

# Assessing the Effectiveness of a Computer Simulation in Introductory Undergraduate Environments

C.J. Keller, N.D. Finkelstein, K.K. Perkins, and S.J. Pollock

*University of Colorado at Boulder  
Department of Physics, Campus Box 390 Boulder, CO 80309*

**Abstract.** We present studies documenting the effectiveness of using a computer simulation, specifically the Circuit Construction Kit (CCK) developed as part of the Physics Education Technology Project (PhET) [1, 2], in two environments: an interactive college lecture and an inquiry-based laboratory. In the first study conducted in lecture, we compared students viewing CCK to viewing a traditional demonstration during *Peer Instruction* [3]. Students viewing CCK had a 47% larger relative gain (11% absolute gain) on measures of conceptual understanding compared to traditional demonstrations. These results led us to study the impact of the simulation's explicit representation for visualizing current flow in a laboratory environment, where we removed this feature for a subset of students. Students using CCK with or without the explicit visualization of current performed similarly to each other on common exam questions. Although the majority of students in both groups favored the use of CCK over real circuit equipment, the students who used CCK *without* the explicit current model favored the simulation more than the other group.

**Keywords:** Computer Simulation, PhET, Peer Instruction, Laboratory, Electric Circuits.

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## INTRODUCTION

Our previous studies on the use of simulations in college environments have investigated a simulation's impact on conceptual understanding in labs and recitations. In interactive recitations using *Tutorials in Introductory Physics* [4], we demonstrated that students perform similarly on measures of conceptual understanding using either a simulation or real equipment [5]. However, in a traditional laboratory, students using a simulation outperformed their counterparts who used real equipment on a conceptual survey of the material and in coordinated, hands-on tasks [6]. We follow these lines of inquiry by studying the use of a simulation in an interactive lecture that utilizes *Peer Instruction* [3] and an inquiry-based laboratory environment to study the effects of an explicit visual model of current flow within this simulation on students' conceptual understanding and their attitudes towards the simulation.

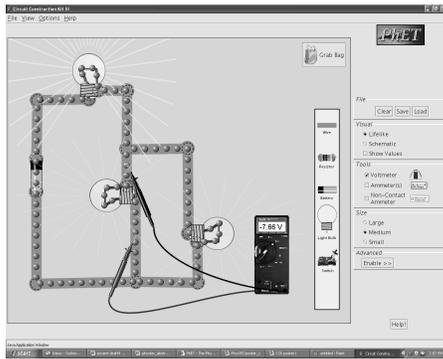
A computer simulation, known as the Circuit Construction Kit (CCK), was introduced into these environments to investigate its impact. In the study conducted in lecture, we observe significant improvements on concept test performance in the domain of DC circuits by students who view a demonstration using CCK compared to those who

view an equivalent physical demonstration and associated chalkboard explanation. In the study conducted in an inquiry-based laboratory, we observe no difference in exam performance between students who used versions of CCK with or without the explicit model for current. The majority of students in both groups favored the use of CCK over their experience with real equipment. Finally, students who used CCK *without* the explicit current representation rated the simulation more favorably than students using CCK *with* this representation.

## PHET SIMULATIONS

The simulation used in these studies was developed and tested by the Physics Education Technology (PhET) project [1, 2]. The PhET project has developed approximately 60 freely downloadable physics, chemistry, and mathematics simulations that include most topics covered in a typical introductory physics sequence. The simulation, 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 virtual ammeters and a voltmeter. Additionally, CCK provides the user an explicit visual representation of current flow by representing electrons as small spheres dots that obey current conservation. As part of this study, we explore what happens when this visual current model is not present.



**FIGURE 1.** Screen shot of CCK with the visual representation of current. Modified version of CCK without current representation does not show spheres in circuit elements.

## EFFECT OF PEER INSTRUCTION

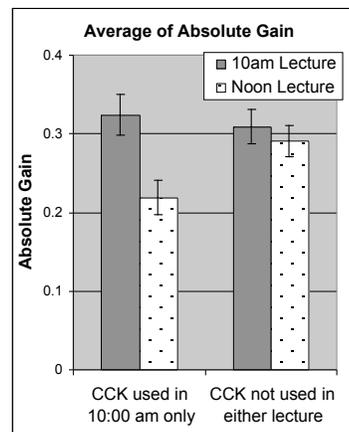
*Classroom Environment:* The first study took place in Fall 2004 in a large, interactive, calculus-based, introductory physics course at the University of Colorado at Boulder. This course was the second semester in a two-semester sequence intended mainly for engineering and physics majors and consisted of 360 enrolled students. Topics include electricity, magnetism, waves, and lenses. The course was divided into two nearly identical 50-minute lectures, each meeting three times per week with the same instructor. One lecture was held at 10:00am ('10am,' N~180), and the other was held at 12:00pm ('noon,' N~180). *Peer Instruction* was implemented in these lectures along with clickers. Students met weekly for a 50-minute, TA-led recitation, during which students worked on *Tutorials* in small groups. For a complete description of this course, see [7].

*Procedure & Data Collection:* When a concept test was initially given, students were instructed to not discuss with their peers and answer the question independently. After students responded, the instructor did not present the students' aggregate responses to the entire class. The instructor would perform a demonstration or lecture, and students were allowed to discuss the question with each other. Students then responded individually a second time to the same question. The results of students' responses were then

revealed to the class and the instructor would present the answer, if necessary.

Data were collected on 5 concept tests given in this format over the term on different topics. For 2 of the 5 questions, CCK was shown to students in the 10am lecture, and an equivalent explanation or physical demonstration was performed in the noon lecture. As a control, the remaining 3 questions were carried out in a similar manner in both lectures.

*Results:* Because students answered the same concept test twice, pre and post discussion results are available. In Fig. 2, the students in the 10am lecture have a statistically larger absolute gain (pre to post) than the noon lecture on the 2 questions where CCK was shown ( $p=0.002$ , two-tailed z-test). The average of these questions for students who saw the simulation improved from 59.8% to 92.1%, while students who did not see the simulation improved from 61.2% to 83.1%. The remaining 3 questions demonstrate that the two lectures are improving similarly during the same instruction ( $p=0.54$ ).



**FIGURE 2.** Absolute gain for 5 concept tests. CCK was only used in the 10am lecture for data on left side.

*Discussion:* Although a more exhaustive study is necessary to make substantial claims, these results suggest that a simulation can potentially spur more productive discussion than viewing real demonstrations during *Peer Instruction*. One possible explanation for these results is that CCK's explicit visual representation for current provides a more productive feature upon which students may base their discussions.

## EFFECT OF VISUALIZATION

*Classroom Environment:* This course was the second semester of a two semester sequence in algebra-based introductory physics at the University of Colorado at Boulder held Fall 2005 (N~160). Topics

covered in this course included E&M and modern physics. This course has a coupled two-hour laboratory section that met weekly, consisting of 15 to 30 students each. Four teaching assistants were assigned to seven laboratory sections. Students completed 10 inquiry-based labs during this 15-week course, working in groups of 2 to 5 students. During weeks where a laboratory was not assigned, a discussion section was held instead.

*Procedure and Data Collection:* The 3<sup>rd</sup> and 4<sup>th</sup> labs of the semester covered voltage and current in DC circuits, respectively. During the 3<sup>rd</sup> lab, *all* students in the course used real equipment to complete the lab. During the 4<sup>th</sup> lab (referred to as the ‘CCK lab’), all students used CCK and two groups were formed—one group of students used CCK *with* the explicit current visualization (‘Current group,’ N=65, 3 laboratory sections), and the second group used CCK *without* the current visualization (‘No Current group,’ N=90, 4 laboratory sections). Both groups completed the same laboratory on DC circuits. Students were given no specific instructions on how to use the simulation, nor did any have prior formal experience using CCK.

Data assessing student conceptual performance were collected from three exams over the course of the semester. A common midterm exam was given during the 9<sup>th</sup> week of instruction, approximately 3 weeks after the intervention. This exam consisted of 20 multiple-choice questions, 7 of which were related to DC circuits. The BEMA exam<sup>1</sup> [8] was given to all students only during the last (15th) week of instruction. The BEMA was *not* given during the first week of instruction<sup>2</sup>. During the 16<sup>th</sup> week, a common final exam was given consisting of 30 multiple-choice questions, 2 of which were related to DC circuits.

Online prelabs contained Likert-scale questions (1 to 5; *not at all* to *very* useful/enjoyable) probing students’ attitudes towards the perceived usefulness and enjoyment of the prior week’s laboratory. Two additional questions were added to compare the usefulness and enjoyment of real circuit equipment with CCK after students completed the 3<sup>rd</sup> and 4<sup>th</sup> labs.

*Results:* The average of all 20 questions on the midterm exam for both groups is statistically similar, as are the averages of all 7 questions related to DC circuits and all 13 questions on other topics (Table 1).

The average of all 30 questions on the final exam for both groups is statistically similar (p=0.5), with the Current group averaging 57.4% (N=60) and the No Current group averaging 56.5% (N=78). The averages of the 2 questions on DC circuits are also statistically

similar, and the averages for the Current and No Current groups are 75.0% and 73.7% (p=0.8).

**TABLE 1. Results of midterm and BEMA exam.**

		% correct [standard error]	
Questions (p-value) <sup>†</sup>		Current Group, N=60	No Current Group, N=81
Midterm	All (p=0.2)	60.3 [1.4]	62.8 [1.2]
	DC Circuit (p=0.7)	66.1 [2.3]	67.4 [2.0]
	Non DC-Circuit (p=0.2)	57.2 [1.8]	60.3 [1.5]
		<b>N=54</b>	<b>N=68</b>
BEMA	All (p=0.6)	37.9 [1.2]	37.0 [1.1]
	DC Circuit (p=0.9)	37.6 [2.5]	37.8 [2.2]
	Non-DC Circuit (p=0.5)	38.0 [1.4]	36.7 [1.2]

<sup>†</sup>p-values calculated by a two-tailed z-test.

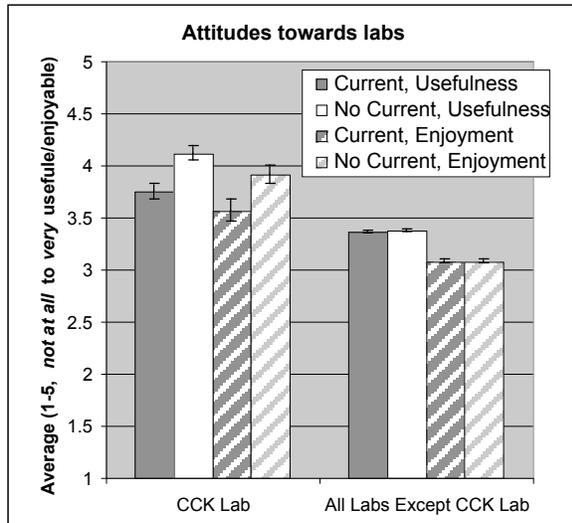
The averages for post-BEMA questions in aggregate appear in the bottom of Table 1. All three categories are statistically similar.

Overall, we observe more favorable attitudes towards the CCK lab compared to all other labs during the term (Fig. 3). The average student rating regarding the usefulness of the CCK lab is more positive for *both* groups than the average of the remaining labs. This trend is even more pronounced for the enjoyment of the labs. Interestingly, we do observe differences between the two groups in their attitudes towards the CCK lab, with the No Current group having a more positive attitude towards the usefulness of the CCK lab than the Current group (p<0.002). We observe a similar difference on the CCK lab for the enjoyment of the labs (p=0.01). The differences between the two groups on all other individual labs are statistically similar (p>0.05).

The two additional questions asking students to compare CCK to real equipment also demonstrate favorable attitudes towards CCK. The fraction of students that rated the simulation as better than real equipment in terms of utility was 77.6% and 88.2% for the Current and No Current groups (p=0.08), respectively. The average ratings of comparative utility (on a scale from 1 to 5, *much less* to *way more* useful/enjoyable) are 4.13 for the Current group and 4.41 for the No Current group, (p=0.05). The question asking students to compare their enjoyment of the simulation to real equipment also demonstrates favorable attitudes towards CCK, where 56.1% and 79.3% of the students gave a favorable response (Current and No Current group, respectively; p<0.002). The average for the Current group (on a scale from 1 to 5) is 3.68, while the No Current group has an average of 4.13 (p=0.008).

<sup>1</sup> This exam also included questions 10, 11, and 12 from the ECCE [9]. Additionally, questions 9, 12, 18, 28, and 29 of the BEMA are not included because this material was not covered in the course.

<sup>2</sup> Scores tend to be predictably low on the pre BEMA exam.



**FIGURE 3.** Average response from students on two questions regarding the usefulness and enjoyment of labs.

*Discussion:* No differences in conceptual understanding of DC circuits were observed between students who did and did not see the current visualization when using CCK to complete a laboratory. However, we do observe differences between students' attitudes towards the two different versions. Students who used CCK *without* the current model had a more positive attitude towards the perceived usefulness and enjoyment of the simulation. We hypothesize that this surprising result stems from how well matched the version of CCK was to the lab task. Perhaps predictions the students must make about circuits during the lab causes the lab to be unchallenging for these students who used a tool that explicitly shows current. Future work will include interviews to expand the hypothesis and design of curriculum to exploit the affordances of CCK.

Despite these differences, it should be noted that *both* groups had more favorable attitudes towards CCK than real equipment. The majority of students felt that using CCK was more useful and more enjoyable than their previous experience with real equipment.

## CONCLUSION

This paper presents two studies documenting the effect of a computer simulation, known as CCK, in two different classroom environments. In the first study conducted in lecture, we observe significant improvements on concept test performance in the domain of DC circuits by students who view a demonstration using CCK compared to those who view a physical counterpart. In the following study conducted in an inquiry-based laboratory, we observe

no difference in exam performance on questions relating to DC circuits between students who used CCK either with or without the explicit model for current. Despite the absence of a difference on conceptual understanding between the two groups, we do find that students who used CCK *without* the explicit current model rated the simulation more favorably than students using CCK *with* this model. We believe this to be related to how well matched the tool is to the task.

It should be noted that the majority of students in both groups favored the use of CCK over their experience with real equipment.

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