Interactive simulations for teaching physics

I have

a) never heard of phet.

b) heard of phet but never played with these simulations.

c) played with the sims, but not used in teaching.

d) used phet sims in teaching.

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⇒ **Physics Education Technology Project (PhET)**
Develop interactive simulations
Research on simulation design and effectiveness

When simulations carefully tested and refined :
- Highly engaging
- Very effective for learning
- Work with very wide range of students
  ("grade school to grad school")

Goals for talk
Examples of good simulations
Little about research on what makes them useful
⇒ principles to keep in mind when using.

show website, sim list, balloons and sweater, moving man, elctromag

PhET (phet.colorado.edu)

- ~ 60 interactive simulations
- Intro physics, modern physics, some chemistry, bit of math, starting to expand into geo and bio, …
- **Phet-based activities database on website--**

run phet sims (all free!):

- directly from web (regular browser, platform independent)
- download whole website to local computer for offline use

2006-- 1 Million sims launched off website;
50,000 full site downloads

Extensive development and testing process--teams (faculty, software engineers, sci. ed. specialists)

Phet Staff

Physics faculty:
Michael Dubson
Noah Finkelstein
Kathy Perkins (manager)
Carl Wieman

Postdocs:
Sam McKagan
Linda Koch (Chem)

Software Engineers:
Ron LeMaster
Sam Reid
Chris Malley
Michael Dubson

Grad students:
Wendy Adams
Danielle Harlow
Chris Keller
Noah Podolefsky

HS Teacher:
Trish Loeblein

~6 full time equivalents

Staff:
Mindy Gratny, Linda Wellmann

Design Features and Criteria

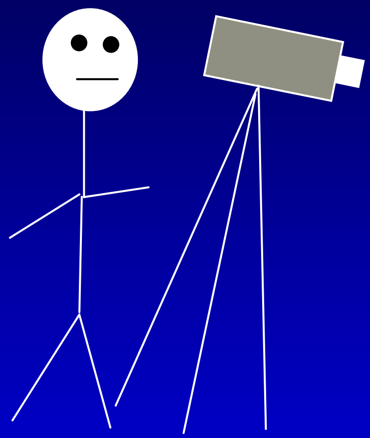
- Engaging and productively fun

(interface design, appearance, …)

- Connection to real world
- Highly interactive- stuff happening, user controls
- Explicit visual & conceptual models (experts')
- Explore and discover, with productive constraints
- Connect multiple representations

K.K. Perkins, et al, "PhET: Interactive Simulations for Teaching and Learning Physics", *Physics Teacher* (Jan 2006)

Most important element--testing with students

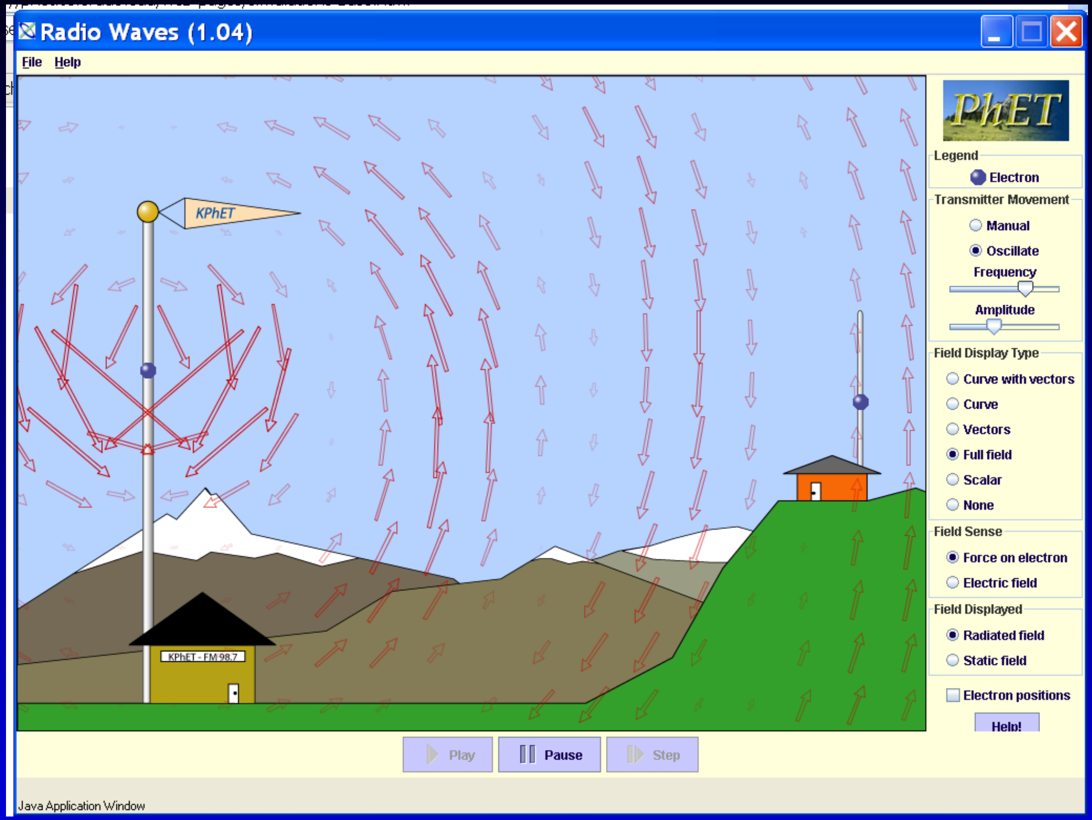



1. Think aloud interviews (~200 hours)

   Explore with guiding question

   very revealing

2. Observations of use in lecture, recitation and lab, homework solving sessions.



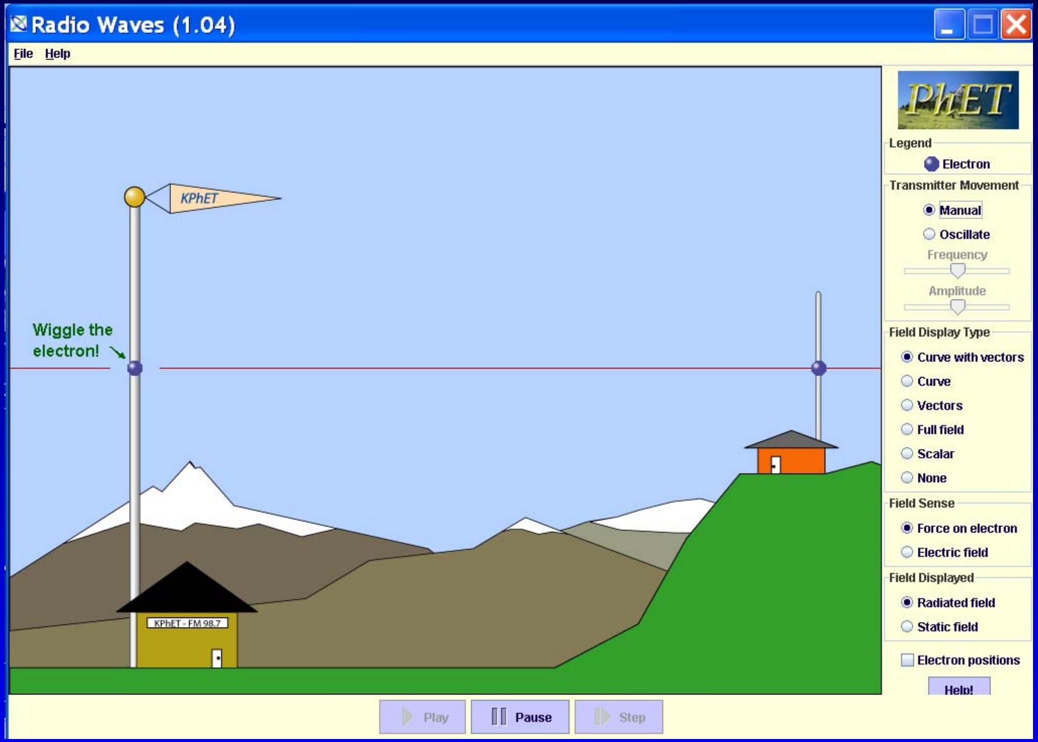
Example- of what revealed by interview studies.

Radio waves. Initial startup.

Experts- - really like.

Students--Watch without interacting. Don't like. Misinterpret.

Start with curve view, manually move electron.
Very different result.
Later move to full field view, manipulate, like, and understand.



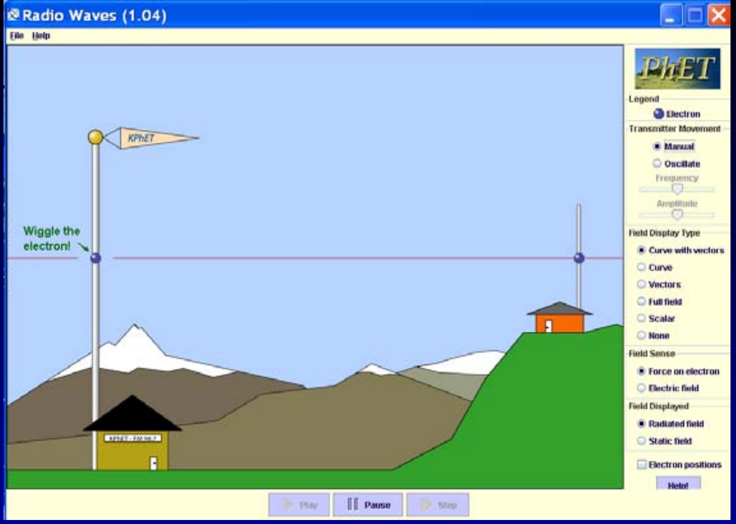
Correctly interpret.

Why do you think starting this way works so much better?

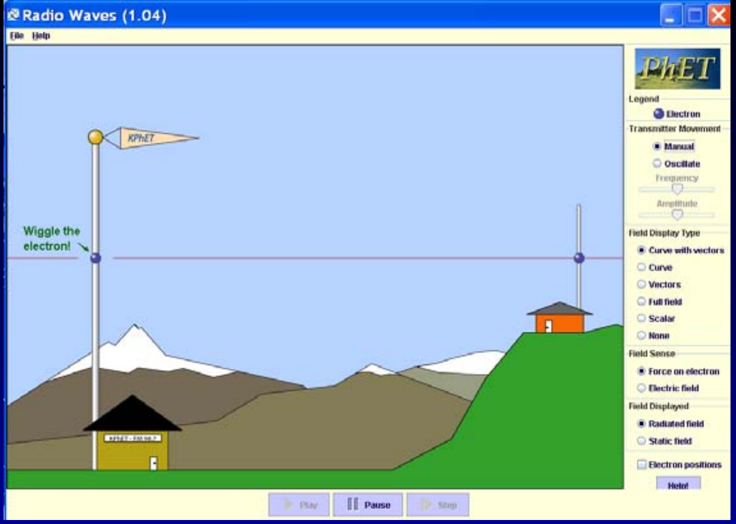
briefly discuss with neighbors, then will collect ideas

Why starting this way works so much better?

(talk with each other)



Why starting this way works so much better?



Matches research on learning.

- Cognitive demand. *Novices don't know what to focus on. treat everything equally important. Much more than short-term working memory can handle, overwhelming*

- Construction of understanding.

Other important features:

Visual model-electrons in transmitting and receiving antennas, display of waves

Interactivity

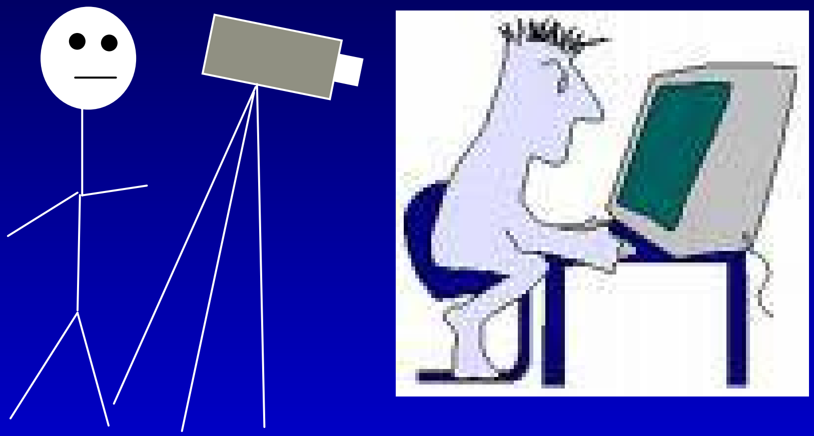
Example illustrates important principle:
students think and perceive differently from experts

Good teaching is presenting material so novice students learn from it, not so looks good to experts!

Violated by most simulations
(and many lecture demonstrations, figures in texts,…)

PhET sims almost never right the first time.
Test and modify to get right.

General results from student interviews*



1. Think aloud interviews (~200 hours)

Explore with guiding question

a. Surprisingly consistent responses, particularly on interface.

b. Vocabulary very serious hindrance to learning and discussion-- see because simulation removes

c. Animation ⇒attention, but not thinking.
Interactivity⇒ thinking & learning.

W. K. Adams, et al. , *A Study of Educational Simulations Part I - Engagement and Learning.*, *A Study of Educational Simulations Part II - Interface Design.*,

Interesting results from interview studies* (cont.)

d. the good, the bad, and the evil sim

Good sim is extremely effective for wide range of students: understand difficult concepts, can explain & apply to real world situations.

Bad sim- very little learned.
Awkward distracting interface, boring, confusing.

EVIL SIM--EFFECTIVE AT TEACHING WRONG THINGS!

e. Student testing critical! Interviews always reveal undesired perceptions or distractions in first versions!

f. A few important interface characteristics*

- Intuitive interactivity vital
- Controls Intuitive when most like hand action
  - Grab-able Objects
  - Click and Drag
  - Sliders to change numeric values
- Representations
  - Cartoon-like features $\Rightarrow$ scale distortion OK
  - Good at connecting multiple representations, but proximity and color coding helps (energy sktprk)

*more than want to know in Adams et al. papers

Simulation testing microcosm of education research

Routinely see examples of principles established in very different contexts.

- cognitive load
- construction of understanding
- build on prior knowledge
- connections to real world
- exploration and deep understanding $\Rightarrow$ transfer
- motivation--factors affecting and connections to learning
- perceptions based on organizational structures, structures change and develop, changes perception.
- …

Sims useful in variety of settings

Pre-class or pre-lab Activity

Lecture/classroom

Visual Aids, Interactive Lecture

Demos, & Concept tests

Labs/Recitations

Group activities

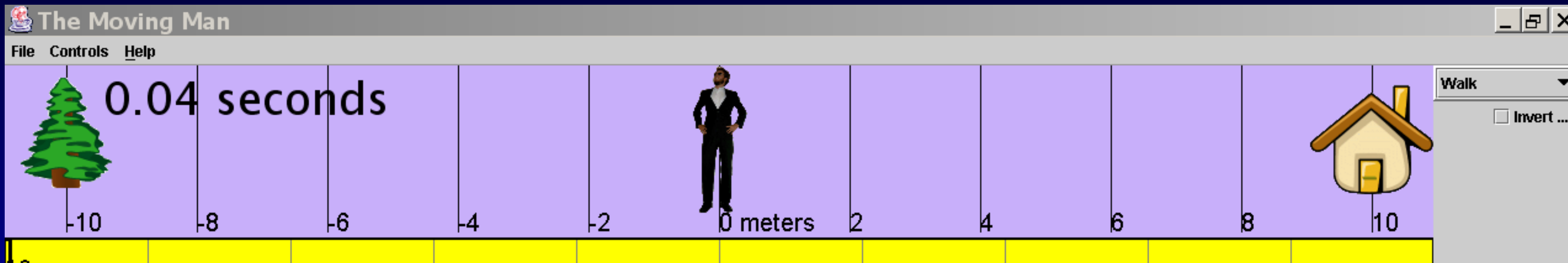
Homework

Need some structure--activities database

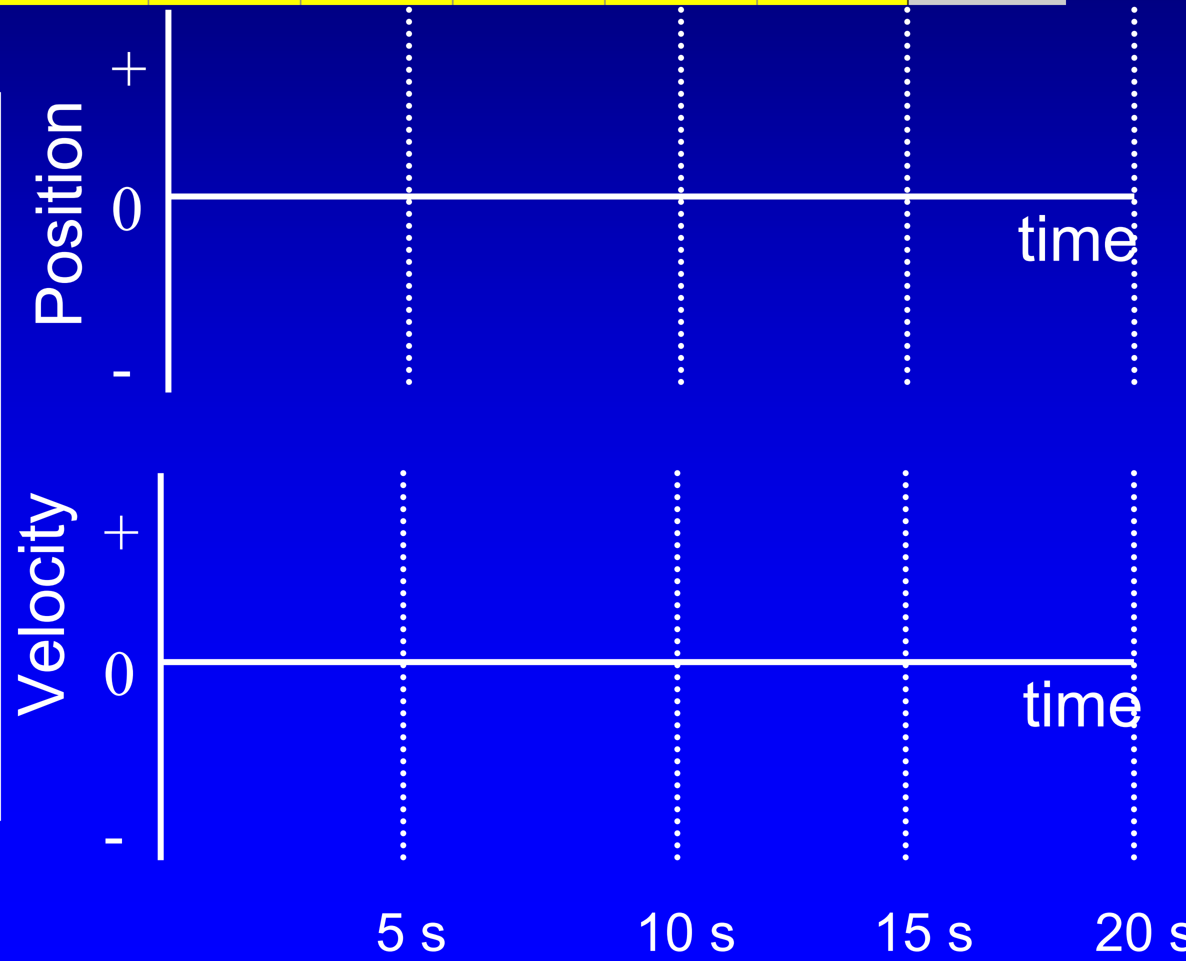
bits of examples of effectiveness in different settings

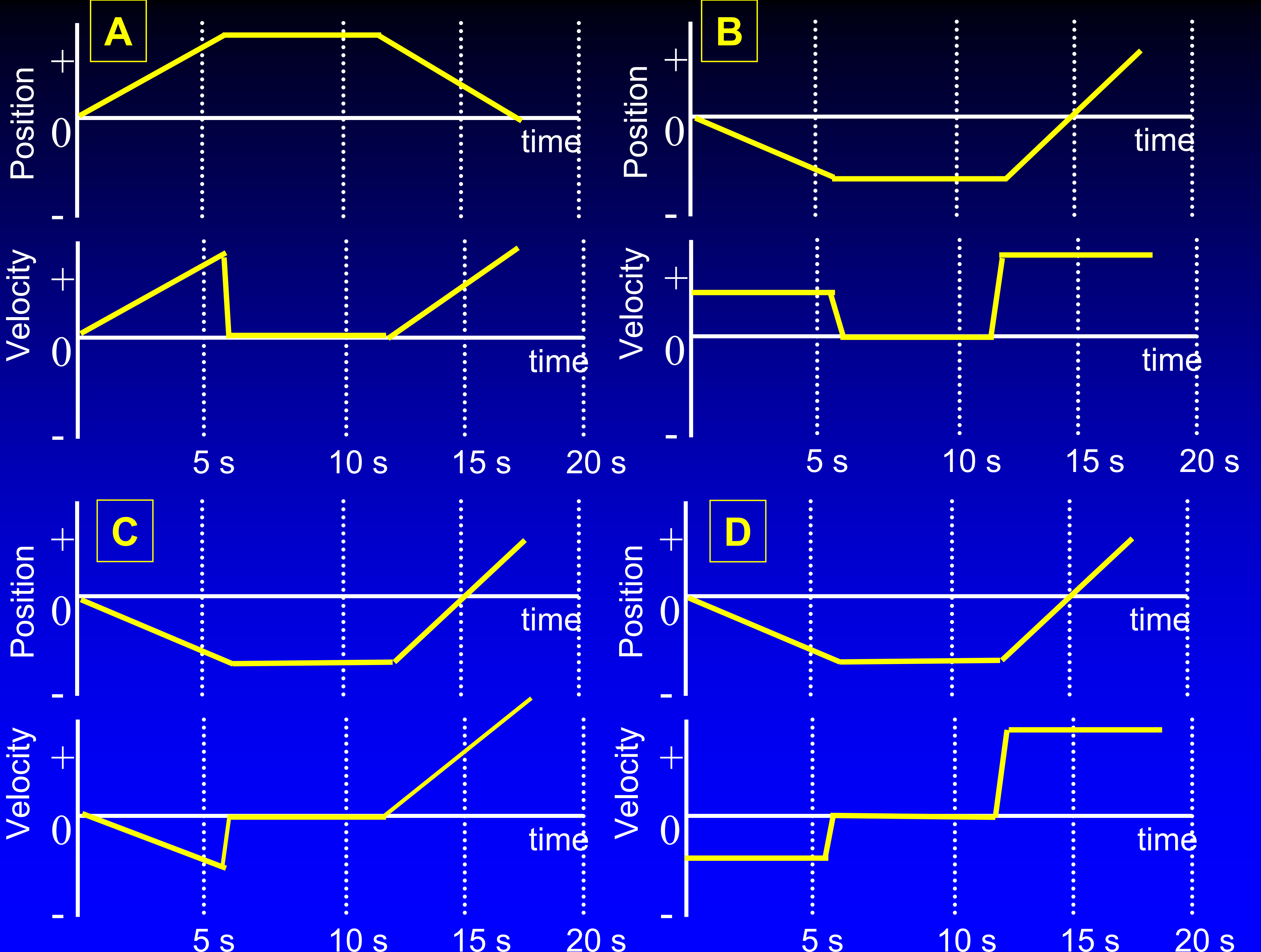
Lecture – Interactive Lecture Demos

Thorton and Sokoloff, 1997



Demo 4:
Sketch **position vs time** and **velocity vs time** graphs for when Moving Man:
walks steadily towards the tree for 6 seconds,
then stands still for 6 seconds, and
then towards the house twice as fast as before for 6 seconds.




A
B
C
D
Position
Velocity
+
0
-
time
5 s
10 s
15 s
20 s

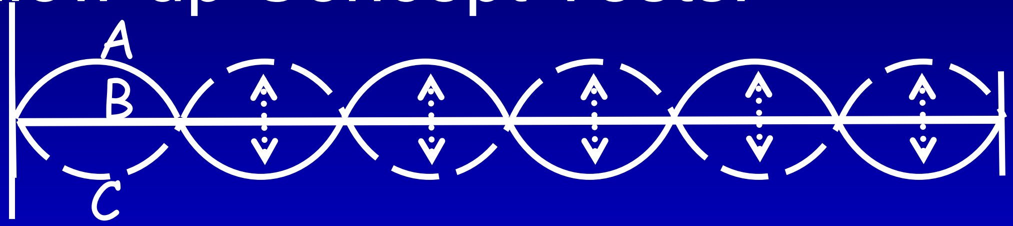
show wave on string

Lecture (Non-science Majors Course)

Standing waves-- Sim vs. Demonstration

Wave-on-string sim vs Tygon tube demo

Follow-up Concept Tests:



snapshots at different times.

1. 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 :
2002 demo: 27%
2003 sim: 71%

2. 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 :
2002 demo: 23 %
2003 sim: 84%

What features make the difference?

Features that make a difference-
experts hardly notice, BIG difference for novices

1. Green beads on string that show moves up and down, not sideways.

2. Speed set so novice brain can absorb and make sense of it. *("curse of knowledge")*

3. Can do controlled changes, most in response to student requests. Sort out what makes a difference and why.

What else does simulation provide over usual figure and explanation in lecture or textbook?

1. see direct cause and effect relations

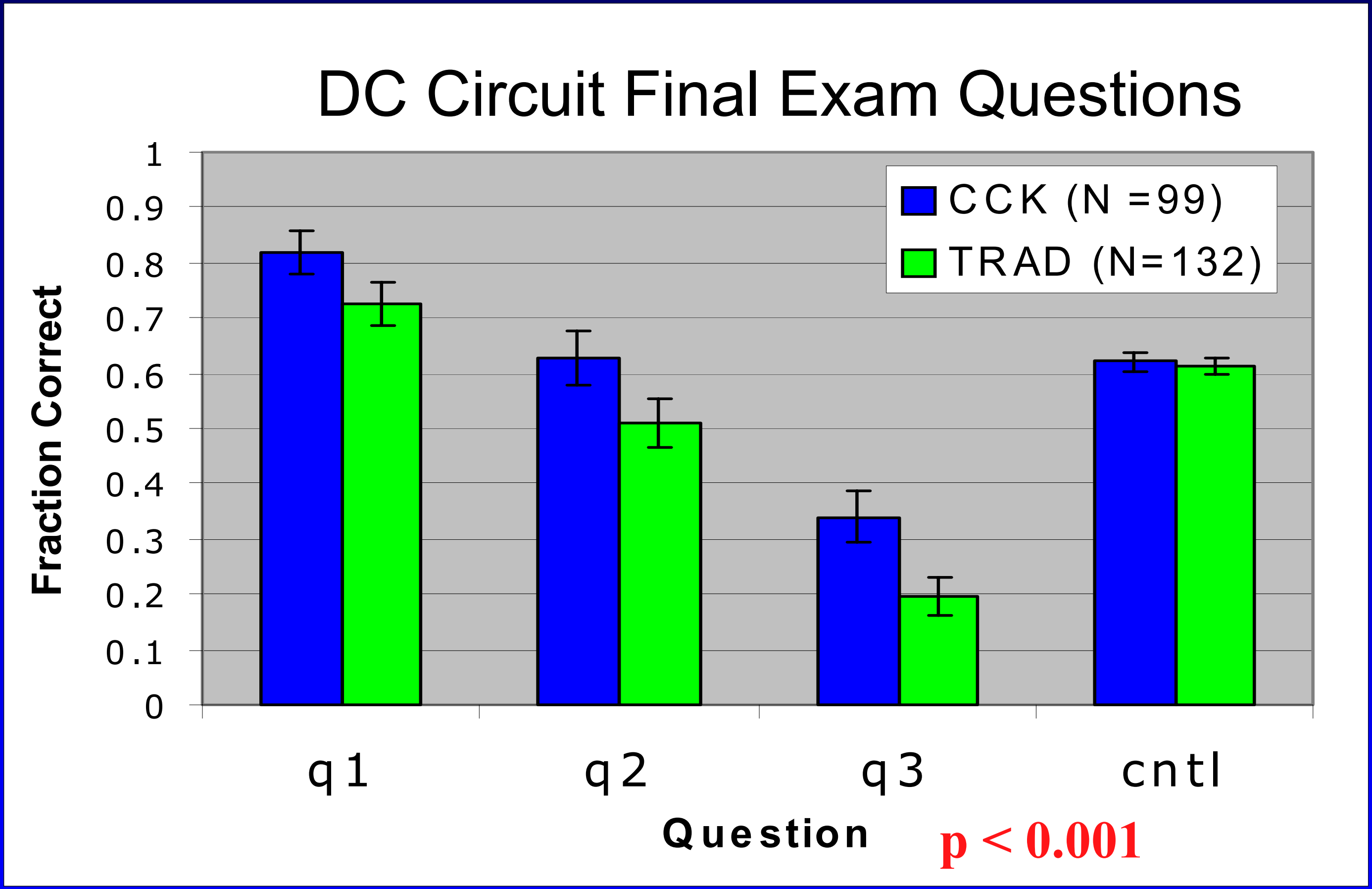
2. explicit visual models
example-electromagnet, friction, gas, cck

show cck

Standard Laboratory

(Alg-based Physics, single 2 hours lab):

Simulation vs. Real Equipment



N D. Finkelstein, et al, "When learning about the real world is better done virtually: a study of substituting computer simulations for laboratory equipment," *PhysRev: ST PER 010103 (Sept 2005)* many other examples of power of visual models

all of quantum! (S. McKagan)

quantum wave interference
lasers
Stern-Gerlach
MRI
tunneling
…

major impact on student thinking

Integrating a sim on a topic (Lect. & HW)

(Photoelectric Effect in Modern Physics) (S. McKagan, to be pub.)

Univ. of Wash.:

- Student learning of photoelectric effect deficient
- Developed & used Photoelectric Tutor (PT)

Exam Q: What would happen to current reading if you:

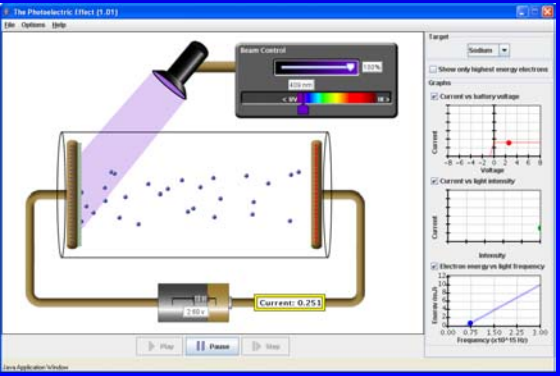
Q1: Changed metal. Why?

Q2: Double intensity of light. Why?

Q3: Increased ΔV across electrodes. Why?

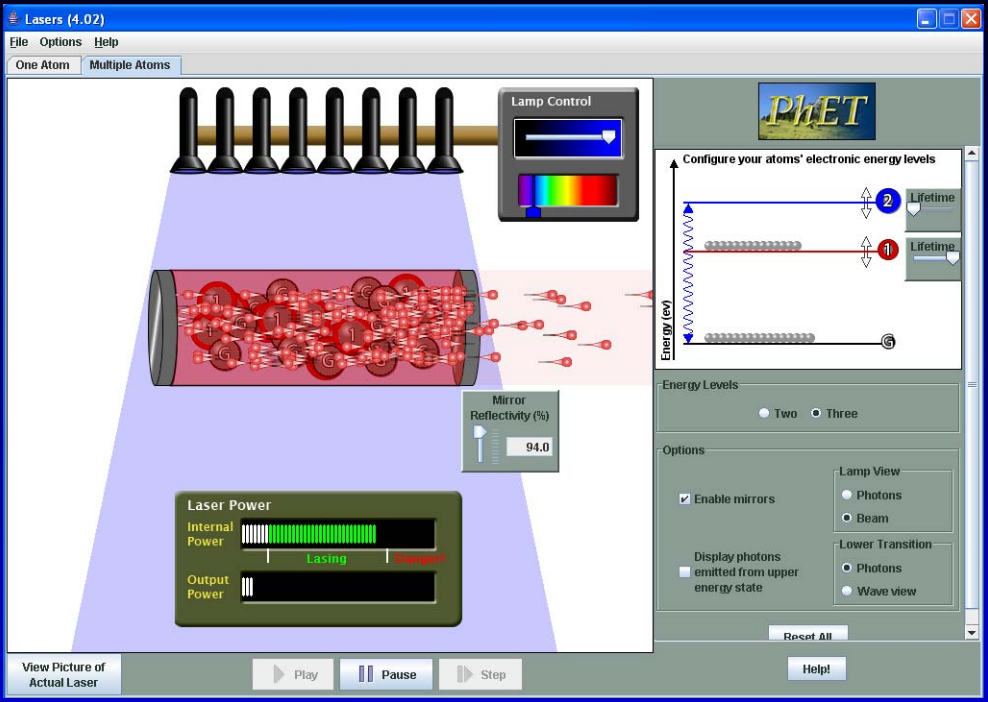
show photoelectric effect

CU: Incorporated sim



% Correct				
Course	**Q1**	**Q2**	**Q3**	**N**
UW w/o PT	65	40	20	26
UW w/ PT	75	85	40	36
CU Fa05	91	87	85	189
CU Sp06	86	88	84	182
CU Fa06	90	78	77	94

Lasers homework



Students work through sim, figure out:

- how to build a laser
- how to fix it if it breaks
- why population inversion necessary
- why need 3 energy levels instead of 2

*Homework available from PhET activities database

Conclusions:
Interactive simulations powerful new technology for learning science. But not automatically good.

phet.colorado.edu