New tools for undergraduate education in physics: the Physics Education Technology (PhET) Project

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Introduction

The Physics Education Technology Project (PhET) has developed a suite of more than 50 free, downloadable simulations that span the content of introductory physics, as well as simulations on more advanced physics and chemistry topics.[1, 2] These research-based simulations are designed to promote student understanding and interest in science and to provide complementary tools to the canonical materials (real equipment, textbooks, etc) used in educational environments. We present the research design and sample studies that document the utility of these simulations in undergraduate physics. More available at *http://phet.colorado.edu*

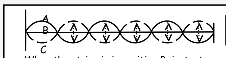
Studies of Sims

Comparison of simulations with other traditional educational approaches

- Lecture demo vs. sim
- Sim vs. lab equipment

Standing waves

2002 – a standing wave is demonstrated with a long tygon tube
2003 – the *Wave-on-a-String* sim is used to demonstrate standing waves

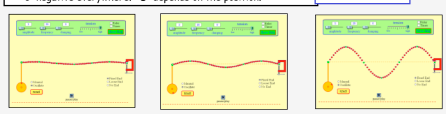


When the string is in position B, instantaneously flat, the velocity of points of the string is...
A: zero everywhere. B: positive everywhere.
C: negative everywhere. **D: depends on the position.**

Correct
demo: 27%
sim: 71%

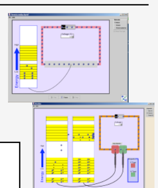
Follow up question: At position C, the velocity of points of the string is...
A: zero everywhere. B: positive everywhere.
C: negative everywhere. D: depends on the position.

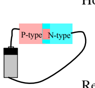
Correct
demo: 23 %
sim: 84%



P-N Junctions and LEDs

Instruction on conductivity. When will electrons conduct?
2003 – static visuals and words
2004 – *Conductivity* and *Semiconductors* sims
Students were asked what happens when you combine P-N-type semi-conductors together





Hook up battery, what happens?
a) electrons flow clockwise
b) electrons do not flow
c) electrons flow counterclockwise

Correct
static pics/word: 58%
sim: 74%

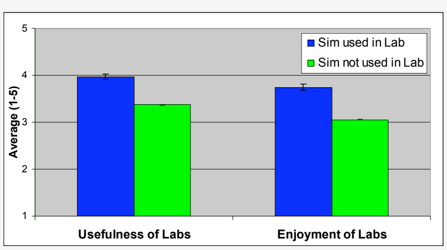
Reverse battery, what happens?
a) electrons flow clockwise
b) electrons do not flow
c) electrons flow counterclockwise

Correct
static pics/word: 86%
sim: 94%

Attitude Towards Sims

Algebra-based intro physics laboratory

- One lab utilized a sim, while the remaining 8 did not.
- Students found the lab with sim more useful and more enjoyable than the other labs



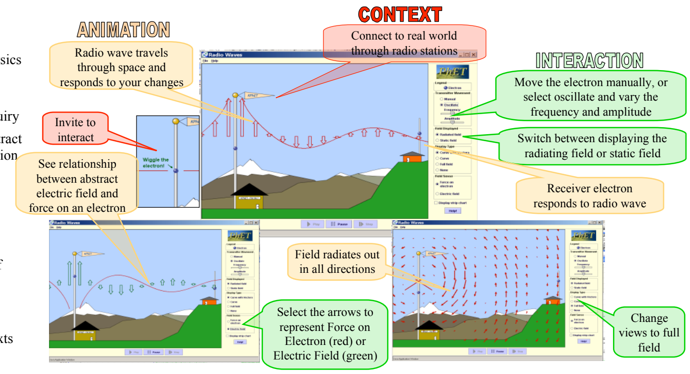
PhET Simulation

Goals for Students

- engage in exploring and understanding physics
- see how much of everyday life is governed by physics principles
- develop accurate visual and conceptual models of underlying principles through exploration and inquiry
- build bridges between conceptual physics and abstract concepts or between different forms of representation
- see physics as accessible and understandable

Design Philosophy

- make the simulations highly interactive
- have an accurate, visual dynamic representation of the physics that provides an animated response
- attend to the context in which the physics is being presented with an emphasis on creating game-like simulations that present physics in everyday contexts



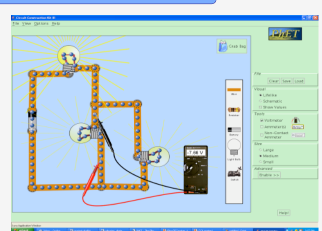
Design Features

- ***Engaging & Interactive Approach*** More supportive of student learning than traditional, passive, instructor- and text- centered environments.
- ***Dynamic Feedback*** Emphasize causal relations by linking ideas temporally and graphically.
- ***Constructivist Approach*** Students learn by building on their prior understanding through a series of scaffolding exercises.
- ***Workspace for Play*** Simulations create a self-consistent world for the students to learn about key features of a system by engaging them in systematic play and investigation.
- ***Visual Models*** Invisible features of physics (e.g., microscopic models) are made explicit to encourage students to observe otherwise invisible features of a system.
- ***Productive Constraints*** By simplifying the systems in simulations, students are encouraged to focus on physically relevant features rather than accidental conditions.

Detailed Study of a Sim

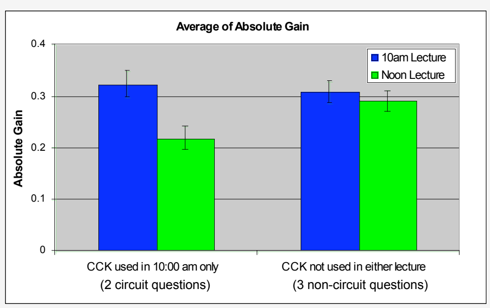
Circuit Construction Kit (CCK)

- 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



CCK in Lecture

- Can CCK help students understand concepts?
- Calculus-based, second semester intro physics course (E&M)
- Directly test *sim+talk* vs. traditional demo (*chalk+talk*, *demo+talk*, talk only)[4]

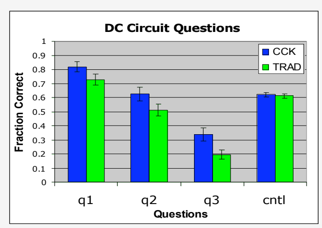


- Students were first asked question in lecture with no discussion, then asked same question again after discussion with peers
- CCK used during 2 different DC circuit questions in 10am lecture only
- *Chalk+talk* used in noon lecture.
- We observe a larger gain in concept test performance when CCK was used in lecture
- Simulations could possibly spur more productive discussion than real demos

CCK in Traditional Lab

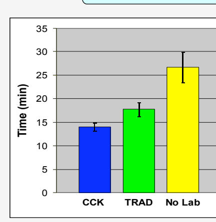
- Intervention in algebra-based, second semester, intro, physics course[2]
- For a traditional DC circuits lab, CCK was used in lieu of real equipment in 4 sections (N=99)
- Real equipment (TRAD) was used in 6 sections (N=132)
- At end of lab, *all* students participated in a challenge building circuits *using real equipment* and writing results
- Note: Nearly all students had no formal experience with real circuits prior to challenge

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 ($p<0.001$).

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 ($p < 0.01$).

Conclusions

- Sims can be productive tools for learning
- Under the right conditions, simulations can be successfully used in lieu of real equipment
- Results suggest conventional wisdom may not be correct—that experience with real equipment is *NOT* essential for conceptual development and laboratory practices
- For more info, go to http://phet.colorado.edu

References and Acknowledgements

1. K. Perkins, W. Adams, M. Dubson, N. Finkelstein, S. Reid, C. Wieman, R. LeMaster. "PhET: Interactive Simulations for Teaching and Learning Physics," *Phys. Thcr.* **44**, 1 (2006).
2. C. Wieman and K. Perkins, "Transforming Physics Education," *Physics Today*, November 2005.
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", Phys. Rev. ST Phys. Educ. Res. 1, 010103 (2005).
4. C. Keller, et al., *PERC Proceedings 2005;* and *PERC 2006* (to appear).

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