# High School Students' Difficulties and their Causes due to the Electromotive Force, in the Study of Direct Current Simple Electric Circuits

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G.G. Vavasis(✉), E.C. Kapotis, G.S. Tombras
Department of Electronics, Computers, Telecommunications and Control, Faculty of Physics, National and Kapodistrian University of Athens, Athens, Greece
gvavasis@phys.uoa.gr

**Abstract—**This work is part of a larger research, conducted in Greece, about the students' difficulties in understanding the concepts and phenomena of Electricity. The goal of this study is to present the high school students' difficulties and their causes into the study of basic direct current (dc) circuits, due to the concept of the electromotive force (emf). Researches in over the world have highlighted that the concepts of the emf and the potential difference (pd) create many problems to the students in the study of dc circuits. These difficulties are presented, analyzed and is made an attempt to identify their causes. The results show that, in addition to confirming the existing literature enriched with new findings, to address these difficulties is necessary the development of a teaching approach based on an education model with a new curriculum, where needed (in Greece, for example) and an appropriate education material so that to overcome the lack of understanding of the concepts and laws shown by the students.

**Keywords—**dc electric circuits, high school students' difficulties, electromotive force, potential difference, Ohm's law, Kirchhoff's laws

## 1 Introduction

The educational community considers that understanding the students' interpretations of the concepts of Physics is very important for the learning process. An appropriate teaching strategy and curriculum improvement can be achieved only with the identification of the conceptual impediments faced by the students in the study of the natural phenomena and relative theories.

More specifically, for electrical phenomena there are several studies on students' understanding of basic concepts like current, potential difference, resistance [1], [2], [3] and laws such as Ohm's and Kirchhoff's laws [4], [5], [6]. These studies have confirmed that the difficulties faced by the students are both conceptual and reasoning and create misunderstanding and alternative ideas [2], [7], [8]. The degree of difficulty seems to be greatest when in the electric circuits the battery is real, that is when the students must use the concept of the electromotive force (emf). Comparatively little research has been published on high school students' understanding of this concept which is fundamental to understanding both dc circuits and electromagnetic induction phenomena and studies performed on teaching and learning emf concept are not encouraging. Garzón et al [9] support that it is important that students understand the difference between emf and potential difference in the context of dc circuits, where both concepts have relevance.

A qualitatively analysis and study of the simple circuits requires a sufficient understanding of emf concept on the part of students [2], [9]. Studies conducted in many countries with different educational system indicate that the obstacles created by this concept are common and insist strongly.

This article describes the attempt to find out what students from Greece have understood about the concept of emf into the study of basic dc circuits. At the same time is performing an error analysis of the students' conceptual and reasoning difficulties so that the causes of these difficulties that students face when they have to use the concept of emf are investigated and identified.

## 2 The emf concept in upper secondary school physics courses

The concept emf appears in the Greek literature as a feature of the electric source. To have current in an electric circuit a device such as a battery that transforms one type of energy (chemical, mechanical or light, for example) into electric energy is necessary. Such a device is called a source of electromotive force. The emf $\mathcal{E}$ of a battery is the maximum possible voltage the battery can provide between its terminals. It expresses the energy $W$ offered by the source in each unit of electric charge $q$. For example, if the power source has a 3 volt emf, it means that it provides 3 joules of energy per 1 coulomb.

$$\mathcal{E} = W/q \quad (1)$$

Because a real battery is made of matter, there is resistance to the flow of charge within the battery. This resistance is called internal resistance $r$. For an idealized battery with zero internal resistance, the potential difference (pd) across the battery (called its *terminal voltage "$V_{term}$"*) equals its emf. For a real battery, however, the terminal voltage is *not* equal to the emf for a battery in a circuit in which there is a current.

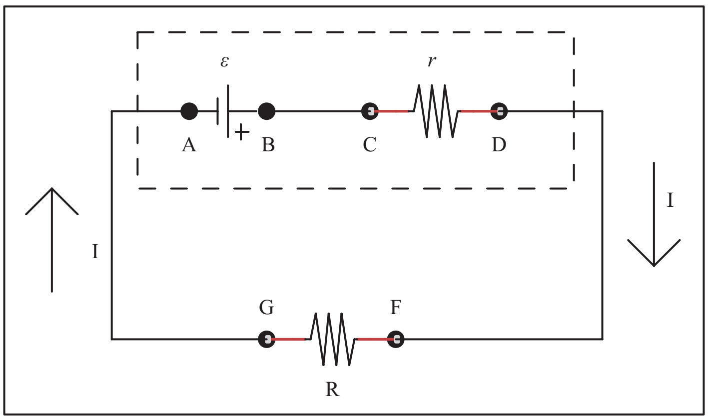


**Fig. 1.** Circuit diagram of a battery of emf $\mathcal{E}$, of internal resistance $r$, connecting to an external resistance $R$

The battery in Figure 1 is represented by the dashed rectangle containing an emf $\mathcal{E}$ in series with an internal resistance $r$. A resistance $R$ is connected across the terminals of the battery.

Passing from the negative terminal to the positive terminal, the potential increases by an amount $\mathcal{E}$. Moving through the resistance $r$, however, the potential *decreases* by an amount $I \cdot r$, where $I$ is the current in the circuit. Therefore, the terminal voltage of the battery

$$\Delta V = V_{term} = \mathcal{E} - I \cdot r \tag{2}$$

The actual potential difference between a battery's terminals depends on the current in the battery as described by Equation 2. But the terminal voltage equals the potential difference across the resistance R: $V_{term} = V_R = IR$. Combining this expression with Equation 2 results

$$\mathcal{E} = I \cdot R + I \cdot r$$

Solving for the current gives

$$I = \mathcal{E} / (R + r) \tag{3}$$

Equation 3 shows that the current in the simple circuit depends on both the resistance R external to the battery and the internal resistance r and corresponds to Ohm's Law for the whole circuit.

In many cases teachers come up with Equation 3 using the principle of conservation of energy. Namely the total energy output of the battery is delivered to the external resistance and to the internal resistance

$$W_{tot} = W_R + W_r$$

or using the power's concept

$$P_{tot} = P_R + P_r$$

$$\mathcal{E} \cdot I = I^2 R + I^2 r$$

and eventually from this expression comes up with the Equation 3.

So, according to the scientific theory the emf measures the work carried out by no conservative forces within the battery as it separates charges to generate a potential difference; potential difference measures the work done on the charges by conservative forces as they move from one point to another in a circuit. However, the traditional curriculum and the classical teaching approach do not point out the different nature of emf and potential difference. Zuza et al [10] argued that the circuit is often not explicitly analyzed in terms of energy balance and the role played by the battery's emf in the movement of electrons is often neglected.

## 3 Context of the research and methodology

The sample of the research consisted of 168 high school students (ages 16–17) who had attended middle school courses to the basic concepts of electricity and electric dc circuit and continue the courses in the high school studying of simple electrical dc circuits (16–18 hours of lectures totally), by applying complex concepts such as emf and the laws of Kirchhoff and Ohm. In Greece, high school students choose groups of courses depending on the University faculty they want to attend. So, in the class of 16 and 17-year-old students, two groups of courses are created: Sciences Pathway (ScPw) with additional courses in Physics and Mathematics and Humanities Pathway (HuPw) with additional human studies courses, while there are also some common courses such as lessons of electrical phenomena.

Two groups of students constituted the total sample. (a) Sample 1 (109 students) who had chosen ScPw's courses and (b) Sample 2 with 59 students who had chosen HuPw's courses.

Simple qualitative questions, in form of a written test, were designed to find out the students' way of thinking and reasoning when they were asked to answer similar questions – problems. The questions were created taking into account relevant surveys and literature, or formed an original and standard composition for this research. In addition, we conducted interviews, in order to get an in-depth picture of the students' difficulties. The interviews were of various forms, such as semi-structured or open-ended questions etc.

Students had to predict the outcome of specific changes in a system, observe, analyze and solve problems that focus on qualitative understanding. The students' answers and ideas were analyzed focusing on identifying their understanding about the emf concept and its role in the simple dc circuits; whether or not the answers given were correct was a minor concern. The aim was to find the causes that create conceptual mainly difficulties and how they prevent the confrontation of combinatorial concepts and problems.

During the survey, simple laboratory equipment was used, consisting of simple batteries, cables, resistors and lamps, up to three in number.

## 4 Experimental procedure

In this study, students had to face qualitative questions and their answers are analyzed. These questions were designed to investigate students' ideas about emf and how it affects the study of simple electrical dc circuits. The questions probe students' conceptual understanding and through their answers an attempt is made to identify the causes of the conceptual and reasoning difficulties.

The questions were asked to the students who had already studied the topic of direct current circuits and emf concept in their physics lectures.

Four questions were designed; some of them required an in-depth discussion with students with the aim of identifying their alternative ideas and the most problematic aspects when they attempted to understand emf; in other questions the questionnaire in the form of a test was sufficient.

**Question 1**

In the circuit given in the Figure 2 the battery is real (emf $\mathcal{E}$ =10V, internal resistance r = 2Ω) and is connected with a voltmeter and an ammeter; in the circuit (a) the voltmeter reading is 10V, while in the circuit (b) its reading is

i) $V = 0$
ii) $V = 5V$
iii) $V = 10V$

Explain your choice

The aim of this question was to investigate students' understanding of the concepts of potential difference ($V$) and emf ($\mathcal{E}$) within a context connected to the normal teaching of simple electrical dc circuits with a real battery.

From the discussion in the form of an interview with students, it emerged that option (iii) was the one that was chosen by most students instead the correct option (i).

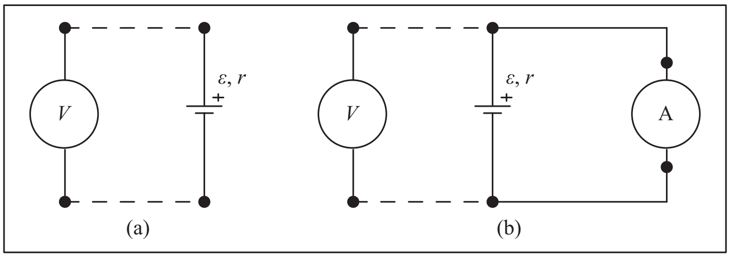


**Fig. 2.** The potential difference and the electromotive force

This question highlighted the students' confusion about emf and the potential difference or the terminal voltage ($V_{term}$) in this case. Only a few students recognized that in the circuit (b) there is current flow through the battery and the ammeter. This value of the current is calculated using the Ohm's law for the whole circuit (Eq. 3), without resistance external to the battery ($I = \mathcal{E}/r = 10/2 = 5A$) and finally the terminal voltage's value results from the Equation 2 ($V_{term} = \mathcal{E} - I{\cdot}r = 10 - 5{\cdot}2 = 0V$). From the discussion with the students it was confirmed [11], that several of them consider that potential difference between the terminals of the battery is conceptually the same as the battery emf and give to emf the same properties as the potential difference, which leads to not distinguishing between the role played by the emf and by the potential difference in the context of electrical circuits.

Thoughts like "*in both circuits there is not current flow because there is not a resistance R connected to the battery*" or "*the voltmeter measures the potential difference which is the same to the emf, as in the first circuit*" were frequent among students.

**Question 2**

In this question, the students were asked to predict the changes in the meters readings when the value of the circuit resistance varies.

In the circuit given in the Figure 3, the battery is real (emf $\mathcal{E}$, internal resistance $r$) and is connected with a voltmeter, an ammeter and a resistance $R$. If the value of the resistance $R$ decreases, then predict the readings of the two meters

(i) The ammeter reading will increase and the voltmeter reading will decrease
(ii) The ammeter reading will increase and the voltmeter reading will remain the same
(iii) The ammeter reading will decrease and the voltmeter reading will increase

Explain your choice

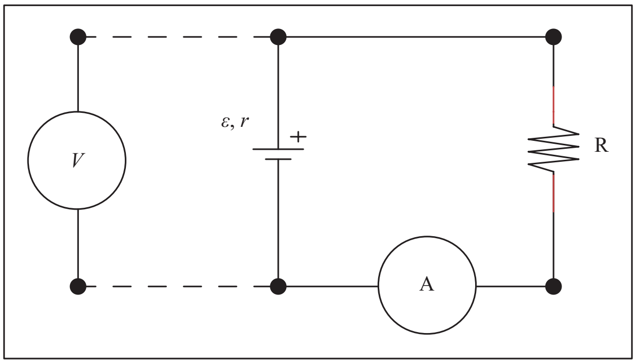


**Fig. 3.** Real battery and the variations of the current and potential difference

Also this question was answered by the students in the form of an interview, so that the dialogue between the teacher and the students would clarify certain points of the students' reasoning through their answers. The participants were 60 students and their replies are summarized in Table 1.

**Table 1.** Students' performance

| | | Correct Reasoning | Incorrect Reasoning |
|---|---|---|---|
| Students | Total ($n$ = 60) | 28.5% | 71.5% |
| | ScPw ($n_1$ = 40) | 37.5% | 62.5% |
| | HuPw ($n_2$ = 20) | 10% | 90% |

*Note:* Overview of students (n: number of students) performance on the question 2.

Only 17 students (28.5%) answered correctly. They recognized that decreasing the value of the resistance R the value of the circuit current increases according the Ohm's law for the whole circuit (Eq. 3); then using the Equation 2 ($V_{term} = \mathcal{E} - I \cdot r$) they resulted that the terminal voltage (voltmeter reading) decreases.

A particular feature of the responses was that while most students knew and remembered the mathematical expressions of concepts and laws, many of them could not implement and combine them properly to reach a correct conclusion. The students' wrong answers were divided into two categories. To the first belong the students' explains for the options (i) and (ii) where the value of the circuit current increases. "*The resistance decreases so the current increases; according the Ohm's law the current is proportional to the potential difference of the resistance R and eventually the indication of the voltmeter increases since it measures the resistance's voltage*" or "*the current must be increasing but the voltmeter measures the value of the emf, so its indication will not change*" are some characteristic students' thoughts. To the second category belong the students' explains for the option (iii) where the value of the circuit current decreases and was the one less chosen. The most of these students were led to wrong conclusion because they tried to use the Equation 2 directly, without considered the changes in operation of the circuit. "*According the expression $V_{term} = \mathcal{E} - I \cdot r$ we can observe that* *the value of the terminal voltage decreases when the value of the current increases since the emf remain always constant*" was a typical answer.

The reasoning impediments emerged more through the students' answers were:

1. Not a clear understanding of the concepts emf and potential difference. It is confirmed [11] that many students try to use science-based arguments without really showing they know the difference between emf and potential difference and what exactly the terminal voltage in a dc electric circuit means.
2. Wrong interpretation and apply the Ohm's law and the relative formulas [$I = \mathcal{E}/(R_{eq} + r)$, $I = V/R$].
3. Failure to recognize the need and use the Kirchhoff's law of voltage, where a different expression of it is the relation $V_{term} = \mathcal{E} - I \cdot r$. Some students were unable to recognize when there is a need to use the second Kirchhoff's law, while some others did not use it correctly. [The Kirchhoff's law of voltage applies to a series of nodes. It specifies that the algebraic sum of voltages between successive pairs of nodes of this series is equal to the voltage between the last node and the first node (total voltage)].

The goal of the next two questions was to identify the impediments of the reasoning, faced by students when they are asked to study the variations caused in a simple electric dc circuit with a real battery. Which are the difficulties created when the students have to combine the concepts emf, potential difference and laws such as the Ohm's and Kirchhoff's laws?

**Question 3**

The circuit shown in Figure 4 is containing a real battery (emf $\mathcal{E}$, internal resistance r), two bulbs L1, L2 and a resistance R. The switch (S) is open and the bulbs are lit. If the switch (S) will close

(i) the L1 bulb's brightness will decrease and the L2 bulb's brightness remain the same
(ii) the L1 bulb's brightness will increase and the L2 bulb's brightness will decrease
(iii) the brightness of both bulbs will increase

Explain your answer considering the bulb's brightness proportional to its power.

The question was given in a test form; participated and answered 168 students (109 ScPw's students and 59 HuPw's students). It was expected that the presence of the real battery and the configuration of the circuit would create significant difficulties.

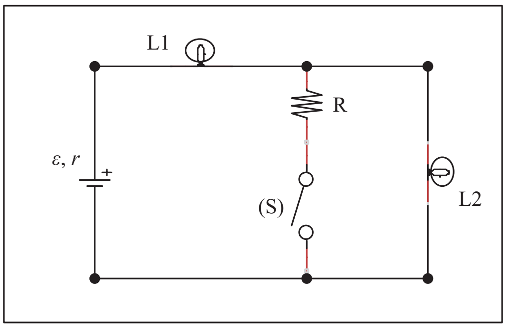


**Fig. 4.** The brightness of the bulbs

Only 33 students (19.6%) answered correctly. They thought that the connection in parallel between the resistance R and the bulb L2 results the reduction of the circuit's resistance value and at the same time the increase of the circuit's current value and the potential difference of the bulb L1 [Ohm's law: $I = \mathcal{E}/(R_{eq} + r)$, $V = IR_L$]; in addition, according the Equation 2 the terminal voltage decreases. Therefore the potential difference of the bulb L2 decreases as results from the second law of Kirchhoff ($V_{term} = V_{L1} + V_{L2}$). Eventually the brightness ($P = V^2/R_L$) of the bulb L1 will increase and the brightness of the bulb L2 will decrease.

The analysis of the results (see Table 2) showed that the main cause of the difficulties faced by the students was their inability to understand that emf and potential difference or terminal voltage, as called the potential difference between the terminals of the battery, are not conceptually the same. This fact led the most of the students to others basic reasoning errors grouped into the next categories:

c1. The potential difference at the ends of the battery (terminal voltage) is independent of the current through the battery.
c2. Mechanical use the Ohm's law for the whole circuit (Eq. 3) and for any passive element of the circuit ($V = IR$), as well as difficulty in using and applying of the second Kirchhoff's law (law of voltages).
c3. Difficulty in selecting the appropriate mathematical expression for the bulbs' power; due to the previous misconceptions and conceptual impediments some students tried to use the power's formula ($P = I^2R$) for both bulbs and other the expression ($P = \mathcal{E}\cdot I$) ignoring the presence of the resistance R and its role.

**Table 2.** Students' performance

| **Percentage (%) of Students Answers Overall and By Studies** | | | | |
|---|---|---|---|---|
| | | **Correct Reasoning** | **Incorrect Reasoning** | **Without Reasoning** |
| Students | Total ($n$ = 168) | 19.6% | 72.1% | 8.3% |
| | ScPw ($n_1$ = 109) | 25.7% | 70.6% | 3.7% |
| | HuPw ($n_2$ = 59) | 8.5% | 74.6% | 16.9% |

*Note:* Overview of students (n: number of students) performance on the question 3.

From the results shown in Table 2 we can highlight the following characteristics.

a. Many students trying to explain their answer made 2 and 3 different errors at the same time.
b. The significant number of HuPw's students who answered without arguing and without giving any reasoning for their choice.
c. The difficulty of the power's formula ($P = VI$, $P = I^2R$, $P = V^2/R$) manipulation in a certain case. The students prefer to use the concept of the current because they consider that understand it better related to the concept of the potential difference; but in many cases, like this one, this choice creates the need of more complex thoughts and arguments resulting in the students being led to incorrect conclusions.

d. The wrong application of Ohm's and Kirchhoff's laws. It is obvious that in the mind of many students the functional relationship between potential difference, current and resistance for a part of the circuit ($V = IR$) and for the whole circuit (Eq. 3) is unclear. In addition, the students try to avoid the use of the Kirchhoff's laws due to the misunderstanding they have of the emf, potential difference and terminal voltage.

In the diagram given in the Figure 5 is shown the percentage appearance of the students' reasoning errors when they tried to answer the question 3.

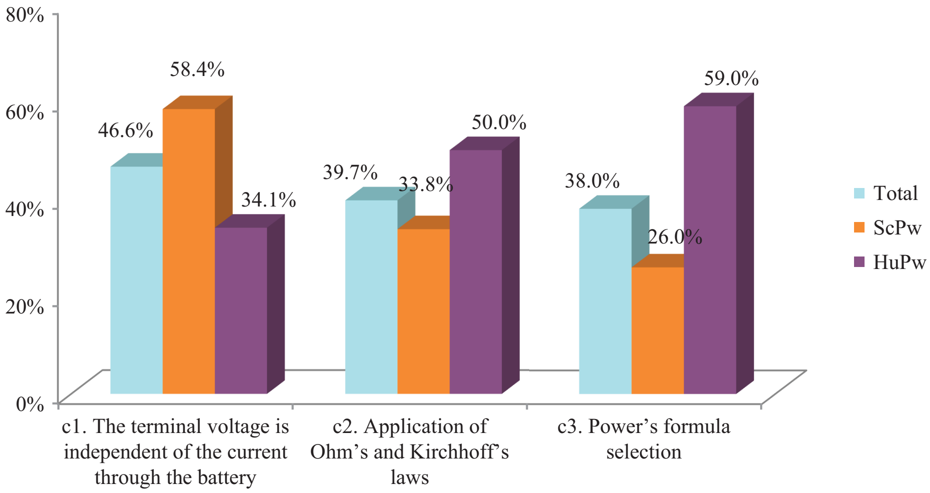


**Fig. 5.** The percentage appearance of the incorrect reasoning

Observing the appearance of errors in students' answers and having discussed with them their ideas about the question 3 we can emphasize the following:

1. HuPw's students generally prefer to use the concepts and relationships they find simplest and believe they understand them better. For this reason they avoided using the concepts of emf and terminal voltage. This resulted in a relatively small percentage of category c1 errors. This fact led most of these students to choose relationships with the concept of current (power's formula, Ohm's law); but in this case, where the current passing through the bulbs and battery is changing, it creates reasoning impediments and wrong conclusions (high percentage of categories c2 and c3 errors).
2. For the most ScPw's students the difficulty was the prediction of the power's variation of the bulb L2. They recognized the appropriate power's formula ($P = V^2/R_L$) and tried to find out the potential difference's variation of the bulb L2; but the battery emf has a constant value while the potential difference at the ends of the battery, called terminal voltage, depends on the circuit topology and the current and equals

the sum of the potential difference of the two bulbs ($V_{term} = V_{L1} + V_{L2}$). This fact and the poor understanding of emf, potential difference and terminal voltage create misconceptions and reasoning errors (high percentage of category c1 errors).

For example some students' thoughts and ideas were:

- "*the resistance R is connecting in parallel with the bulb L2; so the potential difference of the bulb L2 does not change and therefore its power remain constant*"
- "*the circuit's resistance value decreases and according to the Ohm's law the circuit's current value increases; therefore both of the bulbs' power ($P = I^2R_L$) increases*"
- "*the circuit's resistance value decreases and according to the Ohm's law the circuit's current value increases and at the same time both of the bulbs' potential difference increases (Ohm's law); this mean that also the bulbs' power ($P = V^2/R_L$) increases*"
- "*with the connection of the resistance R the circuit's resistance decreases and the circuit's current value increases (Ohm's law); therefore the potential difference ($V = IR_L$) and the power ($P = V^2/R_L$) of the bulb L1 increases and at the same time the potential difference of the bulb L2 and its power decreases since the terminal voltage remains constant (Kirchhoff's law: $V_{term} = V_{L1} + V_{L2}$)*"

After analyzing the results of question 3 and given the fact that students prefer to use the concept of current, we wanted to discuss with them and to ask for their reasoning about the variation of a bulb's brightness in a simpler dc electric circuit. We wanted to identify the causes why the concept emf creates reasoning impediments in a more simple case, as described below. The discussion with the students took place in the form of an interview.

**Question 4**

In the circuit given in the Figure 6, the battery is real (emf $\mathcal{E}$, internal resistance $r$) and is connected with the bulbs L1, L2. Initially the switch (S) is closed and the bulb L1 is lit while the bulb L2 is not. If the switch (S) will open the brightness of the bulb L1 will

(i) increase
(ii) decrease
(iii) stay the same

Explain your choice.

Opening the switch (S) the bulb L1 is connecting in series with the bulb L2 and the circuit's equivalent resistance $R_{eq}$ will increase; so according the Ohm's law (Eq. 3) the value of the circuit's current will decrease. Eventually the power and the brightness of the bulb L1 will decrease ($P = I^2R_L$).

Participated and answered 166 students (107 ScPw's students and 59 HuPw's students) and the results of their answers shown in the Table 3 having the characteristic feature the higher percentage of students' correct reasoning in relation to the results of the question 3 (see Table 2); but at the same time the conceptual difficulties created by the battery emf were identified.

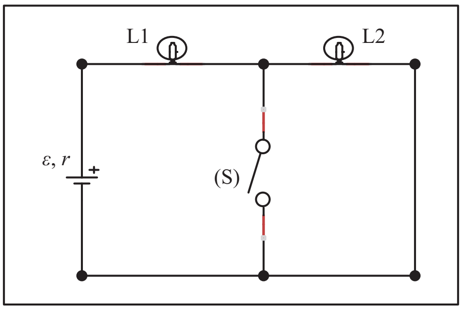


**Fig. 6.** The brightness of the bulb L1

Before question 4 was asked, there was a discussion with the students about the results of question 3, so they had a thought guide that led many of them to the correct reasoning and conclusions. Most of the incorrect reasoning and misconception were due to students' poor understanding of the concepts emf, potential difference and terminal voltage and their inability to manipulate and apply Ohm's and Kirchhoff's laws.

**Table 3.** Students' performance

| Percentage (%) of Students Answers Overall and By Studies | | | | |
|---|---|---|---|---|
| | | **Correct Reasoning** | **Incorrect Reasoning** | **Without Reasoning** |
| Students | Total ($n$ = 166) | 52.5% | 45.5% | 2% |
| | ScPw ($n_1$ = 107) | 63% | 37% | 0% |
| | HuPw ($n_2$ = 59) | 34% | 61% | 5% |

*Note:* Overview of students (n: number of students) performance on the question 4.

Some students tried to answer using the power's formula ($P = V^2/R$); they argued that "*the circuit's equivalent resistance $R_{eq}$ increases so the current's value decreases; therefore the terminal voltage ($V_{term} = \mathcal{E} - I \cdot r$) increases and the potential difference of the two bulbs will increase proportionally as will the L1 bulb's power*". They equated the terminal voltage to the sum of the potential difference at the ends of the bulbs L1 and L2, but were unable to compare the potential difference of the bulb L1 when the switch (S) is closed and open respectively, as well as to apply Kirchhoff's voltage law ($V_{term} = V_{L1} + V_{L2}$) correctly. Other students tried to use the principle of conservation of energy. Namely they considered that "*the total energy output and power of the battery is delivered to the bulb L1 initially and then to the both bulbs when the switch is open. Therefore the L1 bulb's power decreases since the power ($P = \mathcal{E} \cdot I$) of the battery remain constant*"; these students ignored that the battery's power depends on the circuit's current which its value is changed.

There were also students which used the power's formula ($P = I^2R$); even to some students who answered correctly, the reason why they preferred to use this formula instead of ($P = V^2/R$) is not clear. They tried to examine the change of current's value when the switch was closed and then when it is open by applying Ohm's law, but his two expressions for a part of a circuit ($V = IR$) and for the whole circuit [$I = \mathcal{E}/(R_{eq} + r)$] and the presence of emf in the second relationship created to them confusion and reasoning difficulties. Some students even suggested using numerical data to answer the question because they appear to trust more in the quantitative results of an equation than in conceptual arguments based on facts; this preference states that students often use and apply complex concepts and laws more mechanically than because they have understood them conceptually well.

## 5 Concluding remarks and suggestions

During the study, we have identified some conceptual impediments which seem similar to many students, even to the students of both the two groups of courses (ScPw and HuPw) when answering questions related to changing of the dc circuit's operating conditions and emf. This description of the students' ideas concentrated on some persistent specific difficulties and the interpretation thereof; these difficulties are both conceptual and reasoning.

Our results are confirmed by findings in previous studies on students' understanding of electricity, such as a vague understanding by the students of electromotive force [9]. When students are confronted with qualitative questions they show a reluctance to explain the meaning of emf and prefer to use mathematical formulas more in mechanical way. We strongly believe that this reluctance is due to a lack of understanding of the concept of emf and difficulty in distinguishing it from potential difference, but at the same time moreover of other concepts and laws, such as Ohm's and Kirchhoff's laws. For example, the inability of distinguishing the Ohm's law for the whole circuit and for a part of it, or the wrong application of the Kirchhoff's voltage law, or the confusion of both these two laws [9], [12], [13]. In addition, in Greek schools the teachers, following the traditional teaching approach present the theory as fact with the rapid introduction of the related concepts and make it difficult for the students to understand the role of emf in the operation of the circuit and its distinction from the potential difference; the emf pertains to the work done by a non-conservative force to move a charge between the terminals inside the battery, while the potential difference pertains to the work done by a conservative force to move the unit of charge between the terminals outside the battery. Therefore the conclusion of Mulhall et al. [14] is confirmed that both students and teachers have problems describing energy transformations in a circuit within a coherent framework, while A.C. Rose-Innes [15] also argues that any difficulty usually arises from a misunderstanding of the nature of emf. Eventually many lessons delivered in the class still use lecture methods and this situation makes students present a lack of interest in learning even basic concepts of Physics [16].

Students' difficulties with learning the electromotive force concept in electric circuits seem to be strongly linked to the absence of a conceptual framework for thinking and the construction of new knowledge appropriately; as a result laws and concepts like emf become something that is memorized.

Many researches [17] maintain that the education of the Physics requires experimental practice in order to enhance the understanding phenomena and processes on the concepts it is based on. So, modifications to teaching strategies, like educational models with laboratory and auxiliary courses accompanied by appropriate material, may contribute to alleviating the difficulties faced by the students [18]. Senior cognitive skills, such as problem solving can be improved through students' active learning methods, which aim at participants' exploring and applying knowledge, themselves [19]. For example, for students to understand the role of the emf in any circuit and to distinguish it from related concepts such as potential difference and terminal voltage, it is useful to analyze the energy balance in the circuit. Considering the energy balance gives consistency not only to the emf concept but also to the generalized principle of work and energy embodied in Kirchhoff's second law [9], [10], [20].

Zuza [10] argues that identifying which concepts and theories students learn well, and with which they have difficulties, can guide teaching and curriculum development. Therefore, for evaluation of the new procedures' and the teaching ways' should be created equivalent control and experimental groups from research's sample. In the experimental group, will be applied the new proposals and in the control group the existing traditional methods. The evaluation of the students' performance, with suitably configured evaluation tools, could attribute to the enrichment of the research base and to the improvement of the educational strategies.

## 6 Acknowledgment

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## 8 Authors

**Mr. Gerasimos G. Vavasis** is a doctoral candidate at the Physics Department at the National and Kapodistrian University of Athens. He holds a Bachelor degree in Physics and Master Degree in "Naval and Marine Technology and Science". Since 1990 is a teacher of a Greek high school and the last 4 years is also a school principal. (e-mail: gvavasis@phys.uoa.gr).

**Dr. Efstratios C. Kapotis** is a postdoctoral researcher at the Physics Department at the National and Kapodistrian University of Athens. He holds a Bachelor degree in Physics, Master Degree in "Science Education" and Ph.D. Degree in Physics Education and Digital Educational Technologies. He taught various undergraduate and graduate courses in Physics, Physics Education and the Integration of Computers in Education. (e-mail: ekapotis@phys.uoa.gr).

**Mr. George Tombras** is Professor of Electronics at the National and Kapodistrian University of Athens, Director of the Laboratory of Electronic Physics and Chairman of the Faculty of Physics. He is also a member of the University Senate. He received his undergraduate degree (B.Sc.) in Physics from the Aristotelian University of Thessaloniki, Greece, his M.Sc. degree in Electronics from the University of Southampton, UK, and the Ph.D. degree in Physics from the Aristotelian University of Thessaloniki in 1979, 1981 and 1988. (e-mail: gtombras@phys.uoa.gr).

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