Assessing The Effectiveness Of A Computer Simulation In Conjunction With *Tutorials In Introductory Physics* In Undergraduate Physics Recitations

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Abstract. We present two studies documenting the effectiveness of the use of a computer simulation with *Tutorials in Introductory Physics*[1] in a transformed college physics course.[2] An interactive computer simulation, entitled the Circuit Construction Kit (CCK),[3, 4] was introduced to investigate its possible impact on students' conceptual understanding. The first study compared students using either CCK or real laboratory equipment to complete two *Tutorials* on DC circuits. The second study investigated the impact of the simulation's explicit representation for visualizing current flow by removing this feature for a subset of students. In the first study, students using CCK with *Tutorials* performed slightly better on measures of conceptual understanding compared to real equipment, as measured by exam performance soon after the intervention. In the second study, students using CCK with and without the explicit visualization of current performed similarly to students using real equipment, though on some specific questions we note significant variation in student performance. We discuss the implications of adding (or removing) such representations within computer simulations.

INTRODUCTION

Despite the computer's wide-spread presence in various classroom environments, its use is only relatively recently been extensively studied in the college classroom. In traditional college environments, computers have been used to teach physics in lectures, laboratories, recitations, and other environments outside the classroom, such as online homework systems (e.g., see Ref. 6 and references therein).

Some proven curricula do not utilize computers, such as *Tutorials in Introductory Physics*.[1] While *Tutorials* utilize paper-and-pencil-based methods and simple laboratory equipment, we seek to understand whether using virtual equipment is as productive as the originally designed materials. Furthermore, we examine the characteristic features of such virtual tools when used in conjunction with these thoroughly researched curricular materials.

This study addresses these questions by introducing a computer simulation, known as the Circuit Construction Kit (CCK), into introductory physics courses that utilized *Tutorials*. In two coupled studies conducted in similar courses, we measure the effect of CCK in conjunction with *Tutorials* on students' conceptual understanding of DC circuits. Additionally, we compare the use of CCK, which explicitly represents the flow of current, to the use of a modified version of CCK where this visual representation of current flow is not present.

In the first study, we observe small but significant improvements on aggregate exam questions in the domain of DC circuits by students who use CCK with *Tutorials* compared to those who used real equipment with *Tutorials*. No significant effects are observed on the final exam or end-of-term survey. In the second study, we observe no difference in exam performance between students who used either version of CCK or real equipment on questions relating to DC circuits.

PHET SIMULATIONS

The simulation used in this study was developed and tested by the Physics Education Technology (PhET) group at the University of Colorado at Boulder.[3,4] The PhET project has developed approximately 45 physics and mathematics

simulations that include most topics covered in a typical introductory physics sequence. These simulations are designed to be interactive, engaging, and to make explicit certain visual representations.

The simulation used in this study, CCK, [Fig. 1] allows students to build simple DC circuits using batteries, wires, resistors, light bulbs, and switches. The simulation utilizes Kirchhoff's laws to accurately model current and voltage for circuits created by the user. A virtual workplace is provided where users can place components, connect them together, and measure current and voltage using a virtual ammeter and voltmeter. Every component has default parameters (such as light bulb resistance and battery voltage) that can be adjusted by the user to see the immediate change that such adjustments produce. Default conditions model real resistors, wires, and batteries with internal resistance. Additionally, CCK provides the user with an explicit visual representation of current flow by representing electrons in the wires and electrical components that obey current conservation rules. As part of this study, we will explore what happens when this representation of current is not available to the students.
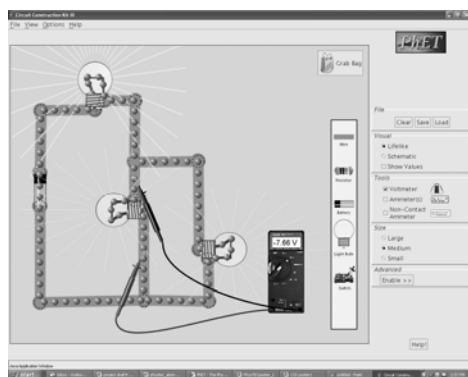
FIGURE 1. Screen shot of CCK *with* the visual representation of current. Modified version of CCK *without* current representation does not show dots in circuit elements.

CLASSROOM ENVIRONMENTS

Fall 2004: The first study took place in the Fall of 2004 in a large, transformed, calculus-based, introductory physics course at the University of Colorado at Boulder. Consisting of 445 students, this course was the second semester in a two-semester sequence intended mainly for engineering and physics majors. Topics included electricity, magnetism, waves, and modern physics. The course was divided into two nearly identical 50-minute lectures, each meeting three times per week with the same instructor.

Students met weekly for a 50-minute TA-led recitation, consisting of roughly 23 students each. During these recitations, students worked on one specific *Tutorial* in groups of 2 to 5 students.

This course also incorporated a number of research-based practices, such as interactive lectures, clickers, and an online homework system. For a complete description of this course, see Refs. 2 and 5.

Spring 2005: While a number of features of this class changed (textbook, online homework system, instructor, etc.), the main structural features of the course remained the same. The format of recitation sections and the implementation of *Tutorials* remained unaltered from the previous semester. The course was slightly smaller, consisting of 312 students.

Procedure & Data Collection

Fall 2004: During the seventh and eighth weeks of instruction, all students participated in the two *Tutorials* on DC circuits. Nine of the recitation sections (Group A, N=180 students) formed the control group, completing these particular tutorials using the recommended equipment: batteries, wires, switches, digital multimeter, and light bulbs. The other 9 recitations (Group B, N=184) formed the experimental group, completing the same tutorial using only CCK (with the explicit current visualization). These students were given no specific instructions on how to use the simulation, nor did any of them have any formal experience using CCK. The control and experiment groups remained the same during both weeks of the study.

Data assessing student conceptual performance were collected from four exams over the course of the semester. The BEMA exam, a 31 multiple-choice question conceptual survey[7] covering a variety of topics in electricity and magnetism, was given to all students during the first and last (15th) weeks of instruction. Three additional questions on DC circuits taken from the ECCE exam[8] that were selected by this study's authors were added to the BEMA. A common midterm examination, consisting of 15 multiple-choice and 2 free-response questions, was given 4 weeks after the intervention. During the 16th week, a common final exam was given consisting of 28 multiple-choice questions.

Spring 2005: The study carried out during the Spring 2005 semester was almost identical to the previous semester. During the seventh and eighth weeks, students completed two *Tutorials* on DC circuits. Students were divided up into two experimental groups and one control group. The control group (Group A, N=79) completed both

TABLE 1. Fall 04 data—DC circuit questions on all 4 exams. Percent correct (aggregate) listed with standard error in parentheses. Number of question on each exam listed in brackets. Statistically significant results (p < 0.05) indicated in bold.

Group	Pre BEMA [9]	Post BEMA [9]	Midterm Exam [6]	Final Exam [2]
Group A (N=180) Real Equipment	23.8 (1.1)	59.3 (1.2)	**64.9** (1.4)	53.8 (2.6)
Group B (N=184) CCK with Current	23.5 (1.0)	59.1 (1.2)	**69.9** (1.4)	54.8 (2.6)

TABLE 2. Spring 05 data—DC circuit questions on all 4 exams. Percent correct (aggregate) listed with standard error in parentheses. Number of question on each exam listed in brackets. Statistically significant results (p < 0.05) indicated in bold.

Group	Pre BEMA [9]	Post BEMA [9]	Midterm Exam [10]	Final Exam [6]
Group A (N=79) Real Equipment	26.4 (1.7)	52.4 (1.9)	62.1 (1.7)	57.2 (2.3)
Group B (N=84) CCK with Current	25.8 (1.6)	55.8 (1.8)	66.1 (1.6)	60.5 (2.2)
Group C (N=72) CCK without Current	25.0 (1.7)	55.9 (2.0)	63.6 (1.8)	56.9 (2.4)

tutorials using real laboratory equipment. One experimental group used CCK with the visual representation of current flow (Group B, N=84), while the other experimental group used the modified version of CCK *without* the explicit representation[*] (Group C, N=72) to complete both tutorials. Recitation sections were assigned to one of the three groups by the authors, and the groups remained the same during these two specific tutorials.

Data were collected from 4 exams. During the first and last week of instruction, the BEMA exam (with the 3 added questions) was given to all students. One week after the second DC circuit tutorial, students took a common midterm examination, consisting of 25 multiple-choice questions. Nine weeks after the intervention, a common final exam was given to all students that included 45 multiple-choice questions.

RESULTS

Fall 2004: The results of all 4 exams appear in Table 1. The performance between groups on a given subset of questions that are statistically different (i.e., p < 0.05) are indicated in bold and discussed below. The pre-BEMA scores on DC circuit questions serve as a control and are statistically indistinguishable, indicating a matched sample. The DC circuit questions on the midterm exam are the only set of questions that yield a statistically significant difference between groups A and B (p < 0.05, using a two-tailed z-test).

Spring 2005: The results of all 4 exams are given in Table 2. On questions relating to DC circuits on the midterm, final, and BEMA we observe no statistically significant differences between the averages of these

questions on each exam. Again, statistically indistinguishable pre-BEMA scores for the three groups demonstrate appropriately matched samples. When we examine specific questions rather than aggregate achievement, we note statistically significant differences in performance on some questions. Consider the question in Figure 2 given on the midterm exam. The average fraction correct for groups A, B, and C are 73.4%, 91.7%, and 79.2%, respectively. The p-values for each pair of groups are $p_{AB} = 0.0017$, $p_{AC} = 0.4$, and $p_{BC} = 0.03$ (using a two-tailed z-test). Additionally, it is worthy of note that on some other questions unrelated to DC circuits we do observe significant differences as will be discussed in future work. These variations are the subject of further investigation.

DISCUSSION

During the Fall 2004 course, students using CCK were initially performing better on questions relating to DC circuits than students who used real equipment. By the end of the term, this small difference in exam performance is not apparent. It is still unknown whether all students in the course improved by the end of semester or if the beneficial effects of the simulation diminish over time. A related study did observe lasting beneficial effects of CCK,[9] which may imply that these effects do survive over the course of a semester.

In the replication study, we do not observe the transient difference in performance between the CCK and real equipment groups; however, the end-of-semester results repeat the earlier findings—there is no statistically significant difference between either of the experimental conditions and the control group.

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[*] Figure 1 *without* the electrons in the wires.
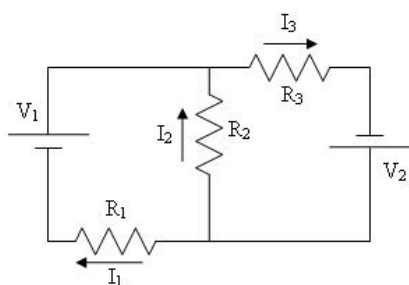
Which of the following equations is the correct current equation, given the choice of current directions?

A) $I_2 + I_3 = I_1$ B) $I_3 + I_1 = I_2$
C) $I_1 + I_2 = I_3$ D) None of these.

FIGURE 2. Question given on midterm in Spring 2005.

In the study of the utility of visualizing current flow, we do not observe any aggregate differences in performance on DC circuit questions among the three experimental conditions. On specific questions, however, we do observe instances where one of the experimental groups (B and C) outperforms the control group (A). It appears that in aggregate under the conditions of these recitations, the explicit visual model for current flow provided by CCK was not significantly beneficial or harmful to these students. Alternatively, the resolution and scope of our measurement instruments might be insufficient to capture the variation among groups.

CONCLUSION

This paper presents two studies documenting the effect of a computer simulation, known as CCK, used in conjunction with *Tutorials* on students' conceptual understanding of DC circuits. The first question this study addresses was whether the use of a computer simulation in this environment can be as effective as real equipment. Thus far, we observe no lasting or repeatable significant differences in conceptual understanding between students who use either a computer simulation or real laboratory equipment, suggesting that in the appropriate contexts, simulations can be just as productive as real equipment.

The second question we set out to answer was whether the explicit visual model for current flow provided by CCK has any beneficial or deleterious effects on students' conceptual development of DC circuits. The results of the Spring 2005 study suggest that this current model has no significant effects in aggregate—students who used CCK without the explicit current model seem to be at no disadvantage.

However, more studies are needed to identify if these effects are too fine grained (i.e., subject specific as may be measured by individual questions, rather than simply aggregated assessments of DC circuits), or whether indeed there are no significant differences in using the visual model of current or not with *Tutorials*. As such these future studies may well contribute to the debates on the role and utility of teaching students micro or macroscopic phenomena in electric circuits.[10,11,12] Although contributing to the debate is not the focus of this paper, we plan to address such topics in future studies.

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