Assessing the effectiveness of computer simulations in undergraduate physics lectures and laboratories

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Introduction

We have introduced an interactive computer simulation known as the Circuit Construction Kit (CCK)[1] into 3 different college intro physics environments and studied the effects on students' conceptual mastery. These environments include:

1. Laboratory (algebra-based)
2. Recitation (calculus-based)
3. Interactive Lecture (calc-based)

Research Questions:

- What happens when a simulation is used in lieu of real laboratory equipment?
- How do simulations affect students' conceptual development?
- What is gained and lost when students use a simulation?

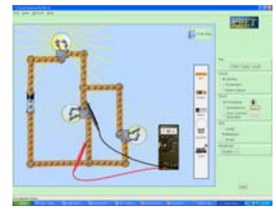
PhET Project Overview

The *Physics Education Technology* (PhET) Project is an on-going effort to create a suite of interactive simulations and related education resources that aid in the teaching and learning of physics.

- Elaborate Java- and Flash-based simulations
- Resources for both educators and students
- Research to formally assess their influence on student learning and attitudes in a variety of settings
- More than 40 physics-related PhET simulations exist and are being used in introductory physics courses around the world
- We employ a design philosophy that incorporates our own[2] and other's research in multimedia learning

Circuit Construction Kit (CCK)

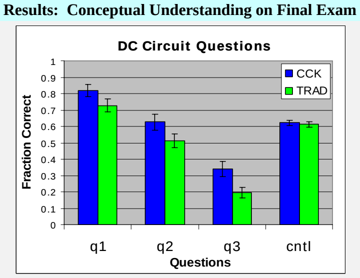
- Students build, manipulate, & test realistic circuits
- Current is explicitly modeled to help students visualize current flow and conservation
- Students can observe cause-and-effect relationships
- Available *free* online http://phet.colorado.edu
- Designed by the *Physics Education Technology* project (PhET) at CU-Boulder[2]



Traditional Laboratory

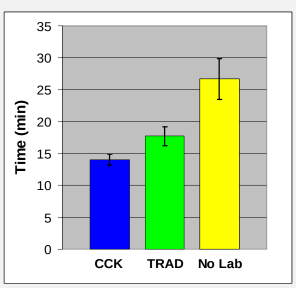
- Intervention in algebra-based, second semester, intro, physics course[3]
- For a traditional DC circuits lab, CCK was used in lieu of real equipment in 4 sections (N=99)
- Real equipment (TRAD) was used in 6 sections (N=132)
- At end of lab, *all* students participated in a challenge building circuits *using real equipment* and writing results
- Note: Nearly all students had no formal experience with real circuits prior to challenge

Results: Conceptual Understanding on Final Exam



Student achievement on three conceptual circuits questions on final exam (q1, q2, q3); "cntl" = remaining 26 questions on final. The mean for all 3 questions is 0.593 for CCK and 0.476 for TRAD groups ($p<0.001$).

Results: Circuit Construction Time



- Mean time for students to build a circuit with *real* equipment and write about it
- "No Lab" was a control group—students in another course without a lab
- CCK was faster at building circuit and writing about it ($p < 0.001$).

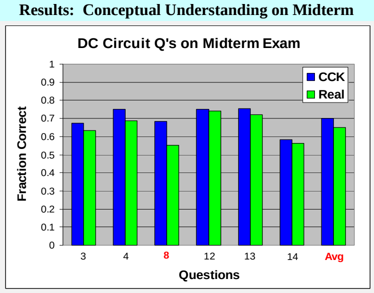
Conclusion

- CCK students take less time than their counterparts at building and describing real circuits
- CCK students demonstrate better conceptual mastery of DC circuits than TRAD students

Recitation with *Tutorials*

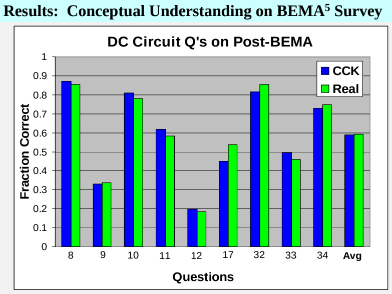
- Intervention in calculus-based, second semester, intro, physics course
- For two inquiry-based recitations using *Tutorials in Introductory Physics*[4] focusing on DC circuits, CCK was used in lieu of real equipment in 9 sections (N~160)
- Real equipment was used with Tutorials in 9 sections (N~160)
- Course included other reforms: online HW, peer instruction, etc.

Results: Conceptual Understanding on Midterm



6 questions on DC circuits given on exam 4 weeks after intervention; Q's #8 and average are statistically different ($p_8 = 0.04$, $p_{AVG} = 0.02$). None of the remaining 9 questions (on other topics) are statistically different.

Results: Conceptual Understanding on BEMA[5] Survey



9 questions on DC circuits given on post-survey (BEMA[5] exam); exam given 9 weeks after intervention. No statistical difference in performance between two groups.

Conclusion

- Simulation seems to improve short term gains: CCK students outperformed students using real equipment soon after intervention; both groups perform equally well at end of course
- CCK students perform better or just as well as students using real equipment (who use thoroughly researched reforms directed at DC circuits) at answering conceptual questions on DC circuits

Interactive Lecture

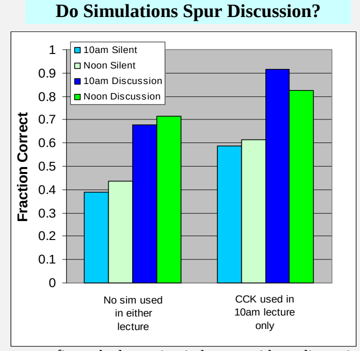
- Can simulations help students understand concepts and change the utility of discussion better when used in lecture?
- Two separate & similar lectures in a calculus-based, second semester intro physics course (E&M)
- Directly test *sim+talk* vs. other methods of information transfer (e.g., *chalk+talk*, *demo+talk*, talk only)

Comparing Simulations to Demos

Topic	% Correct (sims + talk)	% Correct (chalk + talk)
Force by Electric Field	83	90
Motion of particle w.r.t. Electric Field	41	33
Movement of Electrons & Protons	88	78

Mixed results on effectiveness of sims at promoting better conceptual learning in lecture (other data show similar trends). However, observations indicate that sims may be better at promoting discussion and eliciting questions from students.

Do Simulations Spur Discussion?



- Students were first asked question in lecture with no discussion (*silent*), then asked same question again after discussion with peers (*discussion*)
- CCK used during 2 different DC circuit questions in 10am lecture
- Chalk+talk used in noon lecture.
- We observe a slightly *larger* gain in Concept Test performance when CCK was used in lecture

Conclusion

- Simulations could possibly spur more productive discussion than real demos
- Similar data support this evidence; follow-up study to be conducted soon

Conclusions

- Under the right conditions, simulations can be successfully used in lieu of real equipment
- In all cases observed so far, simulations promote the same or greater conceptual mastery when compared to using real equipment
- Results suggest conventional wisdom may not be correct—that experience with real equipment is *NOT* essential for conceptual development and laboratory practices
- Further studies in process, but thus far no finding contradicts the current results

End Notes

References

1. Physics Education Technology Project, http://phet.colorado.edu.
2. K. Perkins, W. Adams, M. Dubson, N. Finkelstein, S. Reid, C. Wieman, R. LeMaster. "PhET: Interactive Simulations for Teaching and Learning Physics," Submitted to The Physics Teacher, 2004.
3. N.D. Finkelstein, W.K. Adams, C. Keller, P. Kohl, K.K. Perkins, N. Podolefsky, S. Reid, R. LeMaster. "When learning about the real world is better done virtually: a study of substituting computer simulations for laboratory equipment", submitted to *Phys. Rev. ST* – PER, 2004.
4. L.C. McDermott, P.S. Schaffer. "Tutorials in Introductory Physics." Prentice Hall, New Jersey. 2002.
5. L. Ding, R. Beichner, R. Chabay, B. Sherwood, "Evaluating and Using BEMA (Brief Electricity & Magnetism Assessment)," contributed poster, PERC. Sacramento, CA. August, 2004.

Acknowledgements

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