International Journal for Innovation Education and Research

ONLINE ISSN: 2411-2933 PRINT - ISSN: 2411-3123

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Published Date: 2/1/2020 **Page.01-07** **Vol 8 No 02 2020**

DOI: https://doi.org/10.31686/ijier.Vol8.Iss2.2161

Addressing Some Physical Misconceptions in Electrostatics of Freshman Engineering Students

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Abstract

While the electrostatics is important topic consisting one among the four pillars of electromagnetic theory, as being represented by Gauss's law, students persist encountering difficulties in its understanding. Even though the trend looks universal, we triggered an investigation to search for the main reasons behind the students' misconceptions of electric field and flux aiming to analyze their origins and to search for intervention pathways to make corrections and, thus, to enhance the students learning of these physical concepts. The subject of our statistical sample is a group of 211 freshman engineering students taking the course of "Physics and Engineering Applications II". Tests were designed for the diagnosis of the origins of students' struggles in an attempt to find plausible interventional solutions to reduce the effects. Indeed, the statistics of results shows evidence of deviation of students in figuring out the correct answers and characterizes the depths of the misconceptions and shortcomings. Under the light of our discussions, alternative interventions are suggested to reduce the size of difficulties in learning and to pave the way for better understanding of the physical concepts and achieving better results.

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PACS Numbers: 01.30.1a, 01.40.-d, 01.40.Fk

1. Introduction

Within the framework of the electromagnetic theory, set in the four equations of Maxwell, the electrostatics is represented by Gauss's law [1-2]. Yet, within the universe, the electromagnetic force stands to be one of the four fundamental forces in nature [1-2]. Because of the fundamental concepts of gravity and electromagnetic forces, as being the two macroscopic "measurable" forces among the four, almost all physics departments worldwide ought to include such two topics deliberately in the first two courses offered to students of all majors. Focusing on teaching Gauss's law, challenges rise at the end of students' acquirement in grasping the concept. Being a universal trend, this challenge has attracted many educators to think about possible existing solutions by investigating the reasons behind students' misconceptions [3-10].

Gauss's law states that the electric flux through any closed surface (S) depends solely on the charge inside it. The electric flux should not depend on the size and the shape of S. The right-hand side of the law being easy to calculate, it has been shown to students that one can explore the law in calculating the strength of the electric field. It has been demonstrated that such task of calculating the electric field would be plausible in case of continuous charge distribution with very high symmetry (e.g., spherical, cylindrical and planar distributions). The effective application of Gauss's law implicitly requires an understanding of the principle of superposition of fields. Developing students' alertness of figuring out how to draw the appropriate Gaussian surface (S) corresponding to a specific charge distribution seems to consist the main challenge. The student problem may root deep into some math deficiencies such as their problems with integration and geometry.

In a related work, Singh [3] administrated free-response and multiple-choice questions (MCQs) and conducted interviews with individual students using a think-aloud protocol to elucidate the difficulties that students have with the concepts of symmetry, electric field, and electric flux. The author developed a set of MCQs to test students in the introductory calculus-based physics courses and to upper-level undergraduates taking electricity and magnetism (E&M) course and to graduate students enrolled as teaching assistants. The author concluded that undergraduate students have many common difficulties with the tested concepts. Singh and his PhD student Li recently reported alternative solutions to improve the students' understanding of symmetry and Gauss's law by providing them with tutorial sessions [4-5]. Chabay and Sherwood [6] performed similar study on undergraduate physics students taking E&M course. They reported that students find it easier to study classical mechanics than to study electromagnetism because of this latter's possession of mathematical complications. Another similar study done by Pepper et al. [5-6] on physics junior students revealed that, even at that level, upper-division students persist to struggle with Gauss's law. The difficulty stems from the inverse nature of the problem. Symmetry considerations must be realized as their main troubles source from recognizing that in situations without sufficient symmetry it is impossible (rather than "difficult") to calculate the electric field using Gauss's law. Pepper et al. [7-8] pinpointed that students cannot make good connection between mathematical expressions and geometrical configurations.

Maries, Lin and Singh [9] extended a study on students' problems with Gauss's law and suggested further solutions. They figured out an additional difficulty confronting students as to deal with drawing plots (e.g., plotting E(r)). They designed two scaffolding interventions. The same authors pinpointed that failure of students in plotting may cause not only to hinder the grasping of concepts but rather causes their deviations to discern the relevance of any further supportive arguments. Based upon the Accreditation Board for Engineering and Technology (ABET) criteria, Byford and Chahal [10] conducted a study on the common difficulties in learning Gauss's law at the junior level of students in electromagnetic engineering course. Five misconceptions were identified, among which three were reported consistent with physics educational literature. Yet, on the common misconceptions, they demonstrated the need for better scaffolding the translation of calculus and multidimensional calculus materials (i.e., differential geometry).

In the present investigation, our statistical sample consists of 211 students taking a calculus-based introductory physics course dealing with electricity and magnetism (i.e., known as "Physics and Engineering Applications II"), offered by the physics department to engineering students at the United

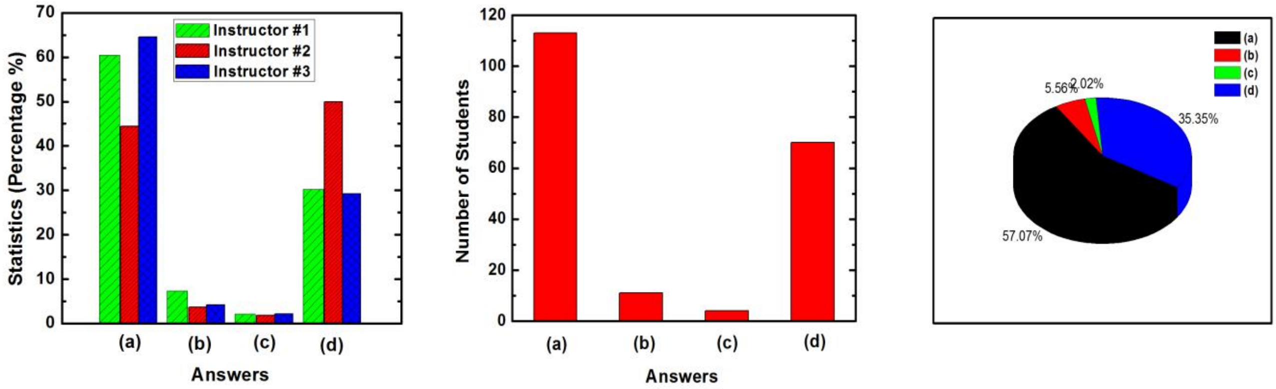

Figure-1: Statistics of answers of 198 students to MCQ #1 about the electric field.

Arab Emirates University. Statistics of results are collected by three instructors (the authors) throughout midterm and final exams during the fall semester 2018. We selected to present the students' answers of MCQs dealing with electric field and Gauss's law, in which students clearly struggle to resolve. In the next section, we will discuss the results of our study and in the last section, we summarize our main findings.

2. Results and discussion

The program of the course in concern covers a total of nine chapters; four chapters on electrostatics (i.e., 1- electric field, 2- Gauss's law, 3- electric potential, and 4- capacitance and dielectrics), two chapters on electricity (i.e., 5- current and resistance, and 6- DC circuits) and three chapters on magnetism (i.e., 7- magnetic force and field, 8- sources of magnetic field, and 9- Faraday's law). We use the book entitled "University Physics with Modern Physics" by H.D. Young and R.A. Freedman [11] as a text book. Usually, the physics department offers sections with enrollment of no more than 30 students per section. Our statistical sample consists of seven sections with a total number of 211 students (i.e., 3 sections for Instructor #1 and 2 sections for each of Instructor #2 and Instructor #3).

Table-1: Statistics of answers of student to MCQ #1. It concerns the electric field. Statistics is also normalized in percentage for each instructor. The right answer is (d).

Answers of MCQ #1	Instructor #1		Instructor #2		Instructor #3		TOTAL	
	Students	%	Students	%	Students	%	Students	%
(a)	58	60.42	24	44.44	31	64.58	113	57.07
(b)	7	7.29	2	3.70	2	4.17	11	5.56
(c)	2	2.08	1	1.85	1	2.08	4	2.02
(d)	29	30.21	27	50.00	14	29.17	70	35.35
TOTAL	96	100%	54	100%	48	100%	198	100%

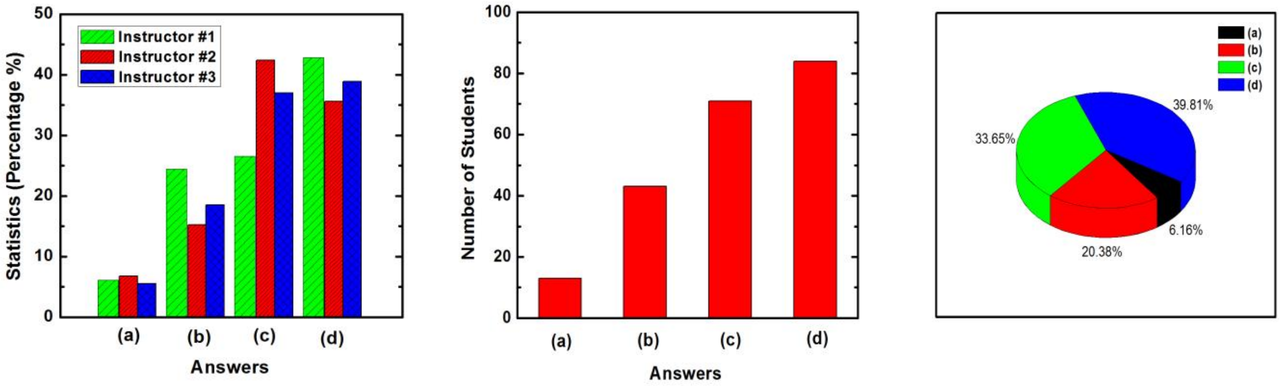

Figure-2: Statistics of answers of 211 students to MCQ #2 about Gauss's law.

Chapter 1 deals with Coulomb's force and the electric field. In this chapter, students are supposed to learn about the concepts of charge, interaction, charging a metallic ball by induction, the electric field, motion of a charged particle as well as rotation of an electric dipole in a uniform electric field. We have prepared a multiple-choice question #1 shown in Appendix, to assess the understanding of students to the effect of electric field due to a positively-charged rod on a solid sphere without mentioning its charge state and type (see Fig.3). Variance considerations for the solid sphere whether it can be a conductor or an insulator should be undertaken by students. Figure 3 shows clearly existence of an electric attraction when the charged rod brought close to the sphere. We formulated a MCQ shown in Appendix. While the correct answer is (d), clear deviation that student predominantly chose wrong answer (a) as they think that the sphere has only one option is to be negatively charged for the attraction to occur. They did not think about a second alternative if it were conducting, although similar situation of conducting sphere was presented throughout the lectures. The statistics of answers of students are summarized in Table 1 and presented in chart and pie diagrams in Figure 1. Statistics in the left-side diagram chart of Figure 1 is resolved into components per instructor. Basically, in all sections taught by the three instructors, we obtained the same trend where students pick up the wrong answer (a) with more chance, 57%, to picking up the correct answer (d) whose proportion is 35%, as an average value. So, this chart should bring an evidence that the trend is

Table-2: Statistics of answers of student to MCQ #2. It concerns Gauss's law. Statistics is also normalized in percentage for each instructor. The right answer is (b).

Answers of MCQ #1	Instructor #1		Instructor #2		Instructor #3		TOTAL	
	Students	%	Students	%	Students	%	Students	%
(a)	6	6.12	4	6.78	3	5.56	13	6.16
(b)	24	24.49	9	15.25	10	18.52	43	20.38
(c)	26	26.53	25	42.37	20	37.00	71	33.65
(d)	42	42.86	21	35.59	21	38.89	84	39.81
TOTAL	98	100%	59	100%	54	100%	211	100%

instructor-independent. The trend has to do with the students' shortcomings in achieving a full understanding of the effects of electric fields on materials.

MCQ #2 deals with the concept of Gauss's law to test students if they can figure out or select the cases suitable for its applications. Although many examples about various charge distributions (i.e., spherical, cylindrical and planar) were solved in front of students in the lectures, the message of drawing the appropriate Gaussian surface did not reach the minds of students yet. Statistics of students' answers are summarized in Table 2 and presented in bar and pie charts in Figure 2. While the correct answer is (b), only 20% among students who picked it up; many others deviated to choose wrong answers, especially (c) and (d) with proportions of 33% and 40%, respectively. The bar-chart on the left side of Figure 2 shows the components of resolved statistics per instructor. It should also give another evidence to show that all sections agree to exhibit the same trend and that trend to be instructor-independent.

3. Conclusion

In consistency with a universal trend, this investigation has demonstrated that freshman engineering students persist to struggle with the applications of Gauss's law. In our diagnosis of plausible sources of their troubles, we discovered their overlook to the geometry of the Gaussian surface and confusion of visualization of electric field due to continuous charge distribution. As intervention to reduce the size of failures, part of the responsibility could be taken on shoulders of instructors to provide more practices through extra tutorial sessions. Namely, within the scope of the present topic of Gauss's law, in the agenda of the practice sessions, students need to be more trained on integrations to calculate the electric fields due to continuous charge distributions. On the second hand, instructors should make students responsible for grasping such concepts of integrating electric field vectors and should include this part in the tests. Furthermore, in the chapter of Gauss's law, more practices are recommended until it becomes obvious for the students to imagine the Gaussian surface appropriate for any charge distribution of high symmetry. Meanwhile, they should achieve a level to evidence to discriminate cases of inappropriateness of applying Gauss's law. Furthermore, instructors should also consider using our novel technology such as exploring demos to illustrate the charge redistribution in order to bring the physical concepts close to their realizations. Last but not least, students must return to read books or at least the text book and one has to find a way to minimize their interactions with computers. We have evidence that our students perform better on questions well elaborated in class; wheras, other questions cause a challenge for them as their grasping of concepts is not complete. They must learn that leaning is a mutual effort done at two ends.

Acknowledgments

The authors are indebted to thank the department of Physics at the United Arab Emirates University and the Emirati Center for Environmental and Energy Research (ECEER-grant #: 31R145) for the continuous financial support.

Appendix: The Multiple-Choice Questions

Chose the correct answer for the following questions:

Question #1: If a suspended object A is attracted to a positively charged object B (Fig.3), what can we conclude about object A?

(a) A is certainly negatively charged.
(b) A is certainly neutral.
(c) A is certainly positively charged.
(d) A is either negatively charged or neutral.

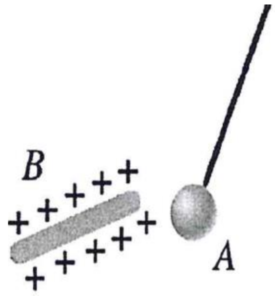

Figure-3

Question #2: Shown below (Fig.4) are three thin-walled insulating objects with a net charge +Q uniformly distributed on their surfaces: a cube, a sphere, and an open ended cylinder of length L (no caps) and diameter L. The objects are distant from each other so that each may be considered electrically isolated.

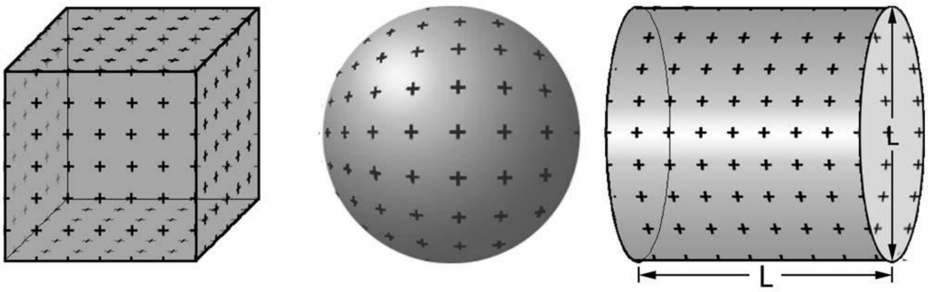

Figure-4: depicted from reference [3]

We can easily use Gauss's law to find the electric field due to the uniform surface charge at a point outside due to:

(a) The cube only.
(b) The sphere only.
(c) The cube and the sphere only.
(d) All the three objects.

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