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# Analysis of an Inquiry-based Electricity Laboratory for Undergraduate Students

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## Abstract

It is well known in Physics Education literature that, even after attending to Introductory Physics courses (lectures and laboratory), students still have some difficulties with direct current electric circuits' concepts. Since 2006, we are investigating the conceptual understanding of electric circuits in Brazilian college students. We observed that only ~13% of students answered correctly a question about the brightness of bulbs in simple circuits (series and parallel). This observation motivated us to adopt new laboratory guide with active learning strategies. The activities were adapted from Tutorials in Introductory Physics. We have been observing a significant gain of students learning using the mentioned question as pre and post-tests. More recently (since 2013) we have been applying the DIRECT which consists of 28 multiple choice questions on electric circuits. This test helps to identify specific difficulties which remain after instruction. In 2016, some groups of students were recorded in audio and video in order to investigate their interaction and learning process during the class. The student's majority evaluated positively the active learning strategies used in the course, mentioning that they contribute to their learning (~78%).

**Keywords**: Electric circuits, Inquiry, Laboratory, Undergraduate.

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## Introduction

In the last few decades, physics educators begun to look closely at what students understand about direct current (**DC**) electric circuits. They found out students still hold some specific difficulties, even after attending lectures and laboratory Introductory Physics courses (McDermott & Shaffer, 1992; Planinic, 2006). Other researches try to understand those difficulties in order to improve instruction (Duit & von Rhöneck, 1997; Engelhardt & Beichner, 2004; Blanton, 2007; Marusic & Slisko, 2012). It is a consensus that most students begin their studies with conceptions about the nature of circuits and circuits' quantities, like current and potential difference, that should be taken into account in order to improve their learning.

In 2006, we started to study the students' learning of DC circuits in Brazilian universities. We applied a qualitative question about circuits composed by a single battery and some light bulbs, adapted from McDermott's (1991), as shown in **Figure 1**. The question was given to students after instruction (lectures and traditional labs), with a total of 286 students, in 4 different states in Brazil (Costa & Catunda, 2008). About ~13% of these students were able to answer and justify the question correctly, in agreement to the result obtained for calculus-based course at the University of Washington.

A light bulb is a resistance. If it is ideal, the internal resistance is almost constant and it attends the Ohm's Law. Supose that 4 identical light bulbs (A, B, C and D) and an ideal battery ($V_0$) compose the circuits in the cases bellow (I, II, III). For each case [(I), (II) e (III)], order the light bulbs according to their brightness. Briefly explain your reasoning.
**Obs**: compare A, B, C and D in (I); A, B, C and D in (II) and A, C and D in (III)

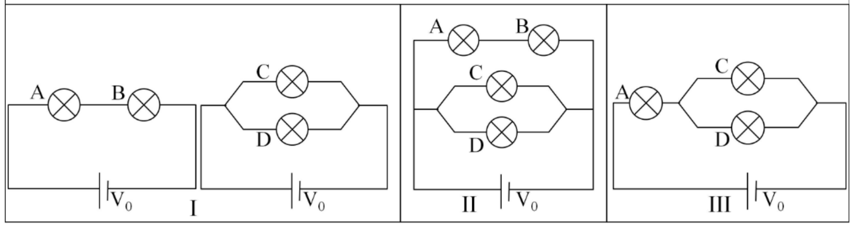


**Figure 1.** Qualitative question on DC circuits (Mc Dermott & Shaffer, 1992)

These findings motivated us to restructure the laboratory guide, to make students active in teaching and learning process and make them think about their actions. The laboratory activities should involve students' active participation (Bradley, 2001). However, many times students do not discuss scientific facts related to their investigation (Roth, 1994). In the traditional laboratory, students follow their tasks without being encouraged to reason about observations. Therefore, they aim only to complete their task and the purpose of the investigation is not understood in depth (Hofstein & Lunetta, 2004).


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Basically, we translated and adapted the experimental activities from the Tutorials in Introductory Physics (Mc Dermott & Shaffer, 2002) to a laboratory course. The Tutorials were developed to supplement theoretical courses, supporting students to conceptual understanding through experiments. Students are guided by questions with emphasis in discovery rather than memorization. They have to make individual predictions about phenomena and discuss with peers. Then, they must do the experiment and check predictions. After that, they have to explain if their predictions were right and explain reasoning. In the end, they synthesize the best answer based on the best arguments and inferences. These tasks allow students to interact with a situation in which they have to reason before observing.

In order to investigate students' learning, we have been applying the McDermott's question as pre and post-test since 2009. The "Determining and Interpreting Resistive Electric Circuit Concepts Test", DIRECT (Engelhardt & Beichner, 2004), which consists of 29 multiple choice questions about DC circuits, was also applied. In this paper, we analyze students' answers to McDermott's adapted question used as pre and post-test in 2009, and from 2013 to 2016. Comparing scores from pre and post-tests, we noticed that students showed significant improvement in their results, rather than in traditional ones. To measure students' learning improvement, we used the gain factor, G (Hake, 1998), that is a common metric used to measure student gains.

## Methodology

This study was conducted with participation of 844 undergraduate students majoring in Chemistry, Computer Sciences, Mechanical, Civil and Environmental Engineering (~180 students per year) attending to the "General Physics Laboratory III – Electricity and Magnetism" course in 5 years between 2009 and 2016. The course is offered by São Carlos Institute of Physics – University of São Paulo (IFSC-USP). Typically, in each year we have about 8 classes with a professor, a teaching assistant (TA) and ~25 students per class. The experiments were performed in groups of three students. The course consists of six 4 hours' laboratory classes, covering the following topics: DC electric circuits (2 classes), capacitors, oscilloscope, magnetism and Faraday's law, RLC circuits. It should be mentioned that students also attend to independent one semester lectures (4 hours per week, total ~50 hours) taught in a traditional fashion, based on the book Physics for Scientists and Engineers, Vol. 2 (Tipler & Mosca, 2009).

The first two classes (total of 8 hours) are related specifically with DC electric circuits and are the ones that we focus in this study. In these topics, students gradually analyze associations of light bulbs in series, parallel and mixed cases, and observe their brightness. They are guided through questions and experiments to develop understanding about concepts like current, voltage, resistance, Ohm's and Kirchhoff's laws, power, real batteries and components (light bulbs, resistors, diodes, LED, LDR, etc.).

A qualitative question (similar to the one used by McDermott) and the DIRECT test were applied as pre and posttests. The pretest was applied in the first class and the post-test was applied ~ 15 weeks later, 11 weeks after the second class on DC circuits. The DIRECT allowed us to measure the gain (G) factor (Hake,1998). Results showed us that students presented a significantly positive G.

## Findings

We observed that our students have difficulties in confronting qualitative experiments with scientific models, since they are used to a very traditional pedagogy in their lectures and previous laboratory courses. Most students learn Physics by memorization, and are not trained to apply the physical concepts to explain simple phenomena.

In general, our observations about student specific difficulties on DC circuits agree with worldwide literature. For instance, McDermott and Shaffer (McDermott & Shaffer, 1992) mentioned: failure to distinguish among concepts of current, potential difference, energy and power; failure to understand and apply the concept of complete circuit; belief that direction of current and order of the elements matter; belief that current is used up in a circuit; belief that the ideal battery is a constant source of current, rather than constant voltage between terminals and failure to distinguish between parallel and series associations. However, some peculiarities are worth discussion.

Most of our students studied DC circuits in pre-university courses know by heart that "in a series circuit the current is always the same". Therefore, when asked to compare the brightness of two bulbs in series (B and C) circuit, they seldom predict that B is dimmer than C because the current is "used up". However, they have a strong misconception that the power supply is a constant current source so they often think that the current of the power supply is the same in both cases (singe and two bulbs in series, as shown in **Figure 2**).

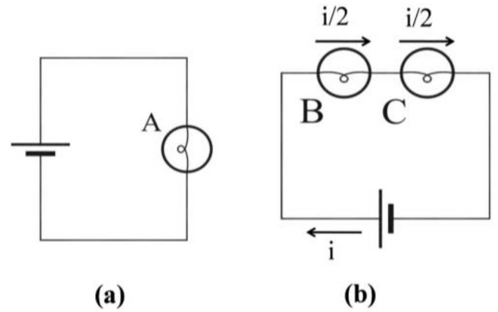


**Figure 2.** (a) A circuit with a battery and a light bulb. (b) A circuit with a battery and two identical light bulbs in series. Part (b) illustrates a common misconception many students use to justify their observation that two bulbs in series are dimmer.

In the experiments, students are asked to observe and compare the brightness of the bulbs A, B and C. When asked why the brightness decreases (B = C < A), they often answer that the power supply current in "divided among the lamps", as one of our students said: "…in both cases (single bulb and series circuit) the current is the same. In the second case, because it has two light bulbs, the current is divided between them, explaining the reason it is dimmer." This reveals a difficult in applying a simple scientific model with 2 main assumptions: "(1) a flow exists in a complete circuit and (2) bulb brightness indicates the amount of flow" (Shaffer & McDermott, 1992).

**Table 1** compares the pre and post results of the qualitative question (Figure 1). These results do indicate some improvement of the conceptual understanding. However, they are still far from very a good one. For instance, in 2009 the value Sf = 46% is an average result of 9 classes with significant discrepancy among them (they vary from 30% to 84%). This discrepancy is also associated with selection criteria to enter in the university. The best performance was observed for the Mechanical Engineering students, where the concurrence to enter in the university is the highest.

**Table 1.** Percentage averages of students' scores, where Si and Sf are the pre and post-test scores, respectively and the gain is given by G = Sf – Si.

| Year | $S_i$ (%) | $S_f$ (%) | G (%) |
|---|---|---|---|
| 2009 | 12 | 46 | 34 |
| 2013 | 3,9 | 34 | 30 |
| 2014 | 9,6 | 39 | 30 |
| 2015 | 14 | 48 | 34 |
| 2016 | 14 | 35 | 21 |

**Figure 3** shows the results obtained in 2013 for pre- and post-test applications of DIRECT (Engelhardt & Beichner, 2004). These 28 questions can be divided in 11 learning objectives that allowed us to identify students' specific difficulties in electric circuits. In most of the questions students have improved their score, from Si = 43% to Sf = 55%. The discrepancy of the performance of different questions is remarkable. In some questions, the gain was not so high because their pre-test score was already high, showing that students had a good conceptual understanding even before attending to classes (questions 5, 7, 10, 18 and 19). In some other questions, students did not improve or got a lower score after instruction (questions 1, 11 and 27). In this short paper, we´ll only comment about question 27, which regards the concept of electric potential in a DC circuit with two resistors in series, a switch and a battery. When the switch is opened, the voltage across the resistors is zero, since there is no current.

We also recorded the laboratory classes in audio and video of 8 groups in 2016. By that, we found out that commonly each student assumes a different role in the group. The one that we identify as a leader, interacts and discusses most of the time, and is usually the one with the high score. The other students discuss the leader's hypothesis and explanations, questioning the validity of them all the time. Students also seemed to get motivated with new discoveries, when they find out why their hypothesis is different than the outcome, they celebrate.

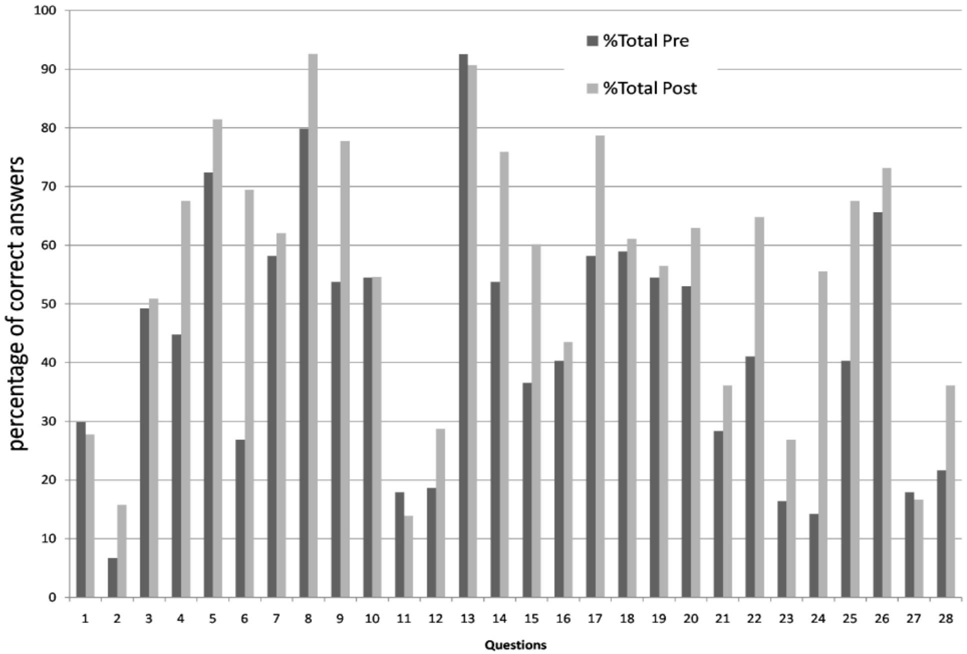


**Figure 3.** Comparison of students' pre- and post-tests scores for each question of DIRECT test.

Finally, we´ll comment the results of a questionnaire about student's impressions of the methodology of the course. Some of the statements are presented in the following:

> *"The predictions were important because they made us think about how the phenomena occur, before we analyze what really happens, making the student think about what happens and not only using equations... The qualitative experiments allow the student to escape for a while from the mathematical severity, making the student to pay more attention at the phenomenon and not only worry about collecting data" (Student A).*

> *"Comparing to my previous experience, the laboratory activities were much more motivating and had better didactics, especially because of the qualitative elements, which were the most part of them, and because of the possibility to discuss with the other group members. In general, my engagement was higher than it would be if I was attending to a traditional laboratory class" (Student B).*

*"The group discussions allow us to think in a different way than we are used to, and we got to the right answer more easily" (Student C).*

*"In this course, in particular, I am happy to be surprised by the results from the experiments without knowing them in advance by reading the laboratory guide" (Student D).*

*"Unnecessary (the need to record the predictions), I prefer the traditional laboratory"(Student E).*

Above are presented four positive and one negative statements from students about the active methodology used in our course. After analyzing all questionnaires, we concluded that 78% of the students think that the new methodology helped them to improve learning, 13% were indifferent and 9% preferred the traditional method.

These statements showed that students became more motivated and presented a higher responsibility with their learning process. We also could see reflexes of it in students' understanding of physics concepts as well as in applying these concepts to different situations, once students' scores rose significantly in the post-test.

## Conclusion

By the use of inquiry methods in laboratory classes, students' average gain (G) was higher in post-tests than in pre-test, for both the McDermott's adapted question and the DIRECT. Furthermore, we noticed that in students' answers to pre-tests were based on formulae whereas in the post-test, they were based on reasonable conceptual argumentation and with qualitative explanations not always allied to formulae.

After instruction, students could overcome various difficulties but still have some others that we couldn't manage to help them yet. Thus, we are also making other researches in order to comprehend students understanding of concepts they are known to have difficulties, by using the DIRECT.

Comparing students' answer to questions and which alternative their answers were concentrated, we are being able to determine persisting specific conceptual mistakes. Thus, we can track and attack where the common difficulties lie. So, we have been improving our course by adding and/or modifying activities in the laboratory guide, based on our findings. In a recent research (Sanches et al., 2016) we discovered that in some cases we could improve students' conceptual understanding but in others they still made the same mistakes.

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