, n (%)	Male, n (%)	Total
Urban	116 (30.5%)	86 (22.6%)	202 (53.2%)
Rural	92 (24.2%)	86 (22.6%)	178 (46.8%)
Total	208 (54.7%)	172 (45.3%)	380 (100%)

It is clear from Table 2 that the sample was female dominated in both rural and urban schools. Moreover, the overall demographic distribution of gender in all eight schools shows that 54.7% ($n = 208$) of all participants were females while 45.3% ($n = 172$) were males (female to male ratio = 1.21). For this study, senior two classes are chosen purposively. These students have some background on introduction of electricity and magnetism from senior one (Rwanda Education Board, 2015). The districts' choice was done to compare students' conceptual understanding in EM in both rural and urban 9YBE schools and in terms of their gender.

Data analysis

The entry of data collected from the 380 respondents using the questionnaire was done with Microsoft Excel. Then, data were cleaned and exported into Statistics Package for Social Studies (SPSS) for analysis. Data were summarized into frequencies using descriptive statistics. Pearson's chi-square was calculated to compare variables and the p-value considered to be statistically significant was $p \leq 0.05$. A chi-square test analysis of the variables was done to determine students' misconceptions associated with their gender and location. Since statistical significance identified from Chi-square alone does not communicate the magnitude of group contribution to the difference, the Cramer's effect size V was calculated.

Results

This section provides results from descriptive analysis and chi-square test on findings of students' conceptual understanding of electricity and magnetism. It starts with descriptive analysis of the overall students' conceptual understanding of electricity and magnetism followed by descriptive analysis and chi-square test including effect size analysis on findings in terms of gender and location. Moreover, this section is ended by results of students' conceptual understanding of electricity and magnetism in terms of gender within urban and rural schools respectively.

The overall participants' responses distribution for students' conceptual understanding of electricity and magnetism

The first seven questions of the test were used to investigate students' understanding of electrostatics. Questions 1 and 2 investigated students' understanding of the relationship between the electric potential in a certain region and the electric field in this region and the information provided by the electric field lines map. For question one, 160 students among 376 respondents (42.5%) believed that the electric field increases in the region with constant electric potential which is a misconception as the gradient of a constant electric potential is zero leading to the zero electric field. Those having the misconception that the electric field is constant but non-zero in this region were 98 (26.1%). Only 54 (14.4%) students were able to answer this item correctly. The item 2 was to investigate students' understanding about the map of electric field lines. 130 (34.7%) students had a clear understanding that the map of electric field lines shows both the direction and the strength of electric field at a point. However, a considerable number 96 (25.6%) think that the map of electric field lines shows the position. It appears that these students did not understand well the relation between concepts of electric field vector and electric field lines, and hence the relation between concepts of field lines density and the magnitude of electric field. Considerable number of participated students showed a misconception on the best way

to protect from lightning in question 3. Almost a half of all participants i.e. 188 (49.7%) said that getting medicine from a witch doctor is the best way to protect themselves from lightning. Only 90 (23.8%) participants have chosen the correct answer. The overall participants' responses to all items investigating their understanding on electricity and magnetism are shown in Table 3 below:

Table 3. The Frequency Distribution of Overall Respondents. The Misconceptions Related to each Question have been Bolded and Underlined

Item	a	b	c	d	Blank	Number of Correct Answers	Misconceptions
1	54	98	160	64	4	54	98, 160
2	116	33	96	130	5	130	96
3	38	188	62	90	2	90	188
4	108	115	107	48	2	107	108, 115
5	132	118	49	79	2	132	118, 49
6	58	129	82	107	4	129	107
7	88	81	118	91	2	118	88
8	98	111	101	69	1	111	98, 101
9	55	71	158	93	3	158	55, 71
10	47	218	64	48	3	218	64, 48
11	142	95	77	62	4	77	142
12	94	95	105	80	6	105	94, 95
13	96	120	97	67	0	96	120, 97
14	114	108	94	62	2	94	114, 108
15	129	202	33	15	1	202	129
16	65	103	121	87	4	121	103
17	90	121	136	29	4	121	136
18	51	94	133	96	6	133	96
19	117	112	84	64	3	84	117, 112, 64
20	70	99	124	81	6	70	99
21	158	73	69	76	4	69	158, 73

Table 3 illustrates the overall students' understanding on electricity and magnetism. Questions 4 and 7, straight forward applications of Coulomb's law of electrostatics, may appear the easiest items for electrostatics section. The investigated misconception by these two questions was that a large, charged object exerted a bigger force of attraction or repulsion on the small one if these two charges are separated by a small distance. However, for both questions, related to the electrical force, we find few correct responses (about 31% or less). Question 4 investigated confusions on both the effect of the magnitude of the charges and the size of bodies on exerted force. From this question, it was found that 108 (28.6%) and 115 (30.4%) participants held misconceptions related to the effect of the magnitude of the charges and the size of bodies, respectively. The same misconception related to effect of magnitude of charges was investigated in question 7 and, 88 (23.2%) of all participants were found to have this misconception. Question 5 investigated students' misconception about neutral body. Option b) of this question clearly indicates misconception that neutral body contains only neutral particles and that it does not contain charges. The 118 (31.2%) of all participated students believed that neutral body contains only neutral particles while 49 (13%) believe that neutral bodies not containing charges. Question 6 investigating misconception of considering charged body as one which contains only one type of charges. It clearly shows a misconception of considering a positively charged body as the ones having positive charges only as and it has been chosen by 107 (28.5%) of all participants.

Students' understanding of electric current was investigated by 8 to 14 items of the test. In fact, options a) and c) in question 8 are clear indication of misconceptions that electrons which flow in conducting wires are generated by batteries and bulbs, respectively, as chosen by 98 (25.8%) and 101 (26.6%) participants. Options (a) and (b) in question 9 are clear indications of attenuation misconception but from different perspective where students think that the current and charge instead of energy will be converted to light. These attenuation misconceptions have been chosen by 55 (14.5%), and 71 (18.8%) participants making the total of 126 (33.4%). The attenuation or the current consumed misconception was also investigated through question 10. By this misconception, students think about the consumption of the current by the electrical devices in the circuits. In this case, students think that the current flowing towards the light bulb in the circuit is greater than the current flowing away from it back to the battery. 112 (29.7%) of participated students have shown the attenuation misconception by either choosing c) or d) as indicated by their respective choices [64 (16.9%) participants for c) and 48 (12.7% participants for d)]. Students that have chosen d) thought that no current returned to the battery as it was used up by element of the electrical circuit. For our study, a considerable number of participants have misconception that when the resistance increases, the current also increase as it is indicated by their choice on question 11 at a rate of 142 (37.8%). The same misconception was also revealed from question 12 where 94 (25.1%) participants have chosen that the current through bulb having higher resistance is greater than the current through bulb having lower resistance when connected in series. These students may also have attenuation misconceptions leading them to think that current goes through bulb A first and then bulb B. The 95 (25.4%) students

believed that current through bulb A (having higher resistance) is less than the current through bulb B and this may be due to their attenuation misconception. The misconception of confusing the electric current and the voltage was investigated through both questions 13 and 14. The 120 (31.6%) thought that the potential difference across bulb A (having higher resistance) is less than the potential difference across bulb B. 97 (25.5%) students believed that the potential difference is the same for a series circuit. This shows respondents' confusion for the electric current and the voltage. The same confusion was investigated in question 14 where 114 (30.1%) students believing that potential difference across bulb A is greater than the potential difference across bulb B might have incorrectly used Ohm's law. 108 (28.6%) students believing that the potential difference across bulb A is less than the potential difference across bulb B might identified the circuit as a parallel circuit and thought that the potential splits for parallel circuits as for the current.

Students' understanding of magnetism was investigated by 15 to 21 items of the test. Item 15 investigated students' understanding of the production of magnetic field. 129 (34%) participants had a misconception that only magnet produce magnetic field. Responses to question 16 revealed that 103 (27.4%) participated students had the misconception on separation of north and south poles of magnetism. Question 17 investigated students' understanding on the materials attracted by magnet. 136 (36.2%) participants held the misconception that all metals are attracted by magnet. The misconception about separation of poles of a bar magnet (when broken) and their polarity was investigated by question 18.96 (25.6%) of participants had the misconception that there is no force between the broken pieces of a bar magnet when divided in two pieces since they are demagnetized. Those who have chosen the option that there is a repulsive force between the broken pieces may not have clear understanding of polarity of broken magnet. However, this may be supported by students' explanations that were not provided here as highlighted in limitations sections of this paper. Question 19 investigates the misconceptions that the strength of a magnet is defined either by the mass of the magnet lifting the metal paper clips, by the size of the magnet lifting the metal paper clips or by the time the magnet lifts the clips. These misconceptions were found in participated students at the rate of 117 (31%), 112 (29.7%) and 64 (21.8%) respectively. In this study, a considerable number of 99 (33.1%) participants thought that the compass needle needs an energy source (question 20). For question 21, 158 (42%) had misunderstanding of the direction of the magnetic field inside the magnet as they believe that the field lines inside the magnet point from north to south. 73 (19.4%) respondents believe that the magnetic field lines exist only outside the magnet.

Participants' responses distribution in terms of gender for their conceptual understanding of electricity and magnetism

This section illustrates findings from descriptive and chi-square test analysis on students' conceptual understanding in electricity and magnetism in terms of gender. The gender distribution of responses to all items investigating their understanding on electricity and magnetism and their corresponding Chi-square test and effect sizes analysis are shown in Table 4 below:

Table 4. The Frequency Distribution of Overall Respondents in Terms of Gender and Chi-Square-test Results. The Misconceptions Related to each Question have been Bolded and Underlined

Item	Gender								Chi-square test		
	Female				Male				χ^2	p	Effect size V
	a	b	c	d	a	b	c	D			
1	30	58	89	29	24	40	71	35	3.142 ^a	0.370	0.091
2	70	23	39	72	46	10	57	58	12.160 ^a	0.007	0.180
3	20	112	38	36	18	76	24	54	10.789 ^a	0.013	0.169
4	59	61	63	24	49	54	44	24	1.309 ^a	0.727	0.059
5	74	70	21	42	58	48	28	37	3.965 ^a	0.265	0.102
6	32	70	46	59	26	59	36	48	.069 ^a	0.995	0.014
7	51	51	58	47	37	30	60	44	4.416 ^a	0.220	0.108
8	42	61	56	48	56	50	45	21	11.721 ^a	0.008	0.176
9	26	46	90	44	29	25	68	49	6.514 ^a	0.089	0.131
10	25	130	33	19	22	88	31	29	6.864 ^a	0.076	0.135
11	76	55	37	38	66	40	40	24	2.931 ^a	0.402	0.088
12	53	53	52	47	41	42	53	33	1.817 ^a	0.611	0.070
13	51	65	61	31	45	55	36	36	4.656 ^a	0.199	0.111
14	68	61	45	34	46	47	49	28	3.022 ^a	0.388	0.089
15	61	117	22	8	68	85	11	7	5.624 ^a	0.131	0.122
16	32	65	60	50	33	38	61	37	5.257 ^a	0.154	0.118
17	55	68	65	20	35	53	71	9	6.560 ^a	0.087	0.132
18	28	46	76	55	23	48	57	41	1.841 ^a	0.606	0.070
19	61	59	51	35	56	53	33	29	1.720 ^a	0.632	0.068
20	43	48	77	36	27	51	47	45	8.990 ^a	0.029	0.155
21	80	42	38	45	78	31	31	31	1.913 ^a	0.591	0.071

A chi-square test of independence was calculated and revealed that a significant association of all respondents in terms of gender was found only on 4 items of the test. The significant association was found on items 2, 3, 8 and 20 with corresponding p-values of 0.007, 0.013, 0.008 and 0.029 respectively. A considerable number of students that is male dominated at 59.4% thought that the map of electric field lines shows the position. The found students holding a misconception that the best way of protecting themselves from lightning in using medicine from a witch doctor, 59.6% were female. While respondents believing that electrons generated by the batteries were male dominated at 57.1%, those believing that electrons are generated by bulbs were females dominated at 55.4%. Our study also found that students had a misconception on the reason of a compass needle motion when it is near a wire with an electric current. In fact, male dominated participants at 51.1% held a misconception that the electric current flows into the compass needle. Due to the practical significance and importance in interpretation of results, the effect size was computed for statistical testing analysis. Therefore, our findings were supported by those found in calculating effect size.

From effect size analysis, all the four items found to be significantly statistically different were also found different. In fact, Cramer's V value of 0.06 or Less=Negligible relationship; 0.17 or less = Weak relationship; from 0.17 to 0.29 = moderate, and above 0.29 = strong relationship (Kim, 2017). Therefore, the identified highest association between male and female responses was moderate association and it was found for only item 2 ($V=0.180$) investigating misconception held by students that the map of electric field lines shows the position and item 8 ($V=0.176$) testing students' misconception that electrons flowing in conducting wires are generated by batteries and bulbs. Two items (items 4 and 6) were found to be with negligible association, in terms of gender, while remaining 17 items were identified with weak association.

Some other studies have also shown differences in performance of males and females in concept inventories in electricity and magnetism, in favour of males (Demirci & Çirkinoğlu, 2004; Henderson et al., 2019; Madsen et al., 2013, and references therein). Some studies showed that interactive engagement methods can reduce the can reduce the gender gap relate to performance in physics concept inventories (Lorenzo et al., 2006), while some other studies have shown that gender gap could not be reduced or instead increased, by using some interactive engagement methods (Chasteen & Pollock, 2009; Pollock et al., 2007). Therefore, the reasons for the gender gap in performance of students in concept inventories and their remedies are not well understood and need further research.

Participants' responses distribution in terms of location

This section illustrates findings from descriptive and chi-square test analysis on students' conceptual understanding in electricity and magnetism in terms of location. The location distribution of responses to all items investigating their understanding on electricity and magnetism and their corresponding Chi-square test and effect sizes analysis are shown in Table 5 below:

Table 5. The Frequency Distribution of Overall Respondents in Terms of School Location and Chi-Square-test Results. The Misconceptions Related to each Question have been Bolded and Underlined

Item	Location								Chi-square test		
	Urban				Rural				χ^2	p	Effect size V
a	b	c	d	a	b	c	D				
1	23	<u>53</u>	<u>91</u>	32	31	<u>45</u>	<u>69</u>	32	3.588 ^a	0.309	0.098
2	50	20	<u>42</u>	86	66	13	<u>54</u>	44	17.640 ^a	0.001	0.217
3	18	<u>83</u>	42	58	20	<u>105</u>	20	32	16.540 ^a	0.001	0.209
4	<u>47</u>	<u>69</u>	58	27	<u>61</u>	<u>46</u>	49	21	6.424 ^a	0.093	0.130
5	69	<u>61</u>	21	50	63	<u>57</u>	28	29	5.489 ^a	0.139	0.121
6	32	78	40	<u>50</u>	26	51	42	<u>57</u>	5.268 ^a	0.153	0.118
7	<u>39</u>	46	66	49	<u>49</u>	35	52	42	3.561 ^a	0.313	0.097
8	<u>51</u>	54	<u>58</u>	38	<u>47</u>	57	<u>43</u>	31	1.793 ^a	0.616	0.069
9	<u>29</u>	<u>40</u>	76	55	<u>26</u>	<u>31</u>	82	38	3.249 ^a	0.355	0.093
10	22	117	<u>41</u>	<u>22</u>	25	101	<u>23</u>	<u>26</u>	4.853 ^a	0.183	0.113
11	<u>75</u>	59	39	28	<u>67</u>	36	38	34	4.838 ^a	0.184	0.113
12	<u>50</u>	46	62	42	<u>44</u>	49	43	38	2.320 ^a	0.509	0.079
13	50	61	<u>55</u>	36	46	59	<u>42</u>	31	.803 ^a	0.849	0.043
14	<u>61</u>	<u>57</u>	50	34	<u>53</u>	<u>51</u>	44	28	.070 ^a	0.995	0.014
15	<u>73</u>	105	19	5	<u>56</u>	97	14	10	3.347 ^a	0.341	0.094
16	25	<u>51</u>	56	67	40	<u>52</u>	65	20	28.341 ^a	0.000	0.275
17	38	63	<u>85</u>	14	52	58	<u>51</u>	15	9.425 ^a	0.024	0.158
18	29	43	79	<u>50</u>	22	51	54	<u>46</u>	4.436 ^a	0.218	0.109
19	<u>55</u>	<u>66</u>	41	39	<u>62</u>	<u>46</u>	43	25	5.467 ^a	0.141	0.120
20	36	<u>57</u>	63	44	34	42	<u>61</u>	37	1.165 ^a	0.761	0.056
21	<u>82</u>	<u>36</u>	43	39	<u>76</u>	<u>37</u>	26	37	2.963 ^a	0.397	0.089

A chi-square test of independence was calculated and revealed that a significant association for all respondents in terms of location were only found on 4 items of the test. The significant association was found on items 2, 3, 16 and 17 with corresponding p-values of 0.001, 0.001, 0.000 and 0.024 respectively. A considerable number of students from rural schools that at 56.25% thought that the map of electric field lines shows the position. For the found students holding a misconception that the best way of protecting themselves from lightning is to use medicine from a witch doctor, 55.9% were also from rural schools. While respondents believing that on separation of magnet poles were dominated by students from rural schools at 50.5%, those believing that all metal are attracted by magnet were dominated by students from urban schools at 62.5%. For all other remaining items of the test, there is no association between location and students' misconceptions (that is p is found to be greater than 0.05 for these items). Our findings were supported by those found in calculating effect size. From effect size analysis, all the four items found to be significantly statistically different while considering their p-values were also found different. Therefore, the identified highest association between students' responses from rural and urban schools was moderately associated for only three items including item 2 ($V=0.217$) investigating a misconception held by students that the map of electric field lines shows the position, item 3 ($V=0.209$) investigating a misconception on getting medicine from a witch doctor as the best way to protect from lightning, and item 16 ($V=0.275$) testing the misconception on separation of north and south poles of a magnet. Three items (13, 14, and 20) were identified with negligible association while all 15 remaining items were identified with weak association.

Responses distribution in terms of gender distribution for urban and rural students

The gender distribution of responses to all items investigating their understanding on electricity and magnetism for urban schools and their corresponding Chi-square test and effect sizes analysis are shown in Table 6 below:

Table 6. The Gender Distribution of Urban Schools Senior 2 Students who Selected Choice a)-d) on Conceptual Test Questions. The Misconceptions for Each Question have been Bolded and Underlined.

Item	Urban				Male				Chi-square test		
	a	<u>b</u>	<u>c</u>	d	a	<u>b</u>	<u>c</u>	D	χ^2	p	Effect size V
1	10	<u>35</u>	<u>53</u>	16	13	<u>18</u>	<u>38</u>	16	4.179 ^c	0.243	0.145
2	33	14	<u>18</u>	47	17	6	<u>24</u>	39	6.621 ^c	0.085	0.183
3	11	<u>48</u>	28	28	7	<u>35</u>	14	30	3.550 ^c	0.314	0.133
4	<u>27</u>	<u>41</u>	31	16	<u>20</u>	<u>28</u>	27	11	0.520 ^c	0.914	0.051
5	39	<u>40</u>	8	28	30	<u>21</u>	13	22	4.921 ^c	0.178	0.156
6	20	46	20	<u>29</u>	12	32	20	<u>21</u>	1.323 ^c	0.724	0.081
7	<u>25</u>	30	36	24	<u>14</u>	16	30	25	3.508 ^c	0.32	0.132
8	<u>23</u>	31	<u>32</u>	29	<u>28</u>	23	<u>26</u>	9	8.822 ^c	0.032	0.210
9	<u>18</u>	26	43	27	<u>11</u>	14	33	28	2.758 ^c	0.431	0.117
10	13	74	<u>21</u>	<u>8</u>	9	43	<u>20</u>	<u>14</u>	6.285 ^c	0.099	0.176
11	<u>39</u>	33	25	18	<u>36</u>	26	<u>14</u>	<u>10</u>	2.201 ^c	0.532	0.105
12	<u>30</u>	25	33	26	<u>20</u>	21	<u>29</u>	16	1.088 ^c	0.78	0.074
13	32	31	<u>34</u>	19	18	30	<u>21</u>	17	2.725 ^c	0.436	0.116
14	<u>40</u>	<u>33</u>	23	20	<u>21</u>	<u>24</u>	<u>27</u>	14	4.359 ^c	0.225	0.147
15	<u>37</u>	62	15	2	<u>36</u>	43	4	3	5.690 ^c	0.128	0.168
16	11	<u>36</u>	27	41	14	<u>15</u>	29	26	7.797 ^c	0.05	0.198
17	27	33	<u>45</u>	11	11	30	<u>40</u>	3	6.799 ^c	0.079	0.184
18	19	23	43	<u>31</u>	10	20	36	<u>19</u>	1.764 ^c	0.623	0.094
19	<u>32</u>	<u>35</u>	27	21	<u>23</u>	<u>31</u>	14	18	1.924 ^c	0.588	0.098
20	22	<u>32</u>	38	22	14	25	<u>25</u>	22	1.428 ^c	0.699	0.084
21	<u>47</u>	<u>22</u>	22	23	<u>114</u>	<u>14</u>	21	16	0.911 ^c	0.823	0.069

A significant association of respondents in terms of gender from urban schools was found only on two items. The significant association was found with the misconception that electrons are generated by the batteries or bulbs and with the misconception on separation of north and south poles of a magnetic bar, with $p=0.032$ and 0.05 respectively. While respondents believing that electrons generated by the batteries were male dominated at 54.9%, those believing that electrons are generated by bulbs were females dominated at 55.2%. Respondents believing that magnetic poles are separated were dominated by female students at 70.6%. From effect size analysis, all the five items found to be significantly statistically different while considering their p-values were also found different.

Therefore, the identified highest association between male and female responses from urban schools was moderately associated for only five items including item 2 ($V=0.183$) investigating a misconception held by students that the map of electric field lines shows the position, item 8 ($V=0.210$) investigating testing students' misconception that electrons

flowing in conducting wires are generated by batteries and bulbs, item 10 ($V=0.176$) investigating misconception that students hold about the consumption of the current by the electrical devices in the circuits, item 16 ($V=0.198$) testing misconception on separation of north and south poles of magnetism, and item 17 ($V=0.184$) investigated students' understanding on the materials attracted by magnet. There was only one item (item 4) with negligible association. The 15 remaining items were identified with weak association.

The gender distribution of responses to all items investigating their understanding on electricity and magnetism for rural schools and their corresponding Chi-square test and effect sizes analysis are shown in Table 7 below:

Table 7. The Gender Distribution of Rural Schools Senior 2 Students who Selected Choice a)-d) on Conceptual Test Questions. The Misconceptions for Each Question have been Bolded and Underlined.

Item	Rural								Chi-square-test		
	Female				Male				χ^2	P	Effect size V
1	20	<u>23</u>	<u>36</u>	13	11	<u>22</u>	<u>33</u>	19	3.619 ^b	0.306	0.143
2	37	9	<u>21</u>	25	29	4	<u>33</u>	19	6.110 ^b	0.106	0.186
3	9	<u>64</u>	10	8	11	<u>41</u>	10	24	13.107 ^b	0.004	0.272
4	<u>32</u>	<u>20</u>	32	8	<u>29</u>	<u>26</u>	17	13	6.446 ^b	0.092	0.191
5	35	<u>30</u>	13	14	28	<u>27</u>	15	15	.837 ^b	0.84	0.069
6	12	24	26	<u>30</u>	14	27	16	<u>27</u>	2.511 ^b	0.473	0.119
7	<u>26</u>	21	22	23	<u>23</u>	14	30	19	2.997 ^b	0.392	0.130
8	<u>19</u>	30	24	19	<u>28</u>	27	19	12	3.845 ^b	0.279	0.147
9	<u>8</u>	20	47	17	<u>18</u>	11	35	21	8.372 ^b	0.039	0.217
10	12	56	<u>12</u>	<u>11</u>	13	45	<u>11</u>	<u>15</u>	1.619 ^b	0.655	0.096
11	<u>37</u>	22	12	20	<u>30</u>	14	26	14	8.459 ^b	0.037	0.220
12	<u>23</u>	28	19	21	<u>21</u>	21	24	17	1.729 ^b	0.63	0.100
13	19	34	<u>27</u>	12	27	25	<u>15</u>	19	7.580 ^b	0.056	0.206
14	<u>28</u>	<u>28</u>	22	14	<u>25</u>	<u>23</u>	22	14	0.297 ^b	0.961	0.041
15	<u>24</u>	55	7	6	<u>32</u>	42	7	4	3.013 ^b	0.39	0.130
16	21	<u>29</u>	33	9	19	<u>23</u>	32	11	0.732 ^b	0.866	0.064
17	28	35	<u>20</u>	9	24	23	<u>31</u>	6	5.411 ^b	0.144	0.175
18	9	23	33	<u>24</u>	13	28	21	<u>22</u>	3.830 ^b	0.28	0.149
19	<u>29</u>	<u>24</u>	24	14	<u>33</u>	<u>22</u>	19	11	1.083 ^b	0.781	0.078
20	21	<u>16</u>	39	14	13	26	<u>22</u>	23	10.996 ^b	0.012	0.251
21	<u>33</u>	<u>20</u>	16	22	<u>43</u>	<u>17</u>	10	15	4.068 ^b	0.254	0.152

From chi-square analysis, a significant association of respondents in terms of gender from rural schools was found only on 4 items of the test. The significant association was found on items 3, 9, 11 and 20 with corresponding p-values of 0.004, 0.039, 0.037 and 0.012, respectively. Female participants dominated at 61% of all students from rural schools holding misconceptions that the best way of protecting themselves from lightning in using medicine from a witch doctor. While respondents believing that the light is produced by converting the electric current were male dominated at 57.1%, those believing that the light is produced by converting the electric charges were female dominated at 64.5%. Our study also found that students had a misconception on the effect of increasing the resistance in the circuit on the electric current. More female at 55.2% believed that while increasing the resistance in a circuit, the electric current will also increase. Related to students having misconception on the reason of a compass needle motion when it is near a wire with an electric current, female dominated participants at 64% held a misconception that the electric current flows into the compass needle. Our findings were supported by those found in calculating effect size. From effect size analysis, all the four items found to be significantly statistically different while considering their p-values were also found different. The eight items had medium effect sizes $V=0.186$, $V=0.272$, $V=0.191$, $V=0.217$, $V=0.220$, $V=0.206$, $V=0.175$, and $V=0.256$ respectively. All remaining items had small effect size of varying between 0.06-0.17 except item 14 having a negligible effect size of $V=0.041$. Therefore, the identified highest association between male and female responses from urban schools was moderately associated for only eight items including item 2, 3, 4, 9, 11, 13, 17 and 20. There was only one item (item 14) with negligible association. The 12 remaining items were identified with weak association. In fact, the effect size analysis revealed additional differences for male and female while analyzing them in terms of school location separately.

Discussion

We found that senior two students have several common misconceptions related to electricity and magnetism. Regarding the best way to protect from lightning in question, almost a half of all participants i.e. 188 (49.7%) said that getting medicine from a witch doctor is the best way to protect from lightning. This finding was surprising as only 90 (23.8%)

participants have chosen the correct answer. A misconception that electrons are generated by the batteries and bulbs was found to be held by 98 (25.8%) and 101 (26.6%) participants, respectively. 129 (34%) participants believe that magnetic field is produced only by magnets while 103 (27.4%) participants have a misconception that magnet poles can be separated- north and south poles of magnet can be separated. Moreover, 136 (36.2 %) participants indicated the misconception that all metals are attracted by magnet. The finding related to lightning is consistent with that found by Ndiokubwayo and Nkundabakura (2019) while investigating lightning myths versus science facts among Rwandans across different range of ages and categories. Our study results revealed that a considerable number of participated students do not apply Newton's third law or the symmetry of Coulomb's law to situations involving electric point charges. Students continue to assume that a charge of greater magnitude exerts greater impact than a charge of lesser magnitude, as reported by Bilal and Erol (2009). A considerable number of participants seem to believe larger "objects" exert larger force than smaller "objects" as indicated by their choice that sphere (having small charge) exerts more force on the point charge (having big charge). This shows students' misconception on Newton's law too as reported in literature. The participated students held misconception related to the application of Coulomb's law and this was also reported in other studies (Bilal & Erol, 2009; Maloney et al., 2001). This study revealed the misconceptions of considering the current to be consumed in the resistor/bulb and that the battery is a constant source of the current among participants and it was consistent with literature (Bilal & Erol, 2009; Engelhardt, 1997). Students aged 8 to 14 years old in many nations, including the United States, New Zealand, Southeast Asia, and the United Kingdom, have the same perception (Arnold & Millar, 1987). The study findings are consistent with the result found by Engelhardt (1997) on students' confusion about the underlying mechanisms of electric circuit phenomena. The author reported that students had difficulty handling simultaneous changes of variables (Engelhardt, 1997) and that was confirmed in our study where a considerable number of participants confuse electric potential with current. For more understanding, the study suggests that distinguishing between the concepts of electric 'current' and 'power' is critical (Dega et al., 2013). Arnold and Millar (1987) recommended that teaching should strive for mastery of this concept before moving on. Extra time spent making sure the distinction between electrical current and energy could pay off in more efficient and effective learning of subsequent material (Arnold & Millar, 1987). However, in order to differentiate participants' misconceptions, further explanations are needed to clarify their choice.

Related to magnetism, our study findings are in accordance with those reported by Chabay and Sherwood (2006) that students think that inside the magnetic bar there are no magnetic field lines. It was found that the field lines representation would provide novices with misleading knowledge about dynamic range. In fact, when students draw field lines around a bar magnet in a pattern of close curves extending from one end to the other, they assume that there is no field on the axis of the magnet, where the field is the strongest (Chabay & Sherwood, 2006). Since the idea of magnetic field is very complicated and nuanced, it is very important for pre-service physics teachers to understand it (Samsudin et al., 2017) to be equipped with necessary knowledge to assist their students effectively.

The findings from chi-square and effect size analysis indicated that there is a small but significant difference in students' conceptual understanding of electricity and magnetism of male and female participants and school location. In fact, males and females have significantly different understandings of electricity and magnetism in some items as indicated in reported results. The revealed statistical significance differences in terms of either gender or location of schools were only for items 2, 3, 8 and 20; and 2, 3, 16 and 17 respectively. Despite few cases where differences in conceptual understanding in terms of gender and school location were observed, on average we see not see statistically significant differences for overall participated students. The found differences in terms in students conceptual understanding may be attributed to several factors, prior physics preparation, amount of exposure to subject, examples used by the teachers/textbooks, methods used by the physics teachers which may be more favorable to male and urban students, etc.

Conclusion

Based on our analysis of data from 380 physics students, we found that several students have misconceptions of basic concepts of electricity and magnetism. In particular, the results indicate that although students have some background on the subject matter, they still seem to believe that a large, charged object exerts a bigger force of attraction or repulsion on the small one if these two charges are separated by a small distance. A considerable number of participated students held the misconception of considering current consumption in the resistor/bulb or the electrical devices in the circuits. They also believed that the battery was a continuous current source. The findings also revealed that students held a misconception that a bar magnet when broken into pieces, is demagnetized. Some student also believe that poles of magnet can be separated and that all metals are attracted by a magnet. A particular finding was that among all participants, those holding a misconception that the best way of protecting themselves from lightning is using medicine from a witch doctor were female dominated. The same female domination for this misconception was found in both rural and urban schools separately. Briefly, our study revealed some of the statistically significant differences in terms of either gender or location of schools for some items by conducting chi-square test supported by effect size analysis. We believe that this study can raise awareness among physics teachers and educators about misconceptions in electricity and magnetism, which in turn can help in curriculum development, use of appropriate instructional strategies and assessments.

Recommendations

Based on the investigated misconceptions related to electricity and magnetism concepts among participated students, authors recommend that physics teachers should pay sufficient attention on students' prior knowledge by referring to the recent results on students' knowledge of electricity and magnetism. This will considerably contribute to the enhancement of the teaching and learning of this subject matter. Considering the identified misconceptions, we advocate for student-centered instructional methods that encourage students to build their own knowledge and improve their conceptual understanding and mastery. The physics teachers must teach explicitly the physics concepts and principles, by emphasizing the qualitative reasoning and providing sufficient opportunities to students in constructing physics concepts as well as electricity and magnetism concepts. Moreover, students should be given sufficient exposure to overcome their prior misunderstanding of physics concepts by using constructivist methods that enable them to interact with new concepts.

Curricula developers should consider students' misconceptions and prior knowledge while designing the physics curricula. Physics teachers are recommended to use of constructivism pedagogy like peer instruction, inquiry-based learning, problem-based learning, and cooperative learning that were claimed to enhance students' conceptual understanding and improving their interaction with new concepts. Some interactive engagement methods that promote students' interaction and cooperation, such as peer instruction can be of use to reduce the gender gap in physics performance.

Researchers also recommend the use of a variety of methods to effectively engage students in improving their intellectual comprehension, including regularly involving students and giving daily inputs, concentrating on empirical phenomena, explicitly exploring misconceptions, using a variety of problem-solving skills and tactics, and providing homework assignments that include qualitative and quantitative analysis of phenomena. This sort of constructivist atmosphere encourages students to use active learning to facilitate their construction of knowledge and comprehension. We recommend some useful instructional materials, which are based on physics education research, for example, *Minds-On Physics: Complex Systems, Activities and Reader* (Leonard et al., 2000), *Teaching Physics with Physics Suite* (Redish & Burciaga, 2004), *A Guide to Introductory Physics Teaching* (Arons, 1990), *Peer Instruction: A User's Manual* (Mazur, 1997), etc. We also recommend that questions related to physics concepts and principles and their applications in everyday life and problem-solving must be part of formative and summative assessments instead of rote memorization questions.

Causes for gender gap in performance in physics concept inventories and its remedies are not well understood, and can be further explored by physics education researchers, particularly in African context. There is a need for study to investigate whether different active engagement instructional strategies work to remedy the misconceptions of Rwandan students in electricity and magnetism. Such a study related to peer instruction method is in progress.

Limitations

Since multiple-choice tests are simple to grade and interpret quantitatively, they were useful for gathering data from a wide number of students. Moreover, the reported findings are from collected data using one-tier test in first phase of our wide project investigating the effect of Peer Instruction (PI) on students' conceptual understanding in electricity and magnetism in Rwandan secondary schools. Due to time constraints, explanations for students and in-depth interviews with a subset of students were not given. Thus, more research into this subject is suggested, by using multiple-choice tests and asking students to clarify their choices through in-depth interviews.

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Authorship Contribution Statement

Mbonyiryivuze: concept and design, data acquisition, data analysis/ interpretation, drafting manuscript, critical revision of manuscript, statistical analysis. Yadav: concept and design, data analysis/interpretation, drafting manuscript, editing/reviewing, supervision, final approval. Amadalo: concept and design, drafting manuscript, supervision, final approval.

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Appendix**CONCEPTUAL UNDERSTANDING TEST FOR ELECTRICITY AND MAGNETISM****Section A: Electricity****Item 1**

The electric potential in a certain location remains constant at 12 volts. Which of the following statements accurately defines the magnitude of the electric field in this location?

- The electric field is zero in this region.
- The electric field is constant, but non-zero in this region.
- The electric field is increasing in this region.
- None from the above.

Item 2

Map of electric field lines provides information of electric field's

- Direction at a point.
- Strength at a point.
- Position.
- Direction and strength at a point.

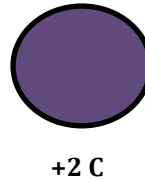
Item 3

The best way to protect from lightning is

- Getting under a tree.
- Getting medicine from witch doctor.
- Getting into a building and stand near a window.
- Getting into a building and avoid standing near a window.

Item 4

A big fixed sphere with a cumulative charge of +2 C is held at a certain distance from a stationary point charge of +5 C. What does the Coulomb force between the point charge and the sphere imply?



- The sphere is subjected to more force by the point charge.
- The point charge is subjected to more force by the sphere.
- The point charge and the sphere exert the same force on each other.
- The sphere and the point charge are exerting zero force on each other.

Item 5

An object is said to be electrically neutral if:

- It contains equal number of protons and electrons.
- It contains only neutral particles.
- It does not contain charges.
- It could not be attracted by a charged object.

Item 6

A positively charged body is one which

- Is rubbed with another material.
- Contains more positive charges than the negative charges.
- Could attract all other objects.
- Contains only positive charges.

Item 7

Two stationary point charges objects +5C and +2C are separated by some distance. What can be said about the electrostatic force between the two charges?

- The +5C exerts more force on the +2C charge.
- The +5C and +2C are exerting zero force on each other.
- Both charges exert an equal amount of force on each other.
- The +2C exerts more force on the +5C charge.

Section B: Direct current**Item 8**

Electricity which flows in conducting wires is from:

- Electrons generated by batteries.
- Electrons from atoms of conducting wires pumped by batteries.
- Electrons generated by bulbs.
- None from the above.

Item 9

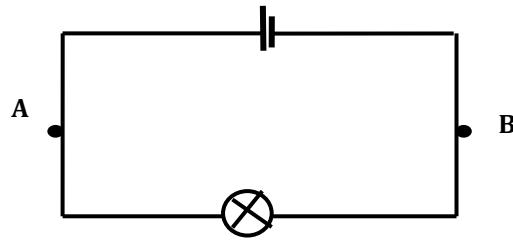
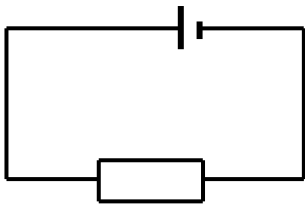
When a bulb is wired to a circuit, why does it light up?

- Light is generated by the conversion of electrical current.
- Light is generated by the conversion of electrical charge
- Light is generated by the conversion of electrical energy.
- All of the above.

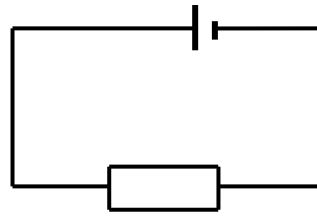
Item 10

How do the currents at point A and B differ?

- Current at B > Current at A.
- Current at A = Current at B.
- Current at A > Current at B.
- Current at B = 0.

**Item 11**

R₁ - Small resistance



R₂ - Large resistance

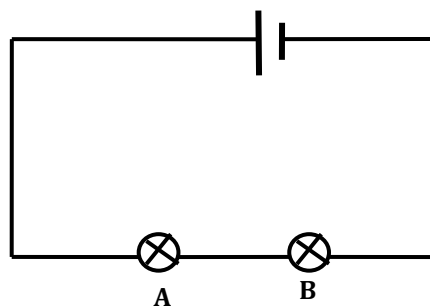
R₁, the first resistor in this circuit, has a low resistance. R₁ is substituted by R₂, a high-resistance component.

What happens to the circuit's current?

- The current increases.
- The current remains constant.
- The current is reduced.
- The current drops to zero.

Item 12

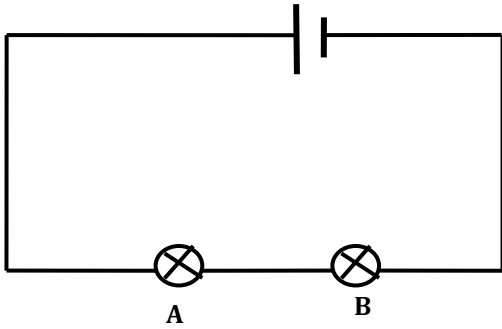
Bulb A's resistance is higher than bulb B's resistance in the circuit below. Compare the current flowing through the lamps.



- Bulb A has a higher current than bulb B.
- Bulb A has a lower current than bulb B.
- The current flowing between bulb A and bulb B is equal.
- There is no way to compare their electric currents.

Item 13

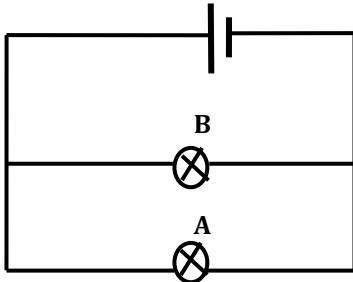
The resistance of bulb A is higher than the resistance of bulb B in the circuit below. Compare the potential difference for the lamps.



- a) The potential difference across bulb A is higher than the potential difference across bulb B.
- b) The potential difference across bulb A is less than the potential difference across bulb B.
- c) The potential difference across bulb A is the same as the potential difference across bulb B.
- d) There is no way to compare their potential difference.

Item 14

In the circuit below, the resistance of bulb A is greater than the resistance of bulb B. Compare the potential difference across the bulbs.



- a) The potential difference across bulb A is greater than the potential difference across bulb B.
- b) The potential difference across bulb A is less than the potential difference across bulb B.
- c) The potential difference across bulb A is the same as the potential difference across bulb B.
- d) It is not possible to compare the potential difference through the bulbs.

Section C: Magnetism**Item 15**

A magnetic field is produced by:

- a) Only magnets.
- b) Both magnets and electric current.
- c) Plastics.
- d) Charcoals.

Item 16

What happens if you split a bar magnet in half between the north and south poles?

- a) Each half is a more powerful magnet than the first.
- b) The magnetic poles are separated from one another.
- c) The production of two new bar magnets.
- d) An electric field is created.

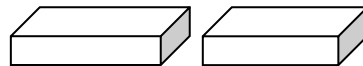
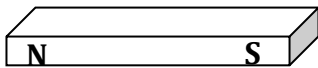
Item 17

A magnet attracts which of the following materials?

- a) Aluminum.
- b) Iron.
- c) All metals.
- d) Glass.

Item 18

A bar magnet is split into two halves. Which of the following statements about the force between the broken pieces is correct if they are facing each other with a slight gap between them?



- a) Between the broken pieces, there is an electric repulsive force.
- b) Between the broken pieces, there is a magnetic repulsive force.
- c) The broken pieces are attracted to each other by a magnetic force.
- d) Since the broken pieces are demagnetized, there is no force between them.

Item 19

A student conducts research about the strength of magnets. He has a variety in magnets of various sizes and weights. He lifts metal paper clips with the magnets. In the inquiry, how is the strength of a magnet defined?

- a) by the mass of the magnet lifting the metal paper clips.
- b) by the size of the magnet lifting the metal paper clips.
- c) by the number of metal paper clips lifted by the magnet.
- d) by the time the metal paper clips stay on the magnet.

Item 20

Why does a compass needle move when it is near a wire with an electric current?

- a) The electric current creates a magnetic field.
- b) The electric current flows into the compass needle.
- c) The compass needle needs an energy source.
- d) All of the above.

Item 21

The field lines outside a permanent magnet point from North pole to South pole. The field lines inside the magnet point:

- a) From North to South.
- b) No field lines inside the magnet.
- c) From South to North.
- d) None of the above