

A study about the learning of students who worked with computational modeling and simulation in the study of simple electric circuits

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Abstract: The purpose of this research was to investigate the learning of students who worked with computational modeling and simulation using the software *Modellus* in the study of simple electric circuits. The theoretical framework was based on Ausubel's theory of meaningful learning and Halloun's schematic modeling approach. The quantitative results show that there were statistically significant differences in the performance of students who worked with the computational activities (experimental group), when compared to the one in which students were just exposed to a traditional method of teaching (control group). The qualitative results suggest that many students from the experimental group seemed to have achieved meaningful learning, and the students' interaction among themselves and with the teacher as well during the computational activities has strongly contributed for that.

Keywords: computational simulation, computational modeling, learning difficulties, simple electric circuits, physics teaching.

Introduction

It is common sense, nowadays, that engagement and interactivity are decisive factors to learning. The studies of Beichner (1990), Redish and Wilson (1993), Hodson (1994), and Beichner y Saul (2003), for example, show that active participation in classes and interactivity with instructional materials are key-points for the students' learning. According to Beichner y Saul (op. cit.), an active learning environment provides more favorable conditions for students to acquire a better conceptual understanding and to become more skillful in the resolution of physics problems.

In the teaching of simple circuits, which is the object of this research, the most traditional way of fostering engagement and interactivity comprises the development of experimental activities that take into account the students' previous knowledge (e.g., Shaffer y McDermott, 1992). More recently interactive simulations as Physlets (2009) and PHET(2009), providing a bridge between the static figure and the physical word (Cox, Belloni y Christian, 2005), and integration between experimental and computational activities (Ronen y Eliahu (2000); Zacharia y Anderson (2003), Finkelstein, Adams, Keller et al. (2005)), besides motivating the students, contributed to the meaningful learning of electric circuits. The drawing of concept maps and V diagrams (Novak y Gowin, 1984; Moreira, 2006) are some of other instructional techniques applied to promote

interactivity. The present study also integrates experimental and computational simulation activities but in addition there are computational modeling activities.

In the literature, acceptance attributed to activities of computational simulation and modeling is not common sense. To our understanding, in *computational simulation* activities, the student has autonomy to assign initial values to the variables, to change parameters, but he/she does not have autonomy to modify the core of the computational model, that is, the access to its most basic elements, mathematical or iconical. In *computational modeling* activities, in addition to being able to act upon the parameters and initial values, the student has access to such basic elements. Computational modeling activities are usually classified in two ways: *exploratory* and *expressive* (or creative). In the exploratory activities, the individual works with computational versions of scientific models and representations (graphs, animations, tables, diagrams) developed by other people and then they explore them through the most diverse perspectives. In the expressive activities, the individual designs his/her own computational models and creates ways to represent them.

Among the many computational tools available (*Interactive Physics, Java applets, Stella, PowerSim, Modellus*, etc.), we selected the software *Modellus* (Teodoro, Vieira y Clérgio, 2008), because with this software it is possible to propose both types of activities (simulation and modeling) and both ways of interaction of students with the computational model (exploratory and expressive). Besides, *Modellus* has an intuitive interface that facilitates the interaction of students with computational models in real time allowing them the observation of multiple conceptual experiments simultaneously.

Nowadays *Modellus* has started being very much used in teaching activities (e.g., Teodoro, 2008, *Advancing Physics*, 2004), however, in literature, studies that systematically look for the benefits of using such tool in relation to students' learning are scarce. Araujo, Veit y Moreira (2008) carried out a study about the use of computational simulation and modeling activities with *Modellus* presented in the form of problem-situations as an instructional complement in the teaching of kinematics graphs. This research involved two groups of students (experimental and control groups) who had already been exposed to formal instruction in kinematics and it was developed as an extra-class course. An adaptation to Portuguese of the "Test of Understanding Graphs in Kinematics" TUG-K (Beichner, 1994) was used to evaluate the conceptual understanding of the students; results show that there were statistically significant improvements in the performance of the students of the experimental group, when compared to the control group exposed to a traditional method of instruction. This finding suggested that the use of computational activities could improve the students' ability to understand kinematics graphs. An important aspect was that the students presented more willingness to learn because during the interactions with the computational models they realized the relevance of some mathematical relations and physics concepts, and the concepts that had previously seemed abstract became more familiar and concrete. These results encouraged us to carry out the present research, which differs from the former one by Araujo, Veit y Moreira (2008) in terms of the physics

content and for having been developed during class periods of a regular discipline of the Engineering course, that typically is attended by 40 students per class.

Learning difficulties in simple electric circuits

Electricity is one of the areas of physics most studied in terms of learning difficulties. A significant part of these studies refers to the teaching of simple electric circuits and, according to these studies, students even after formal instruction are not able to analyze and predict the behavior of physics magnitudes involved in such circuits. In our literature review (Dorneles, 2005) we included the main journals on physics teaching, from 1985 to 2005 in which we found 44 publications about learning difficulties of simple electric circuits, and among those, we point out three: McDermott and Shaffer (1992), Duit y Von Rhöneck (1998) and Englehardt y Beichner (2004).

MacDermott y Shaffer (1992) carried out a systematic longitudinal study to identify students' difficulties in the learning of simple electric circuits. It involved students who had never had physics classes before, students who had completed a specialization course or had already teaching experience, together with two large groups of college students enrolled in the introductory courses of Calculus and Algebra. Results indicate that conceptual difficulties and misconceptions presented by the students as they analyzed an electric circuit seem to vary in difficulty and frequency. It was detected that with formal instruction some difficulties tend to disappear, while others may persist indefinitely and hinder students' learning of more advanced topics. McDermott y Shaffer (op. cit.) classify mistakes made by students during the study of simple electric circuits into three categories: inability to apply formal concepts to electric circuits; inability to use and interpret formal representations of an electric circuit; and inability to qualitatively argue about the behavior of an electric circuit. In a second study (Shaffer y McDermott, 1992), a tutorial was developed based on laboratory instructional strategies to help students overcome their difficulties. This tutorial was tested, modified and reviewed through continuous evaluation based on experiments carried out in the classroom. Its efficacy was compared to traditional teaching in a study involving 600 university students. Results seemed to show significant differences in the conceptual understanding of the students who had used the tutorial compared to the ones exposed only to traditional teaching. In both cases, students able to solve the quantitative problems were often unable of conceptually analyze the same electric circuit, whereas students of the tutorial classes solved substantially better all the qualitative problems proposed. The tutorial materials also seemed to be more effective for overcoming some misconceptions. We point out the relevance of these studies (Shaffer y McDermott) because besides contributing with the identification of main learning difficulties, they also helped verify how students progressed along the study of electric circuits, as well as presenting a pedagogical proposal for helping overcome those hindrances.

Duit y Von Rhöneck (1998) presented a synthesis of research results that show before and after instruction conceptions in the domain of electricity. They emphasized the teaching of simple electric circuits and identified the

role of students' pre-instructional conceptions in the teaching/learning process, while distinguishing between misconceptions and the conceptions that serve as a basis for the students' development of an adequate understanding. The students' learning difficulties in the field of electricity serve as example for Duit y Von Rhöneck (op. cit.) to point out the importance of students' pre-instructional conceptions in the learning of physics.

Engelhardt y Beichner (2004) developed a multiple choice test with 29 questions to detect and interpret concepts about direct current resistive electric circuits (DIRECT – Determining and Interpreting Resistive Electric Circuit Concepts Test), that has been used with hundreds of students of secondary and university levels in the United States and Canada. There are two versions, the first (version 1.0) was applied to 1135 students and the second (version 1.1), to 695. The results show that both versions may be useful in the evaluation of curriculum or instructional materials. Version 1.0 is more qualitative, seeming more adequate to identify misconceptions, while version 1.1 is more quantitative, seemingly more adequate to identify students' mathematical skills. Many of the difficulties identified by Engelhardt y Beichner (op. cit.) with the application of the two versions of the DIRECT test are similar to the ones identified in the studies of McDermott y Shaffer (1992) and of Duit y Von Rhöneck (1998).

Learning difficulties presented in these three studies may be classified as conceptual difficulties, misconceptions and indiscriminate use of mistaken language and reasoning. Table 1 presents a synthesis of the difficulties of specific nature related to the concepts of electric current, potential difference and electric resistance, and the main misconceptions derived from these references.

The indiscriminate use of language is considered a hindrance to learning because the meanings associated to physics concepts by the students are frequently different from those that a physicist attributes to the same concept. For example, the meanings attributed to the concept of electric current in everyday language include a broad range of meanings about energy quite different from those scientifically accepted for this physics concept. The mistakes in a physics class, consequently, are common, and even more frequent if the teacher is not aware of the difference between his/her own context and the one of the students when talking about electric phenomena (Duit y Rhöneck, 1998, Pacca, Fukui y Bueno et al, 2003).

The students who presented faulty reasoning in the study of simple electric circuits seem to tend to develop sequential or local reasoning instead of a systemic one. According to McDermott y Shaffer (1992), students who present sequential reasoning analyze a circuit in terms of "before" and "after" the flow of an electric current, that is, they recognize that a change in the "beginning" of the circuit influences the subsequent elements, although they consider that a change at the "end" of the circuit does not influence "former" elements.

Conceptual difficulties	Misconceptions: The students...
Electric current	
1. To consider the conservation of the electric current. 2. To understand that intensity of an electric current in a circuit depends on characteristics of the source, but also on the equivalent resistance of what has been coupled between their terminals. 3. To recognize that the intensity of the electric current does not depend on the order in which the elements in the electric circuits are found, or on the direction of the current.	a) ... think that the current is consumed passing through an electric resistance (1-3). b) ... think that the battery is a source of constant electric current (1-3). c) ... believe that the order of the elements in the circuit and the direction of the electric current are relevant (1-3). d) ... think that the source provides the charge carriers responsible for the electric current in the circuit (3).
Electric resistance	
1. To distinguish equivalent resistance of part of a circuit and the electric resistance of an individual element. 2. To realize that the equivalent resistance is a useful abstraction for obtaining the total current or the potential difference in part of a circuit. 3. To understand that the electric current divisions at a junction point of the circuit depend on the circuit configuration. 4. To understand the serial association of resistors as a hindrance to current flow; and the association in parallel as an alternative for the current flow. 5. To identify associations in series and in parallel.	e) ... often think of the equivalent resistance of the circuit as if were a property of an individual element of the circuit (1). f) ... when determining how the electric current divides itself into parallel branches of a circuit, consider only the number of branches and not the relative electric resistances of the various branches (1-3). g) ... think that if a resistor reduces the current by x , two resistors will reduce it by $2x$, independently of the resistors' configuration (3). h) ... consider that resistors aligned geometrically in series are associated in series either if there is a junction or not between them; and that resistors aligned geometrically in parallel are associated in parallel even if there is a battery in the branch (3).
Potential difference	
1. To differentiate the concepts of potential difference and of electric current. 2. To differentiate the concepts of potential difference and of electric potential. 3. To recognize that an ideal battery maintains a constant potential difference between its terminals. 4. To calculate the potential difference between pairs of points along the circuit.	i) ... think about the battery as a constant source of electric current and not as a source of constant potential difference (1-3). j) ... understand the potential difference as a property of the electric current (3). k) ... consider that the potential difference between pairs of points along the circuit remains constant (1). l) ... associate brightness of a light bulb to the potential value of one of the terminals of the bulb (2).

Table 1.- Synthesis of the conceptual difficulties and alternative conceptions identified in the third column by (1) Duit y Von Rhöneck (1998), (2) McDermott y Shaffer (1992) and (3) Engelhardt y Beichner (2004).

The students who present local reasoning focus their attention on a point of the circuit as they ignore the rest of the electric circuit. For example, when analyzing the electric current divisions at a point of the junction (current divisor) of a circuit containing many parallel branches, students seem to despise what exists in each branch and consider that the electric current divides itself into equal parts in each branch of the circuit (Duit y Rhöenck, 1998).

Another difficulty often reported in the literature, especially in studies that involve secondary students, is the inability to apply the concept of complete circuit. For example, many students are not able to turn on a light bulb with a battery and one single electric wire, since they do not consider that a light bulb has two terminals (bornes) for establishing a connection (Arnold, Middle y Millar, 1987; Sanchez y Sánchez, 1989; McDermott y Shaffer, 1992; Shepardson y Moje, 1994; Benseghir y Closset, 1996; Chambers y André, 1997; Shepardson y Moje, 1999; Sencar y Eryilmaz, 2004; Chiu y Lin, 2005).

Table 2 presents the other studies found in our literature review (Dorneles, 2005) and the main conceptual difficulties, misconceptions and mistaken reasoning found or mentioned in each study.

Theoretical framework

The theoretical framework of this research is anchored in Ausubel's (1978; 2000) theory of meaningful learning and in Halloun's schematic modeling approach (Halloun, 1996). From Ausubel we took into account the role of previous knowledge, progressive differentiation, integrative reconciliation, and conditions for the occurrence of meaningful learning. Ausubel's theory is a constructivist cognitive theory directed to learning the way it happens in the classroom, everyday in most schools. To Ausubel (1978, p.iv), "The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly". New concepts may be learned and retained as relevant and inclusive concepts are adequately clear and available in the cognitive structure of the individual serving as anchorage to new ideas and concepts. Progressive differentiation and integrative reconciliation are two programmatic principles that refer to classroom dynamics. Progressive differentiation is the principle according to which the most generic and inclusive ideas of the teaching topic should be presented at the beginning of teaching and then they can be progressively differentiated in their details and specificities (Moreira, 2006). To Ausubel (2000), there are two conditions for meaningful learning to happen: i) the material must be potentially meaningful, that is, the content to be studied must be relatable to the students' cognitive structure in a non-arbitrary and non-verbatim way; ii) the students must have willingness to relate the new potentially meaningful material in a substantive and non-arbitrary way to their cognitive structure.

Studies	Conceptual difficulty	Alternative conception	Reasoning	
			Local	Sequential
Andrés (1990)	2.1	-	-	-
Axt y Alves (1994)	1.1	-	-	-
Barbosa, Paulo y Rinaldi (1999)	1.1	a)	-	X
Carter, Westbrook y Thompkins (1999)	1.1	a)	-	-
Castro (1992)	2.1	-	-	-
Dupin y Johsua (1987;1990)	2.3	b)	-	-
Dupin y Johsua (1989)	1.2	-	-	-
Gravina y Buchweitz (1996)	1.1	a)	-	-
Gutwill, Frederiksen y Ranney (1996)	2.1	-	-	-
Liegeois, Chasseigne, Papin et al.(2003)	2.1	-	-	-
Liegeois y Mullet (2002)	2.1	-	-	-
Metioui, Brassard, Levasseur et al (1996)	-	-	-	X
Miera, Rosado y Oliva (1991)	1.1	a)	-	-
Millar, Beh y Alam (1993)	2.1	-	-	-
Millar y King (1993)	2.1	-	-	-
Moreira y Domínguez (1987)	1.1 e 1.2	a) e f)	-	-
Nieto, Campo y Martinez (1988)	1.1 e 2.1	a)	-	x
Olde y Jong (1990)	1.1	a)	-	-
Paatz, Ryder, Schwedes et al (2004)	1.1	-	-	-
Pardhan y Bano (2001)	1.1	-	-	-
Psillos (1988)	2.1	-	-	-
Saxena (1992)	3.3	j)	x	-
Shipstone, Rhoeneck, Jung et al. (1988)	1.1 e 2.1	a)	x	x
Silveira, Moreira y Axt (1989)	1.1	a)	-	-
Solano, Gil, Pérez et al. (2002)	1.1	f)	-	x
Stocklmayer y Treagust (1996)	1.1 e 2.1	-	-	-
Talim y Oliveira (2001)	1.1	-	-	-
Tsai (2003)	1.1	a)	-	-
Vieira, Quillfeldt, Selistre et al. (1986)	1.1	a)	-	-
Webb (1992)	1.1	-	-	-

Table 2.- Research papers about the teaching of simple electric circuits. The identification for the conceptual difficulties use the convention presented in table 1.

From Halloun (1996), we considered his proposal of schematic modeling that may be applied to the solution of paradigmatic problems, defined as those that possess special characteristics and whose solution cannot be obtained through direct formula application and substitution of numerical values, including open-ended questions. The solution of such problems requires students to think about their own conceptions about the physics system, thus favoring meaningful learning. Halloun's schematic modeling processes in five non-hierarchical stages: selection, construction, validation,

analysis and expansion. In the solution of a paradigmatic problem, the first stage of the process consists of the selection of a scientific model from a repertoire of familiar models of a specific theory. The selection is guided by the domain of the model, the objective of modeling (i.e., of the problem) and the validity of expected results (including approximations and precision of results). Then, the solution of the problem is formulated by constructing a mathematical model that takes into account relevant parameters, initial conditions, constraint conditions; finally, a model that can be continuously processed, analyzed and validated to evaluate if it leads to an acceptable solution to the problem at study. These intermediate stages of construction, validation and analysis juxtapose, and some of these steps occur concomitantly. The expansion of the model includes a description or prediction of new situations referring to the same system focused on, or implications to other reference systems, as well as extrapolations for the design of new models.

Methodology

Object of study and research hypothesis

This study investigated the learning of students who worked with computational simulation and modeling presented as a problem situation proposed through the software *Modellus*, in the teaching of simple electric circuits. A problem situation consists of a particular situation in physics upon which questions are made with the purpose of stimulating students to think and interact consciously with computational resources and not merely by trial and error.

As a research hypothesis we assumed that the use of computational modeling and simulation activities as complements to the classroom and physics laboratory activities can favor the students' predisposition for learning, by relating the new information in a substantive and non-arbitrary way to his/her cognitive structure, thus, creating conditions for meaningful learning of physics concepts involved in simple circuits. This could generate better performance from the students in the posttest on the studied topic as well as promoting better conditions for the students to attain specific objectives (Table 3).

Design

This study was carried out when simple electric circuits concepts were taught in the course of Physics II-C (Electromagnetism for Engineering students of the Federal University of Rio Grande do Sul - UFRGS, Brazil). 193 Engineering students who attended the course in the second semester of 2004 participated in the study. The experimental and control group were randomly chosen. A class with 28 students formed the experimental group, and 165 students, from five sections of the course in which the research was carried out, formed the control group. The students of the experimental group worked with computational simulation and modeling during the teaching of simple electric circuits, whereas the control group was exposed only to traditional teaching. Qualitative and quantitative evaluations were applied to the students' learning outcomes. As qualitative evaluation we considered the students' opinions about the treatment and answers to the

discursive questions presented in printed guides during the classes. Quantitative evaluation was developed according to quasi-experimental design (Campbell y Stanley, 1963) in which there is a non-equivalent control group and an experimental group.

Procedures

Based on the learning difficulties presented in table 1 and in mistaken reasoning students usually present, we established general and specific objectives to be attained by students after the teaching of simple electric circuits (table 3).

	Given a	The student should...
General objectives	simple electric circuit	... grasp: 1. that it is necessary to deal with the electric circuit as a system; 2. the conservation of electric current in the electric circuit; 3. the relation between total electric current and the resistances associated in the circuit; 4. the behavior of equivalent resistance to different associations; 5. electric current as a consequence of potential difference and electric resistance;
Specific objectives	resistors' association in series	... grasp that: a) the electric current that runs through the resistors is the same; b) the sum of the potential difference between the terminals of resistors is the same as the potential difference applied by the source; c) equivalent resistance increases (diminishes) when a resistor is inserted (taken out) in a series association;
	resistors' association in parallel	... grasp that: d) the potential difference between the ends of resistors is the same; e) current divisions at a junction of the circuit (current divisor) depend on what already exists in the rest of the circuit; f) the equivalent resistance decreases (increases) when a resistor is inserted (taken out) in a parallel association;
	light bulb circuits	... be able to: g) identify that a light bulb is a resistor and, therefore, the observed behavior in relation to resistors is also manifested in light bulbs; h) associate the brightness of a light bulb to electric current;
	ideal tension source	i) ... grasp that an ideal battery is not a source of constant electric current, but a source of constant potential difference.

Table 3.- General and specific objectives to be attained by the students when working with computational simulation and modeling about simple electric circuits.

To help students achieve the objectives presented in table 3, we designed a series of simulation and modeling computational activities (Dorneles, Ives y Veit, 2005) as an instructional resource. For each activity we developed

material containing: objectives to be attained by the students, a general description of the model, and a printed guide with discursive questions to be answered by the students in class.

The treatment adopted in this study comprised the implementation of designed computational activities, using the collaborative methods, in which the teacher presents the most general ideas of the subject matter in an introductory explanation, typically of 30 to 40 minutes, out of a 1h40min total period, to be progressively differentiated in terms of details and specificities. After the introductory lecture, the students, in small groups of 2 to 3 partners engage in computational activities. For each group there is one PC and the accomplished tasks are handed in by the end of each class for formative evaluation purposes. With the requirement of handing in just one copy per group, we expect to promote the negotiation of meanings among the students, who are committed to finding a solution that complies with the ideas of all members of the group. The small and large group discussions favor students' interaction among themselves and with the teacher, who acts as mediator in the interaction between computer and learner and in the internalization of meanings by the learner (Vygotsky, 2003). Reflection, interaction, and engagement are encouraged with the use of a method we can call PIE – Predict, Interact, Explain – adapted from the POE method – Predict, Observe, Explain – proposed by White and Gunstone (*apud* Tao y Gustone, 1999), which consists of describing problem-situations in physics, or of presenting them through visual demonstrations, video projections or, as discussed here, computational simulations so as to help students *predict* what might happen. Then, opportunity is given to them to *interact* with the computational resource in order to generate results and evaluate what can effectively happen and, finally, to *explain* the differences and similarities between their ideas and the scientific solutions already accepted for the problem-situation at issue.

Treatment

The treatment was applied to a total of five classes of 1h40min each in the computer laboratory, where the students from the experimental group worked in pairs with computational simulation and modeling. At the beginning of each class the students received printed guides with discursive questions to be answered in groups with the PIE method. At the end of the class, each group handed in a single copy of the guide containing consensual group answers for evaluation purposes. From the second class on, we began each class with a coordinated discussion (~ 15 minutes) with all the students about the activities performed in the previous class.

Evaluation tools for students' learning

In the present study we have chosen to apply the test on simple electric circuits as proposed by Silveira, Moreira y Axt (1989), transcribed in Appendix A, because it is well accepted among teachers who have already taught the subject matter that is the focus of this study. Then, it had provided us a large control group. Furthermore, the reliability coefficient of the instrument (Cronbach's alfa) was calculated for a target population seemingly similar to ours (Silveira, Moreira y Axt, *op. cit.*). Since the

reliability coefficient is not a property exclusively associated to the instrument, but a property of it pertaining to a certain group, we recalculated the reliability coefficient of the test, that will be presented in the next section.

We applied this instrument as a pre-test both in the control and the experimental groups in the first day of classes to verify learning difficulties measured by this test as well as to use them as a covariable for the analysis of the results of the post-test. That test was applied to both groups at the end of classes about electric circuits to verify possible effects of the treatment. It took students approximately 30 minutes to answer the tests, and the application interval between the pre-test and the post-test was of seven weeks.

Results and discussion

Reliability analysis of pre and post-tests

We calculated the reliability coefficient of the test proposed by Silveira, Moreira y Axt (op. cit.) before (pre-test) and after (post-test) the teaching of simple electric circuits based on the answers of students who attended the course Physics II-C, in the semester in which we carried out the present study, but who did not participate in the experimental or control group. The internal consistence analysis (ICA) was carried out according to Cronbach (1967, apud Moreira y Silveira, 1993). The ICA included the calculus of the Cronbach's alpha coefficient, whose result is presented in table 4, together with the correlation coefficient of the score of each item with the total score. In both cases the coefficients were higher than 0.7, showing the capacity of the test to discriminate students with scientific conceptions from those with misconceptions about simple electric circuits.

Test	N	Total score average	Standard deviation of the total score	Items	Cronbach alfa coefficient
Pre-test	66	7.70	2.82	13	0.75
Pos-test	53	8.36	3.25	13	0.85

Table 4.- ICA synthesis for the test on simple electric circuits applied to engineering students before and after instruction.

Comparison between the experimental and control group

The percentages of correctness of each item of the pre-test and of the post-test of the experimental and control group are presented in table 5. The data referring to item 8 of the test were not part of our analysis, for it involves a RC circuit, and when we applied the post-test the students had only studied the simple circuits. We can observe that for both groups the percentage of correctness of each item in the post-test is higher than the one presented in the pre-test.

Objectives*	Item	Experimental group (28 students)		Control group (165 students)	
		Correct items (Pre-test)	Correct items (Pos-test)	Correct items (Pre-test)	Correct items (Pos-test)
a)	1	82	100	89	90
a)	2	14	86	53	59
e)	3	39	64	56	67
c), e)	4	18	43	38	41
-	5	18	79	55	64
e)	6	29	86	47	54
a)	7	21	25	29	28
a)	9	71	100	88	90
e)	10	71	79	89	90
f)	11	11	57	15	18
f)	12	0	57	16	21
a), e)	13	61	75	79	84
a), c), e)	14	36	68	39	42

Table 5.- Students' performance from the experimental and control group on the pre and post-tests. In the first column, we indicate the specific objectives measured for each item of the test. *The objectives g) and h) pervade all the test's items.

In table 6 we observe the total score averages of the experimental and control groups in the pre-test and in the post-test. In the pre-test, the control group average (6.94) was higher than the average of the experimental group (4.71); the statistical level of significance of the difference between the averages was less than 0.01. We also did a Variance and Covariance Analysis – ANOVA/ANCOVA (Finn, 1997). Table 7 shows the adjusted average in the post-test to both groups, and also the ratio F of Snedecor (through which the level of statistical significance is obtained) for the difference between the two averages and the level of statistical significance of this difference.

Group	Pre-test			Pos-test		
	Total score average	Standard deviation	Correct answers	Total score average	Standard deviation	Correct answers
Experimental	4.7	2.5	36%	9.2	2.4	71%
Control	6.9	2.7	53%	7.5	2.7	58%

Table 6.- Comparison between experimental and control groups in the averages of the pre-test and post-test. Maximum score = 13.

Group	Adjusted average in the post-test	F	Level of statistical significance
Experimental	10.2	38.7	0.000
Control	7.3		

Table 7.- Comparison between the experimental group and control group of the adjusted averages of the post-test.

Based on the comparison between the average performance of the experimental and the control group in the adjusted averages of the post-

test (Table 7), we used the null hypothesis, concluding that the average performance of the students who worked with computational simulation and modeling was higher than that of the other students, with a level of statistical significance lower than 0.01.

To compare the performance of the two groups in terms of the objectives measured through the test, we compared the gain of the experimental and control groups in the average scores of the questions associated to each specific objective (column 1 table 5), the level of statistical significance being obtained with the U-Test of Mann-Whitney (a non-parametric test equivalent of the t-test to the average difference). The results are shown in table 8, in which we can observe that for every objective analyzed the performance of the students from the experimental group was higher than the one of the control group, with a level of statistical significance lower than 0.01.

Group		Gain a)	Gain c)	Gain e)	Gain f)
Experimental	Average	1.68	0.57	1.61	1.04
	Average standard error	0.27	0.18	0.32	0.18
Control	Average	0.15	0.05	0.29	0.08
	Average standard error	0.10	0.06	0.10	0.07
Level of statistical significance		0.000	0.002	0.000	0.000

Table 8.- Comparison between the experimental and the control groups in terms of each specific objective (column 1 table 5). The level of statistical significance was obtained through the U-test of Mann-Whitney.

To illustrate the simulations developed with the students, in table 9 and in figures 1 to 3 we present in detail the computational activity that helped students attain objectives a), c) and e). In this activity, the students initially answered questions 1 and 2 from table 9 to make predictions about the behavior of the equivalent resistance and of the electric current shown in figure 1. Then, they interacted with animation 2 (Figure 2) to generate results, and afterwards they evaluated the divergences and convergences of their predictions (question 3 from table 9). Finally, they answered four conceptual questions about the potential difference along the circuit shown in figure 3 (questions 4 to 7 from table 9).

Qualitative analysis of the answers of the students of the experimental group to questions 1 to 3 of table 9 agrees with the quantitative results related to objectives a), c) and e) (Table 3). Following, we present some examples of the students' answers.

Answers to question 1, related to objectives c) and e):

The equivalent resistance decreases because the current does not pass through R1 anymore, for the segment of the wire that passes through A has negligible electric resistance, which turns it preferable. We noticed that because of the increase of the total electric current when we closed switch A-B (Group 2).

As we close switch A-B, the electric current does not pass through R1 anymore and the resistance in the whole circuit decreases. The electric current tends to follow what makes less electric resistance easier (Group 6).

The equivalent resistance of the circuit goes down with the switch in position A, the electric current passes all through the new path, increasing the amperage (current) in the circuit (Group 15).

General description
Running the model and changing the position of the switch shown in figure 1, an ammeter registers an electric current variation at a specific point of the circuit, through which the total current of the circuit (I_t) runs. With the help of the ammeter (Figure 2), it is possible to observe the behavior of the electric current along the circuit and with the voltmeter (Figure 3), it is possible to observe the potential difference between many pairs along the circuit.
Objectives of the activity
<p>1) given a potential difference between two points of a simple circuit, the student should: a) be able to understand the electric current as a consequence of the potential difference and the electric resistance; b) relate the increase of electric current in the circuit to the decrease of the equivalent resistance;</p> <p>2) given a junction of the circuit (current divisor), the student should notice that the division of currents depends on what is connected in the circuit;</p> <p>3) given an association of resistors in series, the student should realize that: a) the current that runs between them is the same; b) the equivalent resistance increases when a resistor is associated in series; c) the sum of the potential difference between the ends of resistors is the same as the potential difference applied between the ends of the source; d) the potential difference applied between the ends of the source is an intrinsic characteristic of the source; e) it is necessary to deal with the circuit as a system.</p>
Questions proposed to the students
<p>1) Run the model and answer the following question: closing the switch A-B, what happens to the equivalent resistance shown in Animation 3? Why?</p> <p>2) The intensity of the electric current in point E, in relation to the intensity measured in the ammeter is: a) lower; b) equal; c) higher</p> <p>3) Open Animation 2. Verify prior answers. What can be said about the behavior of the electric current in the circuit?</p> <p>4) Open Animation 1. On the right side of the animation window there are voltmeters to measure the potential difference between different pairs of points of the circuit. Modify the value of the electric resistance of the resistors. When switch A-B is in position B and the resistors R2 and R3 in the maximum value, what is the potential difference between points b-d?</p> <p>5) When switch A-B is in position A and the resistors R2 and R3 are at their lowest values, what is the potential difference between points a-d?</p> <p>6) When switch A-B is in position B, click with the left button of the mouse over the analogic meter of R4 and inform the value 1000 (value in ohms). To which values tend the electric current and the potential difference between points d-e? Why?</p> <p>7) Is it possible to modify the potential difference (V) between the ends of the source at any position of switch A-B? Why?</p>

Table 9.- Detail of a computational activity that helped students attain specific objectives a), c) and e) presented in table 3.

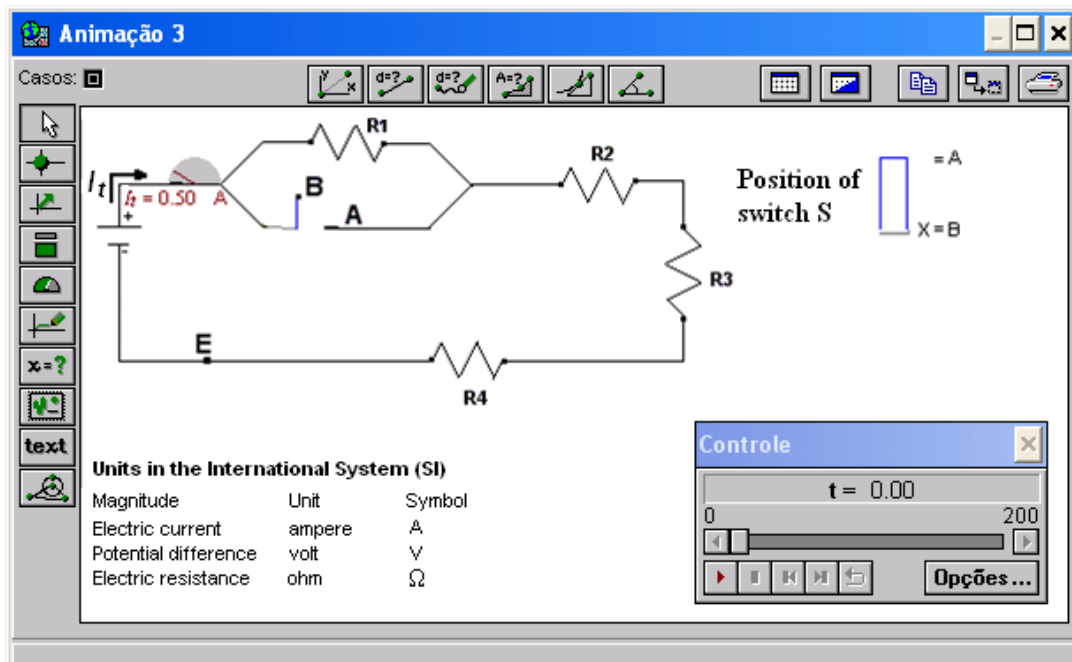


Figure 1. – Screenshot: Animation 3 of the computational simulation presented in table 9.

Answers to question 2, related to objective a):

In an association in series, the intensity of the electric current is the same at all points (Group 11).

The electric current does not vary, it remains the same along the circuit (Group 13).

The electric current remains the same in an association in series (Group 15).

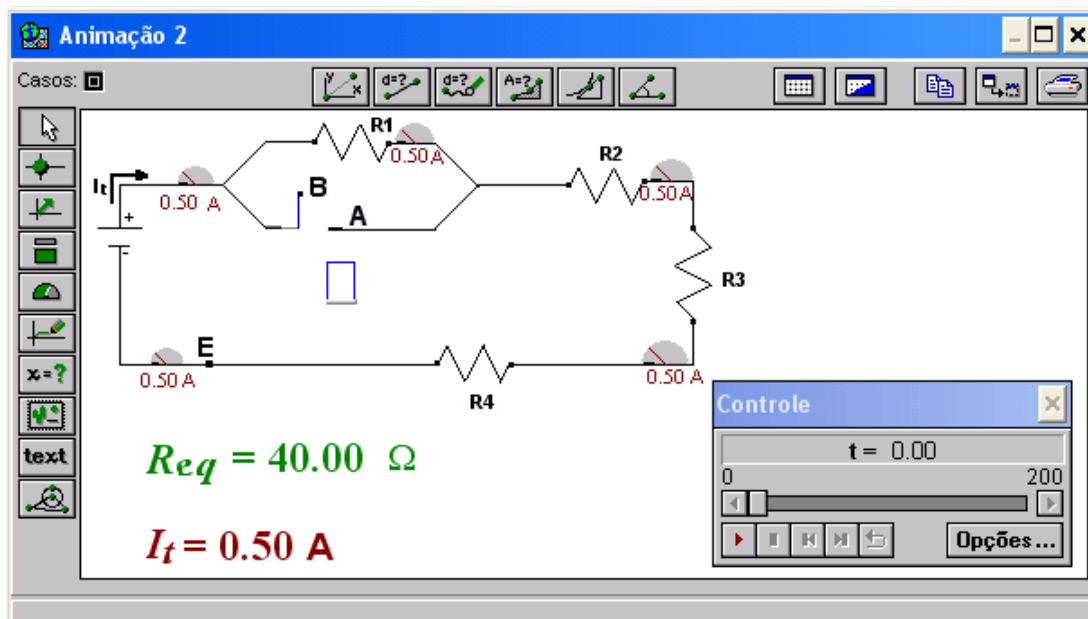


Figure 2.– Screenshot: Animation 2 of the computational simulation presented in table 9.

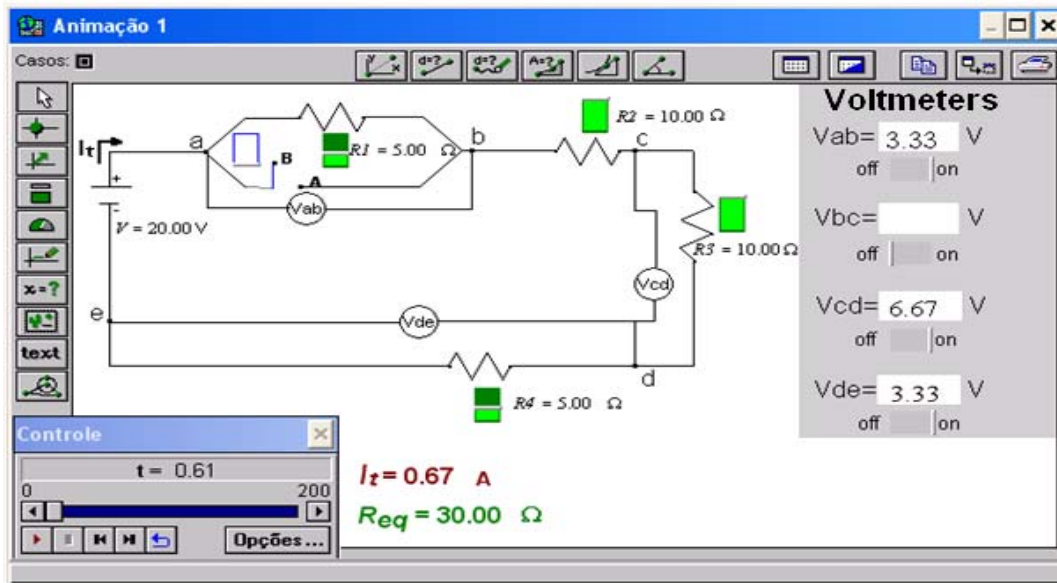


Figure 3.– Screenshot: Animation 1 of the computational simulation presented in table 9.

These results suggest strong indications that the computational simulation presented in table 9 has helped students overcome a misconception according to which the electric current is consumed when passing through an electric resistance. Other important result is that by varying a parameter in a circuit students could instantaneously observe alterations along the circuit, which motivated them to develop systemic reasoning, that is, to deal with an electric circuit as a system. For example, many students while analyzing the current division at a point of junction of the circuit did not apply local reasoning, that is, they did not focus their attention on just one point of the circuit; quite the contrary, they considered the divisions of electric current at a point of junction of the circuit to depend on what already existed in the whole of the circuit.

Since none of the test items adequately measures objective b), we qualitatively analyzed question 6 from table 9. The results suggest that a few students have reached such objective, since only three groups, from a total of 15, have presented clear argumentation based on the concept of potential difference, which will be transcribed next.

The electric current tends to zero because resistance R4 is too high, the higher the resistance, the lower the electric current. The potential difference between d-e tends to the maximum value 20V (Group 10).

It is that the total electric current tends to zero (0.002A) and V tends to the maximum (20.0V), because resistance increases, decreasing the electric current" (Group 9).

The electric current tends to zero because the higher the resistance the lower the electric current. And the potential difference tends to 20V, which is the maximum value, because, as resistance is increased, the potential difference between the two points also increases (Group 11).

This result may not necessarily mean that computational simulation did not contribute to a better understanding of the students about potential differences in an association of resistors in series, but that the question proposed might not be appropriate for this evaluation. The instructional material could be more efficient in relation to this objective if it included questions that would necessarily require students to apply the concept of potential difference.

As for the objective d), we have qualitatively analyzed the students' answers to question 1) of the computational simulation described in table 10 whose main screen is presented in figure 4. We have found strong indications that the majority of students reached such objective. In their own words:

The currents I_1 and I_2 remain constant since the resistors are in parallel and the total current changes. When the value of R_3 is greater, I_t it decreases and when R_3 is lower, I_t it increases (Group 10).

I_1 and I_2 remain constant because R_1 and R_2 and the tension are constant, and the current depends on these parameters. I_t diminishes with the increase of R_3 , for this increases the total resistance of the circuit (Group 2).

Circuit in parallel ($V=cte$) altering the value of R_3 (decreasing) more current passes through it, I is proportional to $1/R$ (Group 3).

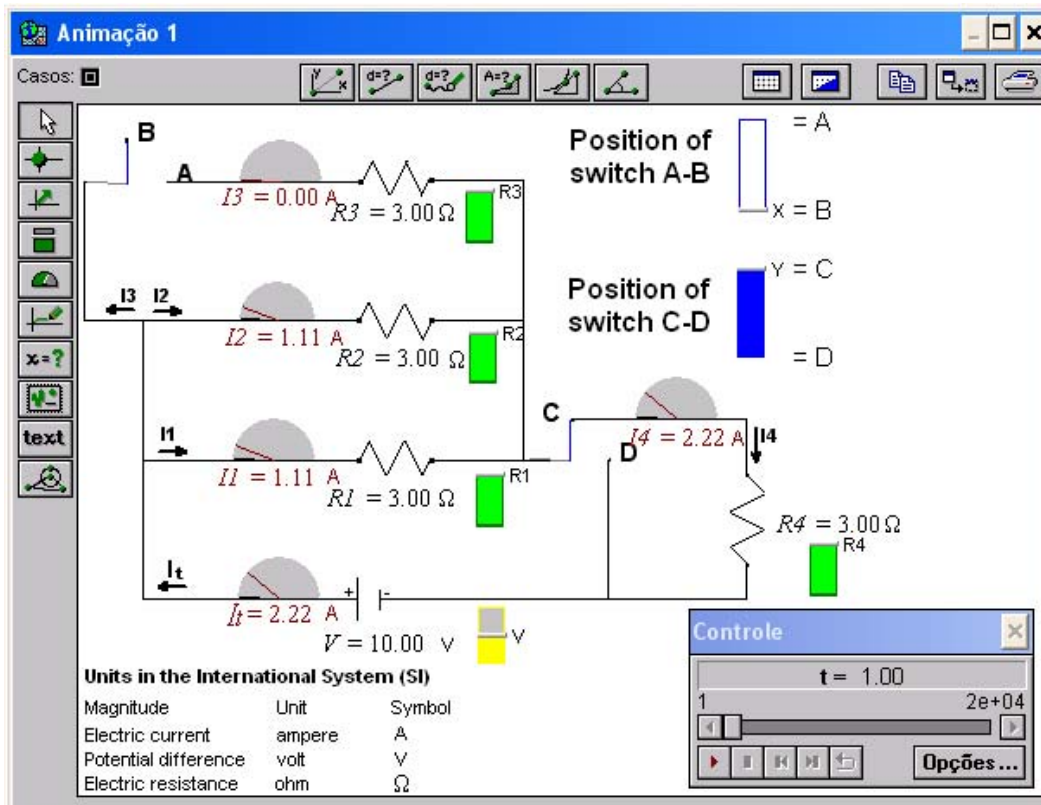


Figure 4.– Screenshot: Animation 1 of the computational simulation described in table 10.

General description
By running the model, it becomes possible to obtain two or three resistors associated in parallel, by varying the position of the switches. There is still the possibility of associating them in series with a fourth resistor. The ammeter registers the electric current that passes through each resistor at any position of the switches. We can modify the value of the electric resistance in the resistors and the potential difference between the ends of the source, as shown in figure 4.
Objectives of the activity
Given a circuit with resistors of mixed association, the student should be able to: a) deal with the circuit as a system; b) notice the behavior of the equivalent resistance; c) identify the behavior of potential difference on the ends of the resistors; d) identify what is the intensity of electric current that passes through each resistor.
Questions proposed to the students
1) With the switches at positions A and D, modify the value of R3. Explain the behavior of the values of i_1 , i_2 and i_t . 2) With the switches at positions A and C, modify again R3. Explain why, in this case, all the currents vary.

Table 10.- Details of a computational activity which helped the students attain the specific objectives d) and l) presented in table 3.

Another important aspect is that interacting with the computational simulation described in table 10, many groups (13) did not apply sequential reasoning and did not analyze the electric circuit in terms of "before" and "after" the passage of electric current; quite the contrary, they dealt with the circuit as a system and were able to recognize that an alteration in one parameter of the circuit causes instant alterations along the circuit. Following we present how the students from group 14 answered question b).

Once R1, R2 and R3 are associated in parallel, the potential difference must be the same in each one. Diminishing R3, I3 increases and consequently I4 becomes higher. For that, potential difference in R4 will have to be higher, because R4 remains equal. That's why the potential difference of the resistances in parallel will change (will be lower) what makes I1 and I2 also change (Group 14).

As for objective i), just three groups, when working with the computational activities proposed in this study, presented the misconception that an ideal battery is a source of constant electric current; the others, 12 groups, seemed to have reached the objective, that is, considered that the intensity of an electric current of a circuit does not depend only on the characteristics of the source but also on the equivalent resistance of what has been coupled between its ends, and that an ideal battery is a source of constant potential difference. Following, we show two examples of each case:

First case:

The total electric current in an association in parallel is equal to the sum of the currents in all the resistors. If you take out one resistor from the association, the remaining ones will have a greater current (Group 11).

In a circuit associated in parallel, the partial currents added result in the total current. Since we have eliminated one resistor, the current that passed through it will be added to the other resistors" (Group 2).

Second case:

Since the resistors R1, R2 and R3 are associated in parallel, the currents I1 and I2 do not depend on the electric resistance of R3, that's why they remain constant as R3 is modified. The total electric current increases with the decrease of R3, because by decreasing R3, Req diminishes, while increasing the intensity of the total electric current. The potential difference between the resistors is constant for it depends only on source characteristics (Group 11).

In this case (the three resistors are associated in parallel) the currents I1 and I2 remain constant when the electric resistance of R3 is altered and the potential difference remains the same in all resistors(Group 13).

In synthesis, we have strong indications that the computational activities developed in this research helped the experimental group students attain the objectives related to the concepts of electric current and electric resistance. However, it did not show efficiency in helping them to reach the proposed objectives for potential difference. Many students, even after the treatment, showed difficulties in understanding the decrease on potential difference across an association in series.

In the next topic, we present some of the students' opinions about the treatment used in this study.

Raising opinions

We have also tried to evaluate our research hypothesis by analyzing the students' opinions about the treatment. The raising of students' opinions was encouraged by electronic mail during the second semester of 2005, when the students had already received the final grade for the course. Based on the analysis of the students' statements we believe that the use of computational activities may offer students opportunities for a better conceptual understanding. On their own words they stated:

The use of computers facilitated understanding of the studied physics phenomena. Simple use of the blackboard to explain the subject rarely brings about clarity to physics concepts and with the simulations we were able to observe everything that could possibly happen (Student 5).

It was easier to learn by visualizing what happened each time we changed something in the circuit (Student 1).

I remember that after the simulations on the screen, the laws became clearer, it was cool to see the resistors influencing the circuit! (Student 2).

It was quite nice to study in the computers, it made the content clearer (Student 9).

Moreover, we believe that treatment is a motivational factor for improving the students' learning. On their own words:

The simulations give us a concrete view of what we learn theoretically in class. The visualization of the circuits makes learning much easier, stimulating and interesting (Student 3).

The development of assignments during the classes contributed a lot to learning because by interacting with the simulations we had a very good view of the physics concepts and moreover, with pair work, we had the chance of discussing the observations right there and clearing out doubts (Student 5).

I point out the disposition in the assistance of the student, always searching for ways to present the best way of learning, besides the change from the classical and formal environment of a conventional classroom to a room with computers and audiovisual resources (Student 7).

The computational activities proposed brought about many doubts, sometimes the simulation itself answered the doubt, or we would ask the teacher (Student 4).

These results seem to show that the computational activities developed in this study can offer better conditions for meaningful learning of electric circuits.

Conclusions

Nowadays, studies that identify learners' difficulties with some contents of physics have not been restricted just to the detection of difficulties, but they also present alternatives to help students overcome them. We worked with simple electric circuits, because many research results (e.g. McDermott y Shaffer, 1992; Duit y Rhöeneck, 1998 and Engelhardt y Beichner, 2004) show that many students even after being taught this topic, continue with some misconceptions and mistaken reasoning. In order to help students overcome such difficulties, McDermott et al. proposed some experimental activities. In this study, we present as an alternative to overcome these difficulties the use of computers. So, we developed computational simulation and modeling activities that were designed taking into account difficulties commonly experienced by students in the learning of electric circuits to be worked in class with the PIE (predict, Interact, Explain) and the use of collaborative methods.

The quantitative results of this study showed that there was a statistically significant difference in the performance of students from the experimental group, in comparison with that of the control groups, leading us to believe that computational simulation and modeling activities can help students overcome their learning difficulties usually faced when they study simple electric circuits. The results of our qualitative analysis show that the conceptual questions presented in the guides which require constant students' interactions with the computational models, might have promoted the students' predisposition to learn by relating in a substantive manner to their cognitive structure the physics concepts involved, thus, allowing for a better conceptual understanding. The willingness to learn is one of the conditions for meaningful learning. The other is that the material must be potentially meaningful. We believe to have attained both of these conditions

in this study, which agrees with Araujo, Veit y Moreira (2008), Ronen y Eliahu (2000) and Finkelstein, Adams, Keller et al. (2005) whose findings, suggested that the use of computational activities can improve conceptual understanding while being itself a motivational element for learning.

We conclude pointing out that by using computational activities in the teaching of electric circuits we are not proposing them as a replacement for laboratory classes, but we believe we are increasing the range of possibilities for helping students overcome their learning difficulties.

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Apendix

We here transcribe the test proposed by Silveira, Moreira y Axt (1989).

IMPORTANT: DO NOT MAKE MARKS ON THE QUESTION SHEET. ANSWER ONLY ON THE ATTACHED ANSWER SHEET.

In all questions of this test it is assumed that the light bulbs are alike. The brightness of the light bulbs increase when the intensity of the electric current increases. The battery presented has negligible electric resistance.

1) As for the circuit of figure 1, one can state that:

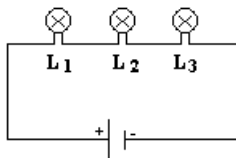


Figure 1

- a) L1 is brighter more than L2 and this one is brighter than L3.
- b) L3 is brighter than L2 and this one is brighter than L1.
- c) The three have the same brightness.

2) In the circuit of Figure 2, R is a resistor. In this circuit:

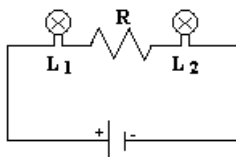


Figure 2

- a) L1 and L2 have equal brightness.
- b) L1 is brighter than L2.
- c) L2 is brighter than L1.

3) In the circuit of figure 3, R is a resistor. In this circuit:

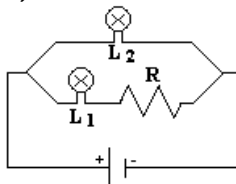


Figure 3

- a) L1 has the equal brightness as L2.
- b) L2 is brighter than L1.
- c) L1 is brighter than L2.

4) In circuit of figure 4, S is an open switch. Closing it:

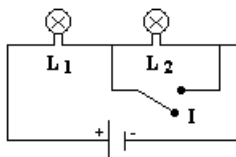


Figure 4

- a) The brightness of L1 increases.
- b) The brightness of L1 remains the same.
- c) The brightness diminishes.

5) In circuits of figures 5 and 6, the light bulb L, the resistor R and the battery are exactly the same. In these situations:

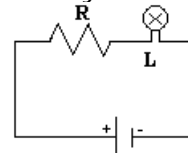


Figure 5

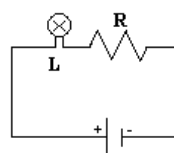


Figure 6

- a) L is brighter in the circuit of Figure 5.
- b) L has equal brightness in both circuits.
- c) L is brighter in circuit of Figure 6.

6) In the circuit of figure 7, R is a resistor and S is an open switch. Closing the switch:

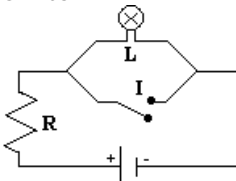


Figure 7

- a) L is brighter in the circuit of Figure 5.
- b) L has equal brightness in both circuits.
- c) L is brighter in circuit of Figure 6.

7) In the circuit of figure 8, R_1 and R_2 are two resistors. The black box can have resistors, batteries or a combination of both. In order for the current in R_1 to be the same as the intensity of the current in R_2 , the black box:

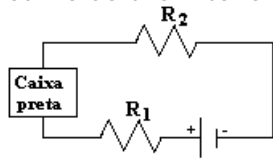


Figure 8

- a) Should have only resistors.
- b) Should have at least one battery.
- c) Could have any association of resistors and batteries.

8) In the circuit of figure 9, L is a light bulb, R is a resistor, C a discharged capacitor and S an open switch. Closing the switch:

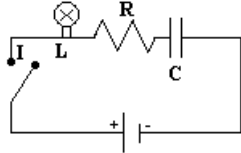


Figure 9

- a) L starts to shine and keeps shining while the switch is closed.
- b) L will not shine while the capacitor is not charged.
- c) L may shine during part of the charging process of the capacitor.

Questions 9 and 10 refer to the circuit of figure 10.

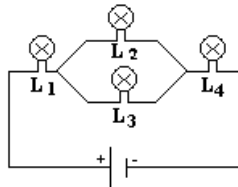


Figure 10

9) In the circuit of Figure 10, the brightness of L_1 is:

- a) The same as the one of L_4 .
- b) Higher than the one of L_4 .
- c) Lower than the one of L_4 .

10) In the circuit of Figure 10, the brightness of L_2 is:

- a) The same as the one of L_4 .
- b) Higher than the one of L_4 .
- c) Lower than the one of L_4 .

The circuit of figure 10 has been modified, for the light bulb L_3 was taken out. The new circuit is, therefore, the one shown in figure 11.

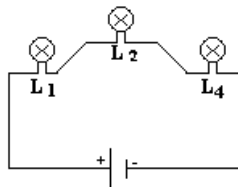


Figure 11

11) When we compare the brightness of L_1 in the circuits of Figures 10 and 11, it is:

- a) Higher in circuit of Figure 11.
- b) Lower in the circuit of Figure 11.
- c) The same in both.

12) When we compare the brightness of L_4 in the circuits of Figures 10 and 11 it is:

- a) Higher in Figure 11.
- b) Higher in Figure 10.
- c) The same in both.

13) In the circuit of figure 12:

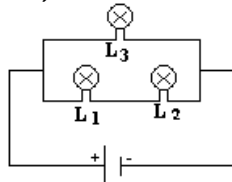


Figure 12

- a) L_1 brights more than L_2 and than L_3 .
- b) L_1 and L_2 have the same brightness which is smaller than the one of L_3 .
- c) L_1 , L_2 and L_3 bright equally

14) In the circuit of figure 13, when the switch is open, the light bulbs L_3 and L_4 stop shining, although L_2 brights. What happens to light bulbs L_1 and L_5 ?

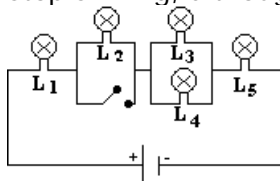


Figure 13

- d) Neither L_1 , nor L_5 bright.
- e) L_1 brights and L_5 does not bright.
- f) L_1 and L_5 brig.