Can one lab make a difference?

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Introduction

Many studies[1] have demonstrated that carefully constructed active learning activities[2] can improve student conceptual understanding. However, only a few studies, all involving use of microcomputer-based laboratory (MBL) based mechanics activities, have shown significant improvement resulting from a single isolated treatment in the context of a traditional lecture class.[3-6] We wanted to see whether replacing a single traditional laboratory activity with a widely used, non-MBL, research-based activity could produce improved conceptual understanding for a topic in electricity.

All students in this study were in the same lecture section of the second semester introductory physics course for engineers at North Carolina State University (NCSU) during the summer of 1999. The lecture section met for 90 minutes, five days a week. The instructor (GWP) lectured for 50 minutes and then led an in-class problem solving session for 30 minutes. One TA taught all lab sections. The two-hour labs met once a week for five weeks. The lab activities are typical of those found in introductory physics courses at many colleges and universities. There was no separate discussion/recitation section.

The instruction for all students in the study was the same except for a single two-hour laboratory period. For the DC circuits lab, students were split into two groups based on which lab section they attended. The students in the experimental group (EXP) did a single activity based on the two batteries and bulbs activities from *Tutorials in Introductory Physics.*[7] Instead of a traditional lab report, the EXP students were assigned a worksheet that combines elements of the suggested homework assignments that accompany the two *Tutorials*.[8] The students in the control group (TRD) carried out a more traditional Ohm's law activity from the NCSU lab manual[9] and prepared a standard lab report. An experienced TA familiar with the traditional labs taught all lab sections. To prepare for the *Tutorial*, the TA met with one of the authors (DSA), took the pretest, and worked through the activity,

It is important to note that, while Shaffer and McDermott[10] have shown that the DC circuit *Tutorials* can improve student performance on qualitative problems when used as part of a series of *Tutorial* activities, individual *Tutorials* are not intended to be used as "stand alone" activities.

Student understanding was measured by performance on items from course tests and a DC circuits pretest (described below). Only students who were enrolled in lab and took all the tests, including the DC circuits pretest, were included in the study. There were 20 students in the EXP group and 18 students in the TRD group.

Results

The students took the first course exam before any instruction on DC circuits. The exam scores for both groups were virtually identical (EXP-77% vs. TRD-76%, $t = 0.4$, $p = 0.7$). A fifteen-minute, free response DC circuits pretest was given at the end of the lecture session on the day that resistive circuits were introduced and before the lab on DC circuits. The pretest was a shortened combination of the two *Tutorial* pretests.[11] Both groups did very poorly on the pretest, with the EXP group scoring somewhat lower than the TRD group, although the difference is not statistically significant (EXP-28% vs. TRD-37%, $t = -1.9$, $p = 0.06$).

Student understanding after instruction on DC circuits was measured by performance on 14 multiple choice items from the second unit test and the final exam. The course instructor, who has made up the common exams at NCSU for many years, chose eight of these questions from a bank of past common exam questions. The remaining six questions were selected by two of the authors (JMS and DSA) from DIRECT, a 29 item multiple-choice DC circuits concept test.[12]

Students in the EXP group did significantly better overall on the six DIRECT questions (EXP-60% vs. TRD-37%, $t = 2.6$, $p = 0.01$), outscoring the TRD group by 10% to 40% on each question. While one DIRECT question (29) closely resembles the *Tutorial* activity, removing this item from the comparison still yields a statistically significant result (EXP-62% vs. TRD-42%, $t = 2.0$, $p = 0.04$). The results imply that, at least for the situation established during this study, a single instructional experience utilizing the research-based *Tutorial* materials was noticeably better at helping students understand DC circuits concepts than a traditional laboratory experience on the same topic.

Even though traditional test questions, like those used in this study, may not effectively detect differences in the amount of learning between two groups, the results from the eight traditional exam questions are encouraging. The EXP students significantly outperformed the TRD students (EXP-90% vs. TRD-55%, $t = 2.4$, $p = 0.03$) on one test question, which is analyzed in detail below. There was no difference on the remaining seven questions. On five of these seven questions, students from both groups did extremely well (EXP-88%, TRD-90%), with more than 75% of the students in each group answering each question correctly. The other two questions that showed no difference dealt with topics not addressed by either lab activity.

The EXP students outperformed the TRD students on the question based on the circuit shown in figure 1. Students were asked to find the voltage across the battery. The EXP students were apparently able to extend the qualitative analysis from the *Tutorial* to a similar, but not identical quantitative problem. In the *Tutorial*, students predict what happens to the brightness of bulb B when the switch is closed in the circuit in figure 2 and explain their answer. A series of questions leads students through an analysis of the circuit based on junction rule and voltage rule. This method, reinforced by several items in the *Tutorial* homework, is more useful in solving the question in figure 1 than a method based on the equivalent resistance formulae stressed by the activity from the NCSU lab manual. The outstanding performance of the EXP group on this item is especially encouraging, because this problem involves two complications not directly addressed by the *Tutorial*: quantitative calculation and non-identical resistors.

Conclusions

We found that a single instructional experience utilizing the research-based *Tutorial* materials was noticeably superior to a traditional quantitative laboratory experience on the same topic for helping students build a conceptual understanding of DC circuits. Not only is the *Tutorial* activity better than the traditional quantitative lab at promoting conceptual understanding, but the *Tutorial* appears to be at least as good at promoting successful problem solving.

This study suggests the exciting possibility that replacing a single traditional activity may also lead to improved performance on some types of quantitative problems, but more work needs to be done to assess the impact on problem solving. Studying student performance on test items specifically designed to address the strengths and weaknesses of each treatment would provide a better picture of how problem solving was affected by both treatments.

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[6]E. F. Redish, J. M. Saul, and R. N. Steinberg, "On the effectiveness of active-engagement microcomputer-based laboratories," American Journal of Physics **65** (1), 45-54 (1997).

[7]L. C. McDermott and P. S. Shaffer, *Tutorials in Introductory Physics* (Prentice Hall, 1998).

[8]Since students had only 48 hours to complete the homework, the first and fifth pages of the homework for "A model for circuits: Part 2" were eliminated from the homework assignment. The first page reviews material covered in the homework for "A model for circuits: Part 1." The fifth page asks students to evaluate the discourse between two fictional students.

[9]R. A. Egler, *Physics in Action* (Contemporary Publishing Company, Raleigh, NC, 1997).

[10]P. S. Shaffer and L. C. McDermott, "Research as a guide for curriculum development: An example from introductory electricity. Part II: Design of an instructional strategy," American Journal of Physics **60**, 1003-1013 (1992).

[11]At the request of the instructor, the pretest was designed to take less than fifteen minutes. The two Pretests from the Instructor's Guide were combined into a single form. Item 2 from the Pretest for Part 1 was dropped.

[12]P. Engelhardt, "Examining students' understanding of electrical circuits through multiple-choice testing and interviews," Ph.D. dissertation, North Carolina State University, 1997.

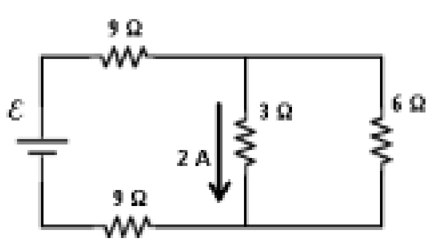

Fig. 1. The circuit students analyzed on the final exam. Students were given the current through the 3 Ω resistor and asked to find the voltage across the battery.

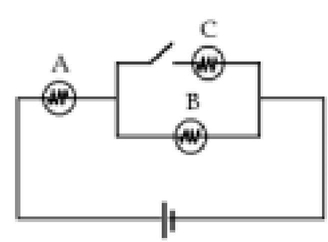

Fig. 2. The circuit students analyzed in the Tutorial and DIRECT item 29. Students were asked to predict what happens to the brightness of each bulb when the switch is opened or closed.