

# PhET Interactive Simulations: Engaging students and supporting learning

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# Goals

Become familiar with PhET:

When, how, and why might you use a PhET sim?

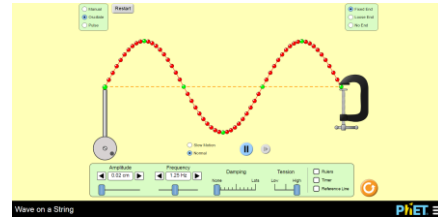
Explore different ways to use simulations in teaching

Use research findings around simulations to guide that use in class

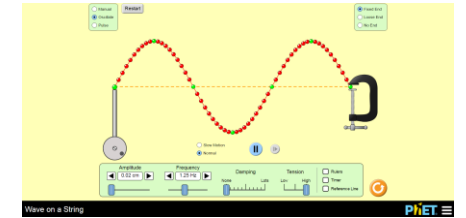
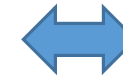
Look forward at the frontier of simulations in education

# PhET Overview

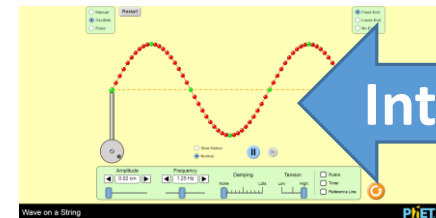
## Product Development



## Research



## Classroom



Integration

Teacher



Student



Student

# PhET Overview

Founded in 2002 by Carl Wieman  
(Originally Physics Education Technology project)

Nobel Prize in Physics



Physics 2000 (Marty Goldman, PI)

A screenshot of a web browser displaying the Physics 2000 website. The browser address bar shows "http://www.colorado.edu/physics/2000". The page title is "Bose-Einstein-Condensation". The main content area features several interactive applets: "Gas Temperature" (a box with particles), "Energy Levels" (a funnel-shaped energy level diagram), "Laser Cooling I" and "Laser Cooling II" (particle diagrams with laser beams), "Laser Cooling III" (a particle diagram with a laser beam), "Optical Molasses" (a cross-shaped laser beam diagram), "Magnetic Trapping" (a parabolic potential well diagram), and "Evaporative Cooling" (a particle diagram with a laser beam). The "Science Trek" logo is visible at the bottom of the applet area. A sidebar on the left contains a navigation menu with categories like "Physics 2000", "Einstein's Legacy", "The Atomic Lab", and "Science Trek".

# PhET Overview

## PhET Interactive Simulations

140+ simulations & 1600+ sim-based lessons

Physics, Chemistry, Math, Earth Science, Biology

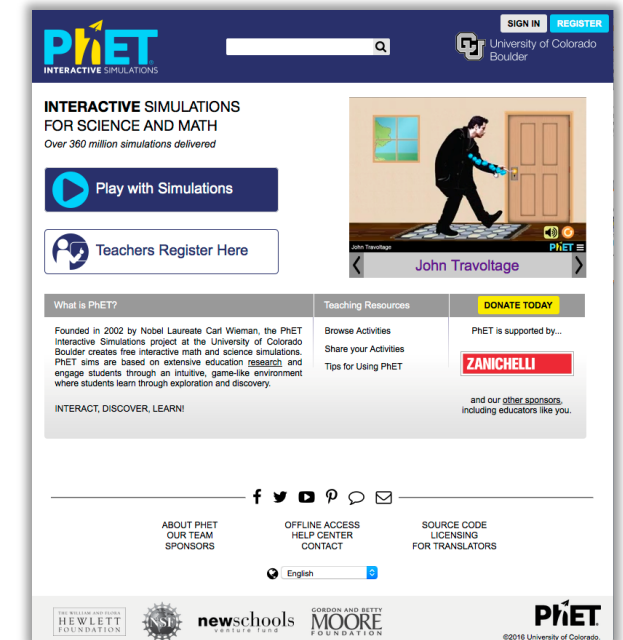
Research-based and user-tested

K-12 and College

Open education resources (free)

Java, Flash, and HTML

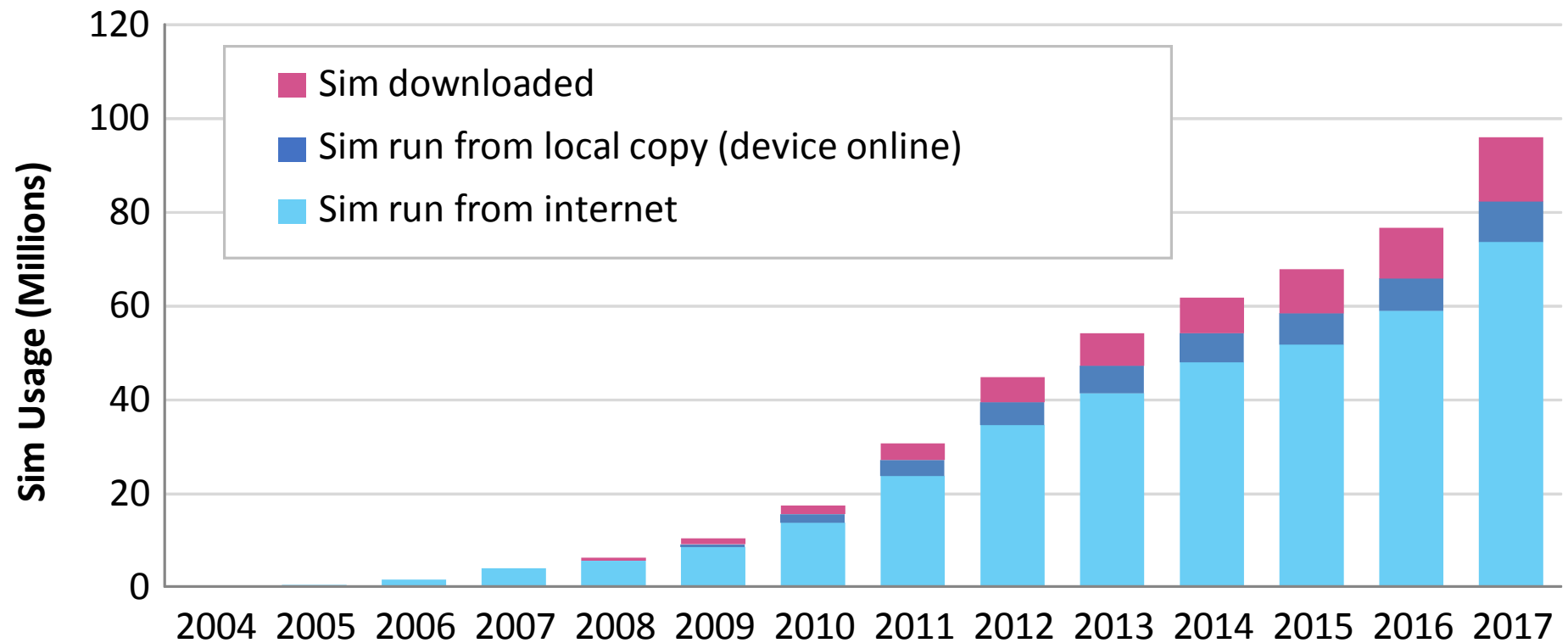
Run online or offline



# PhET Overview

## Over 80 Million Uses/Year

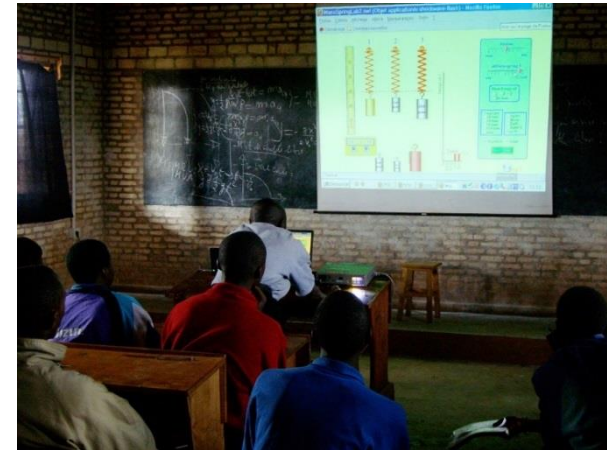
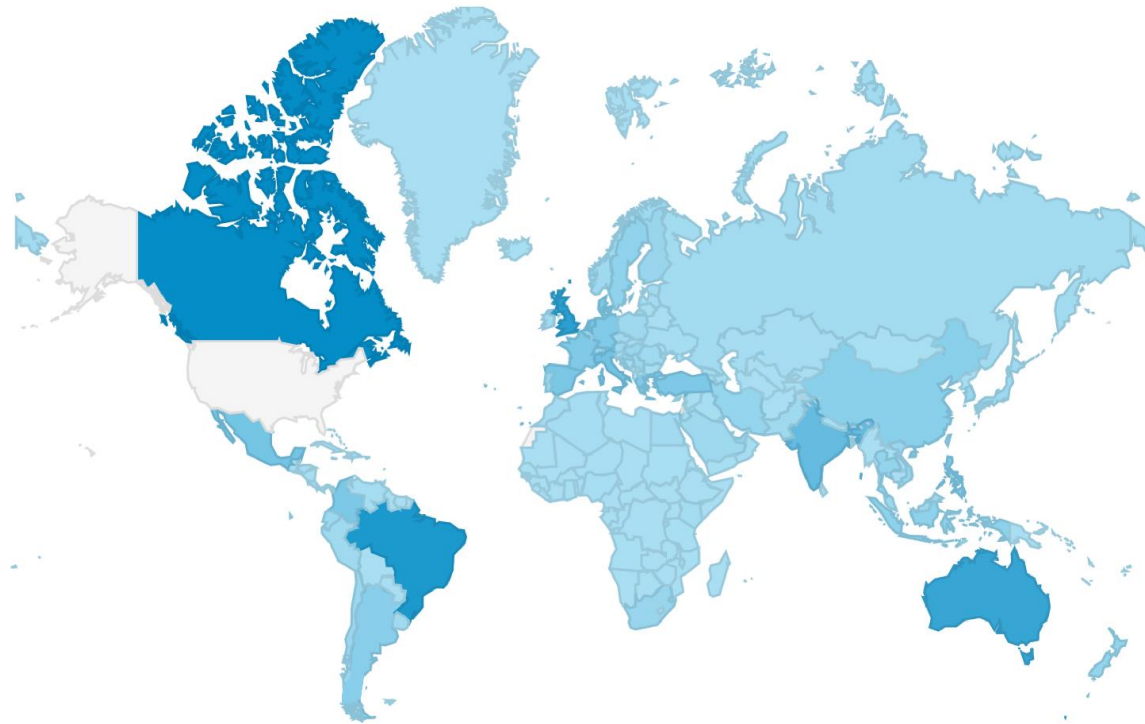
PhET simulation usage: All sims – HTML, Java, Flash  
(2017 projections based on measured 25% growth in Jan-Mar 2017)



# PhET Overview

## Global

~33% International. In 90 languages.



BURUNDI

# Sim Tour

## Examples

The 'Bending Light' simulation interface features a central circular protractor with a red laser ray passing through its center. The ray is incident on a horizontal boundary between two media. The top medium is labeled 'Material: Custom' with an 'Index of Refraction (n)' of 1.00. The bottom medium is also labeled 'Material: Custom' with an 'Index of Refraction (n)' of 1.60. A red ray is shown reflecting off the boundary and another red ray is shown refracting into the bottom medium. The interface includes a 'Ray' selection button, a 'Normal' checkbox, and a 'PiET' logo at the bottom.

The 'Gravity And Orbits' simulation interface shows a yellow sun in the center and a blue planet in orbit. A red arrow indicates the planet's velocity vector. The interface includes a 'Gravity' toggle (on/off), a 'Velocity' checkbox, and a 'Path' checkbox. It also features sliders for 'Star Mass' (0.5 to 2.0) and 'Planet Mass' (0.5 to 2.0). Playback controls include 'Fast Forward', 'Normal', and 'Slow Motion' buttons, along with a '71 Earth Days' timer and a 'Clear' button. The 'PiET' logo is at the bottom.

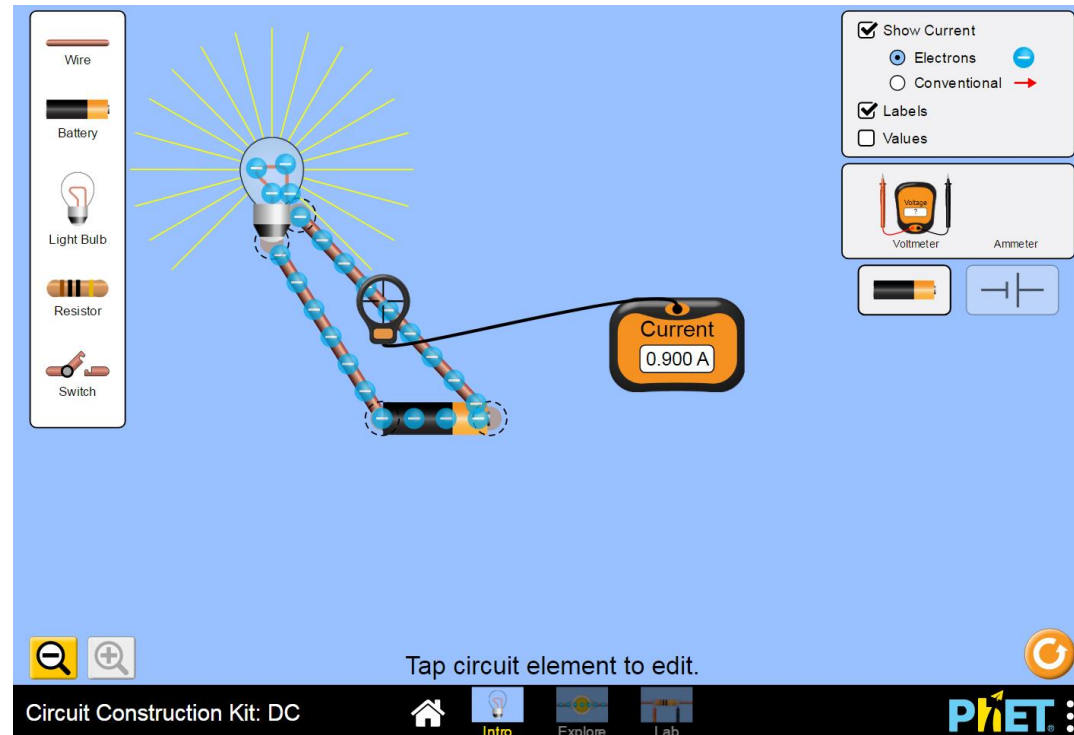
The 'Circuit Construction Kit: DC' simulation interface displays a circuit with a battery, a light bulb, a resistor, and a switch. A current meter shows a reading of 0.900 A. The interface includes a 'Show Current' section with options for 'Electrons' and 'Conventional', and checkboxes for 'Labels' and 'Values'. It also features a 'Voltmeter' and an 'Ammeter' icon. The 'PiET' logo is at the bottom.

The 'Wave on a String' simulation interface shows a string oscillating on a screen. The string is represented by a series of red and green dots. The interface includes a 'Restart' button and a 'Manual' selection button. It features sliders for 'Amplitude' (0.75 cm), 'Frequency' (1.50 Hz), 'Damping' (None, Lots), and 'Tension' (Low, High). There are also checkboxes for 'Fixed End', 'Loose End', 'No End', 'Rulers', 'Timer', and 'Reference Line'. The 'PiET' logo is at the bottom.



# Sim Design

## Implicit Scaffolding



*Adams et al. (2008a), J. Interactive Learning Research*

*Adams et al. (2008b), J. Interactive Learning Research*

HIGHLY INTERACTIVE

IMMEDIATE DYNAMIC FEEDBACK

REAL WORLD CONNECTIONS

ACCURATE, DYNAMIC VISUAL  
MODELS & REPRESENTATIONS

SHOWS THE INVISIBLE

SCAFFOLDED THROUGH DESIGN

ALLOWS ACTIONS NOT POSSIBLE  
IN THE REAL WORLD

INTUITIVE INTERFACE

# Sim Design

## Support Multiple Learning Goals

**CONTENT:** Concepts, Models, Representations, Relationships

**PROCESS:** Explore, Question, Design, Predict, Data, Evidence, Reason

**SOFT SKILLS:** Argumentation, Collaboration, Planning, Reflection

**HARD SKILLS:** Lab techniques, Quantitative problem solving

**AFFECTIVE:** Enjoyable, Understandable, Relevant, Student Agency

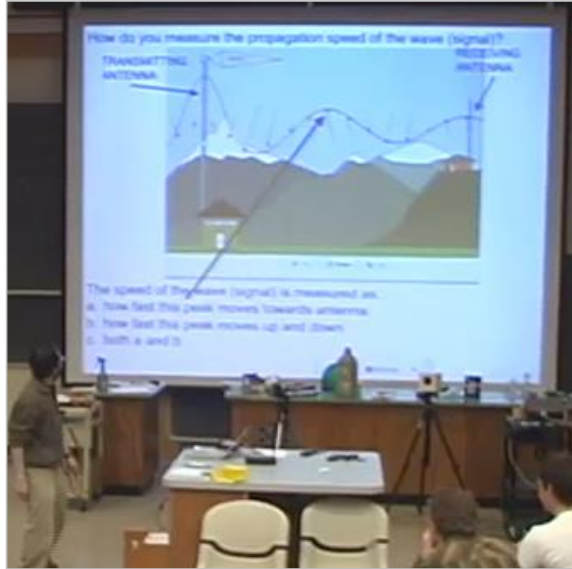
Sim-based  
Learning

How might you use  
these sims in your school?

# Sim-based Learning

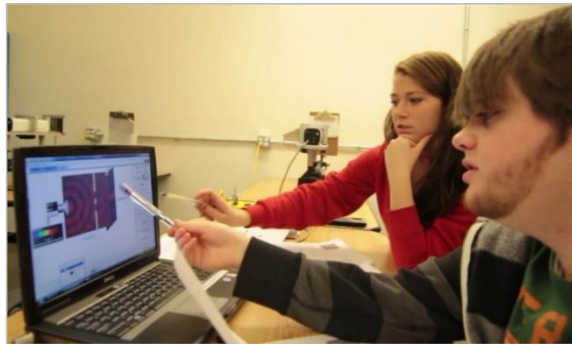
# Versatile tool for teaching and learning

Interactive Lecture



Lecture Tutorial

Activity/  
Lab



First, students make predictions and then investigate with the sim.

To answer the following questions, you should use the [PHET photoelectric effect simulation](#).

7. (1 pt) Suppose you set up the experiment so that the plate is ejecting electrons. Predict which of the following changes to the experiment could increase the maximum initial kinetic energy of the ejected electrons. (Select all that apply.) Then test your prediction.

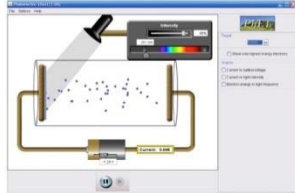
- A. Increasing the intensity of the light beam
- B. Decreasing the intensity of the light beam
- C. Increasing the wavelength of light
- D. Decreasing the wavelength of light
- E. Increasing the frequency of light
- F. Decreasing the frequency of light
- G. Increasing the voltage of the battery
- H. Decreasing the voltage of the battery
- I. Replacing the target with a material that has a larger work function
- J. Replacing the target with a material that has a smaller work function

A short essay is used to emphasize the importance of **explaining concepts** in every-day language.

12. (essay) Explain what the phrase - 'the work function for sodium' - means in a way that would make sense to a non-science person.

Finally, using the simulation's "mystery metal" feature, students have to **develop their own procedure** for measuring the work function in a real experiment (there are several ways to do this with the sim).

You have a plate of metal, but you have no idea what kind of metal it is. You come up with the brilliant idea of increasing the work function of this metal by using it as the target in a photoelectric effect experiment. You can perform this experiment virtually by selecting "???" as the target in the simulation. What is the work function, in eV, of the mystery metal?



Pre-lab/  
Pre-class/  
Homework

# Sim-based Learning

## **Engaging Students in Lecture**

Lecture Demonstration / Visualization

Coupled with Concept Tests and Peer Instruction

Interactive Lecture Demos

Interactive Discussion with Predications

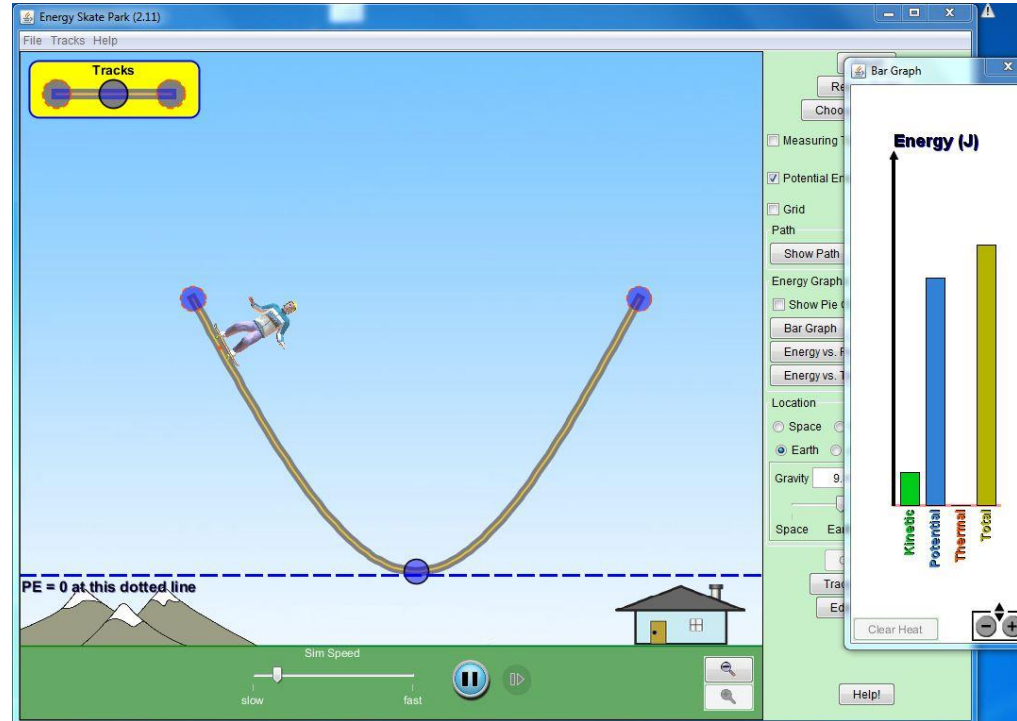
Whole Class Inquiry (student-suggested experiments)

**See Teaching Resources for helpful videos:**

<http://phet.colorado.edu/en/teaching-resources/usingPhetInLecture>

# Sim-based Learning

## Concept Questions



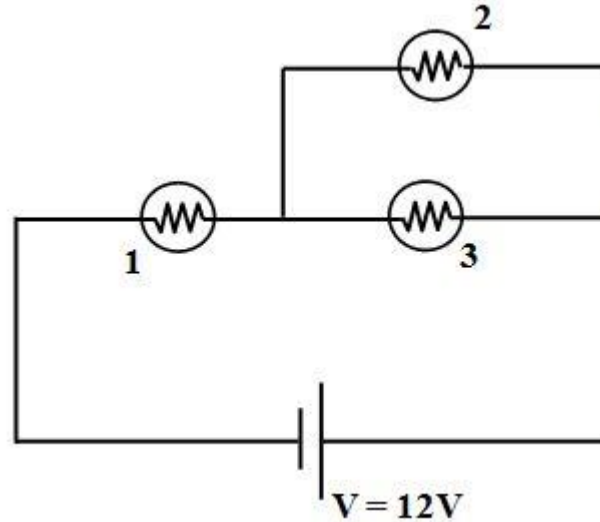
I move the zero of PE up to the starting point of the Skateboarder (skateboarder still starts from rest).

The total energy of the system is now:

- A) Zero
- B) Positive
- C) Negative
- D) Depends on the position of the skateboarder

# Sim-based Learning

## Concept Questions

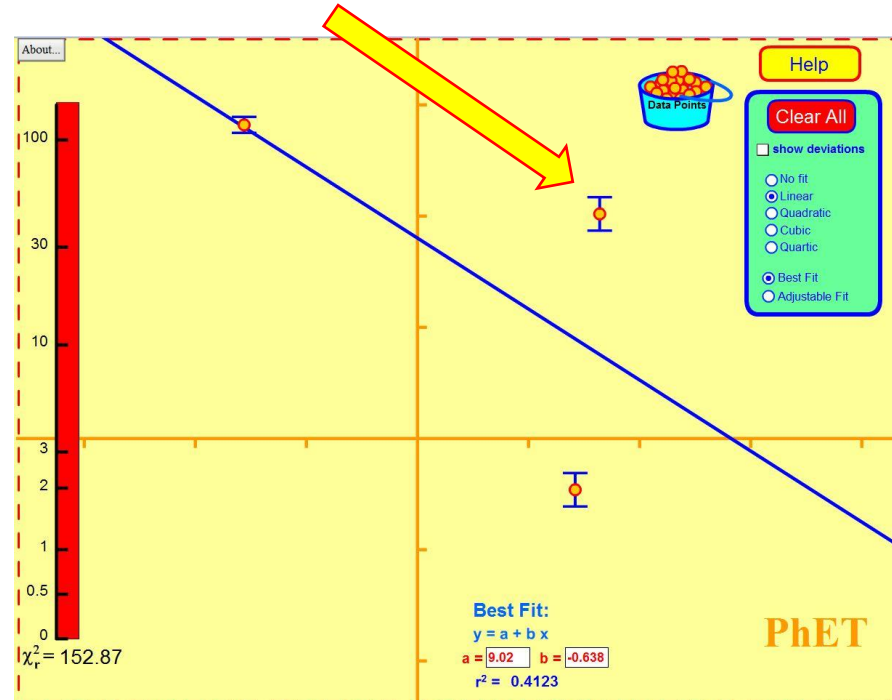


What happens to the brightness of bulb 1, when bulb 2 burns out? (When a bulb burns out, its resistance becomes infinite.)

- A) Bulb 1 gets brighter
- B) Bulb 1 gets dimmer.
- C) Its brightness remains the same.

# Sim-based Learning

## Concept Questions



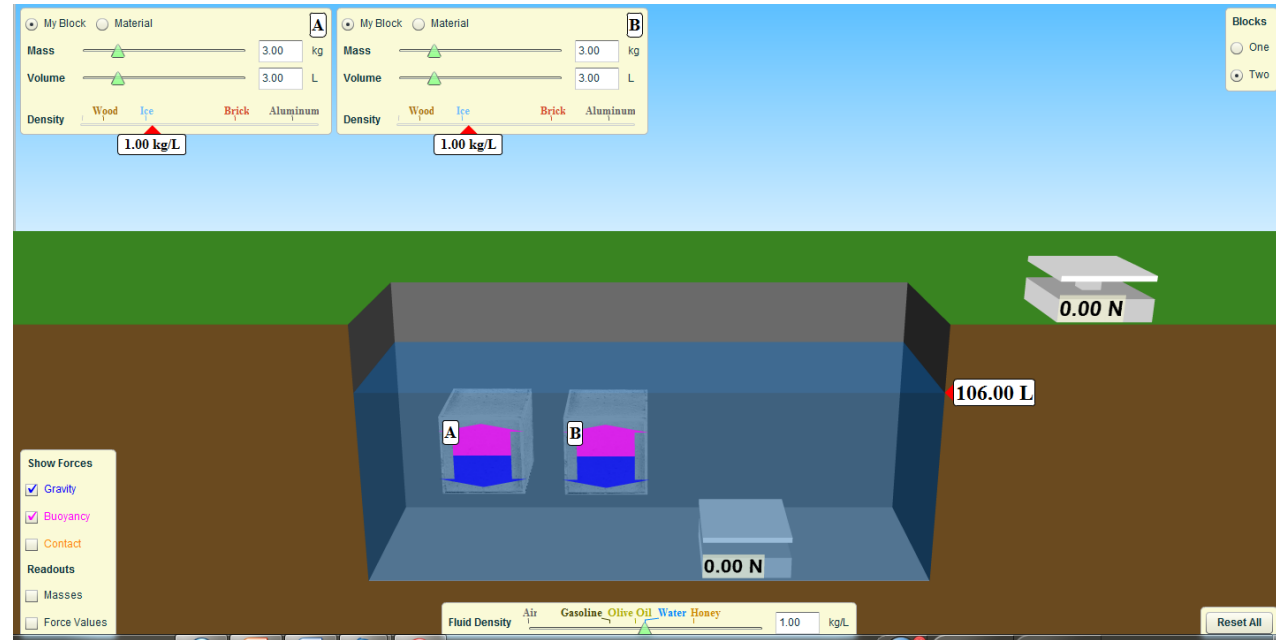
If we increase the error bar on the data point shown, what happens to the slope of the best-fit line?

- A) It becomes more negative (line tilts CW).
- B) It becomes less negative (line tilts CCW).
- C) It does not change.



# Sim-based Learning

## Whole Class Inquiry



What change would make these blocks float?  
And why?  
(How many strategies can you find!)

A look  
inside the  
classroom

## Concept test & Follow-up discussion

Is there a force of friction acting on my laptop which is sitting stationary on the table?

- A) Yes
- B) No
- C) Not sure



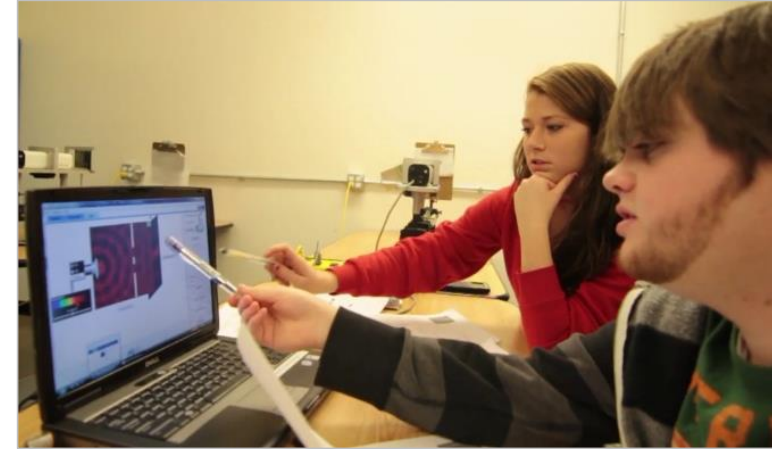
A look  
inside the  
classroom

## Follow-up discussion



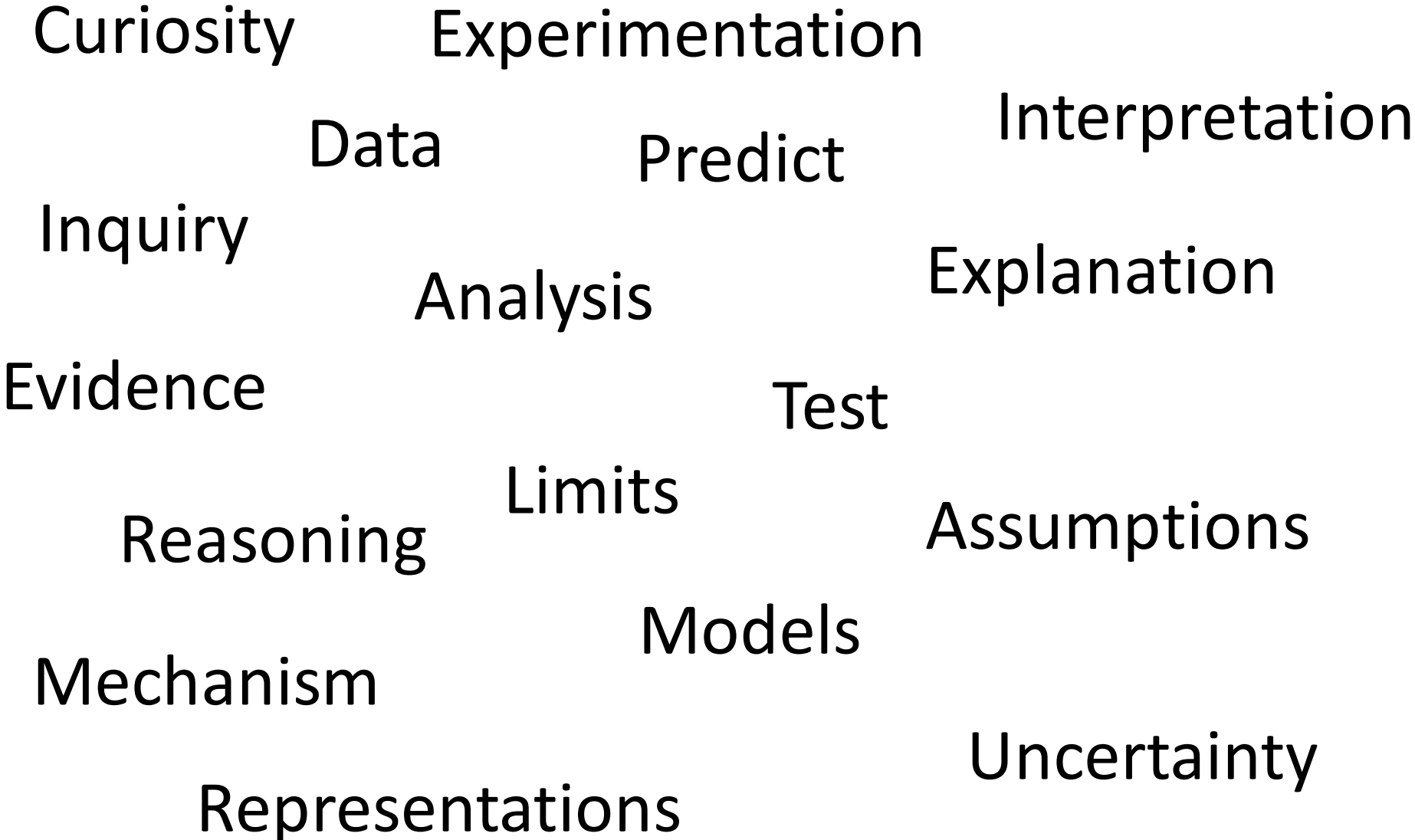
# Sim-based Learning

## Instructor versus Student Control



Opportunity for students to engage in and think about exploration, experimentation, design, evidence

# Science



# Science Learning

Science learning often far from science practice

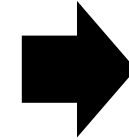
In lab:  
Specific  
Procedures

In class:  
Content  
Knowledge

# The Challenge

## Learning science through science inquiry

Science Inquiry  
Scientific Practices  
Problem Solving



Advance (their)  
understanding,  
knowledge, and  
ideas

# A look inside the classroom

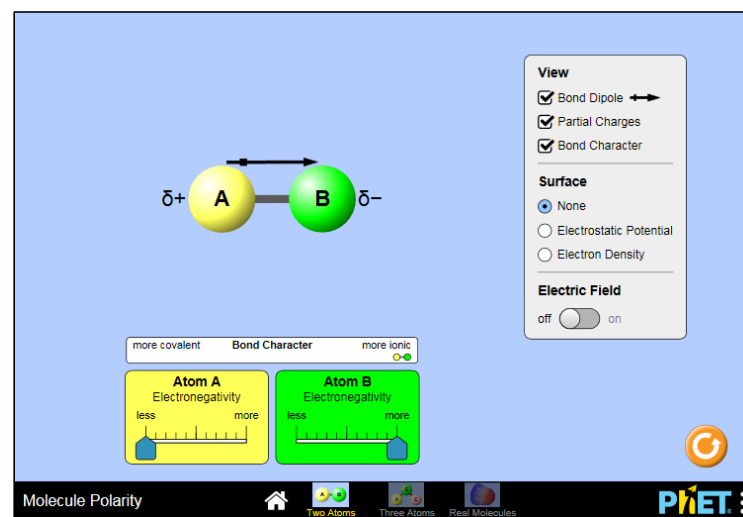
Wrap up of Molecule  
Geometry Topic  
**20 min.**

Sim  
Exploration  
**10 min.**

Guided-Inquiry Activity  
with Sim  
**25 min.**

## Molecule Polarity Sim

80 Students

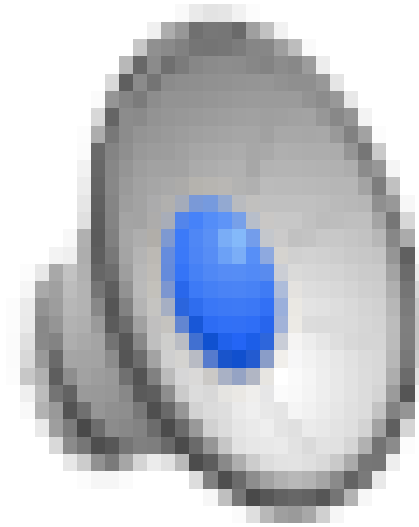


Moore et al. *Chemistry Education Research and Practice*, 14(3), 257-268, 2013.



A look  
inside the  
classroom

## Initial Exploration (first 2:20)



*Moore et al. Chemistry Education Research and Practice, 14(3), 257-268, 2013.*

A look  
inside the  
classroom

## Science Practices Observed

Messing around

Sensemaking

Experimentation

Reasoning

Identifying Relationships

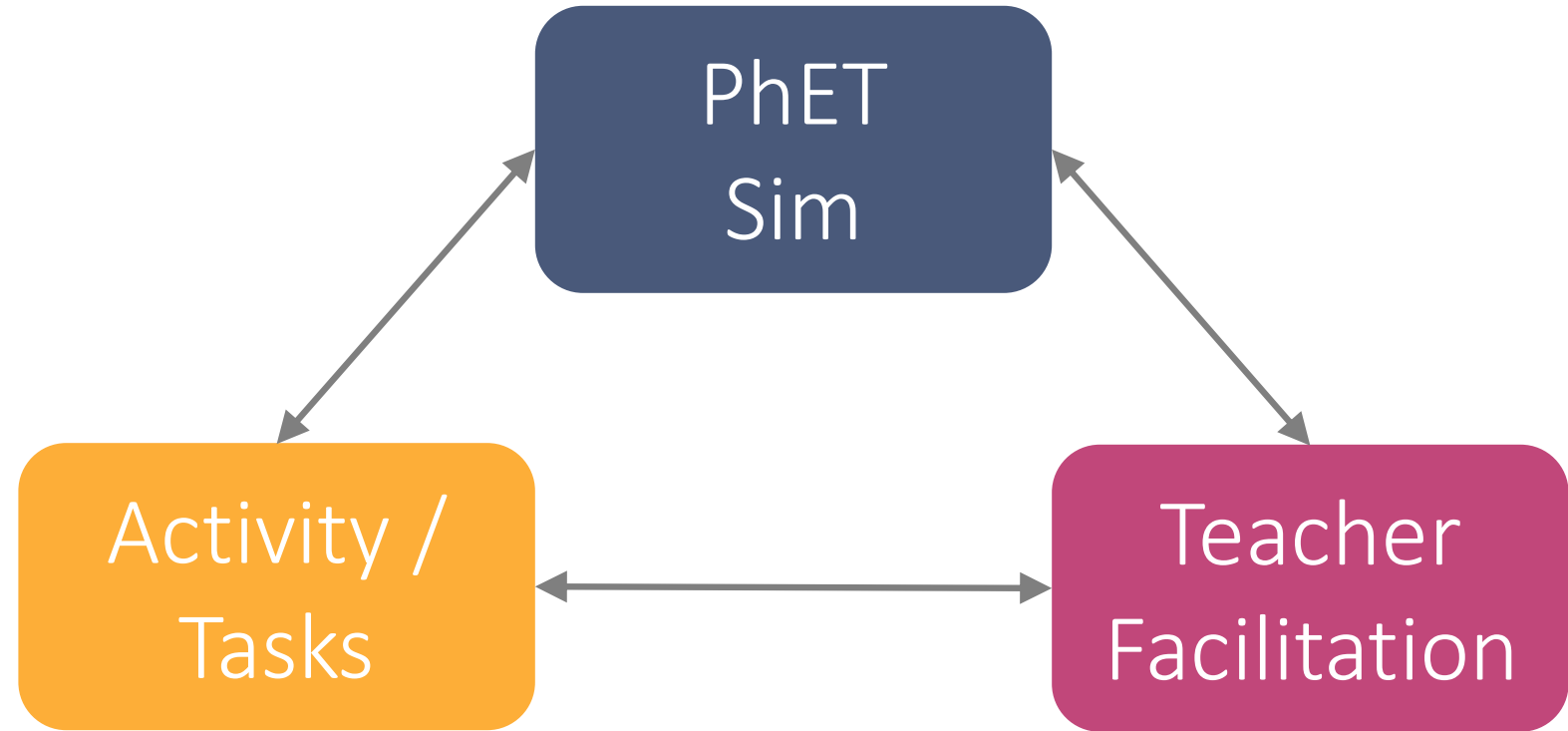
Testing

Predication

Asking Questions

Sim-based Learning

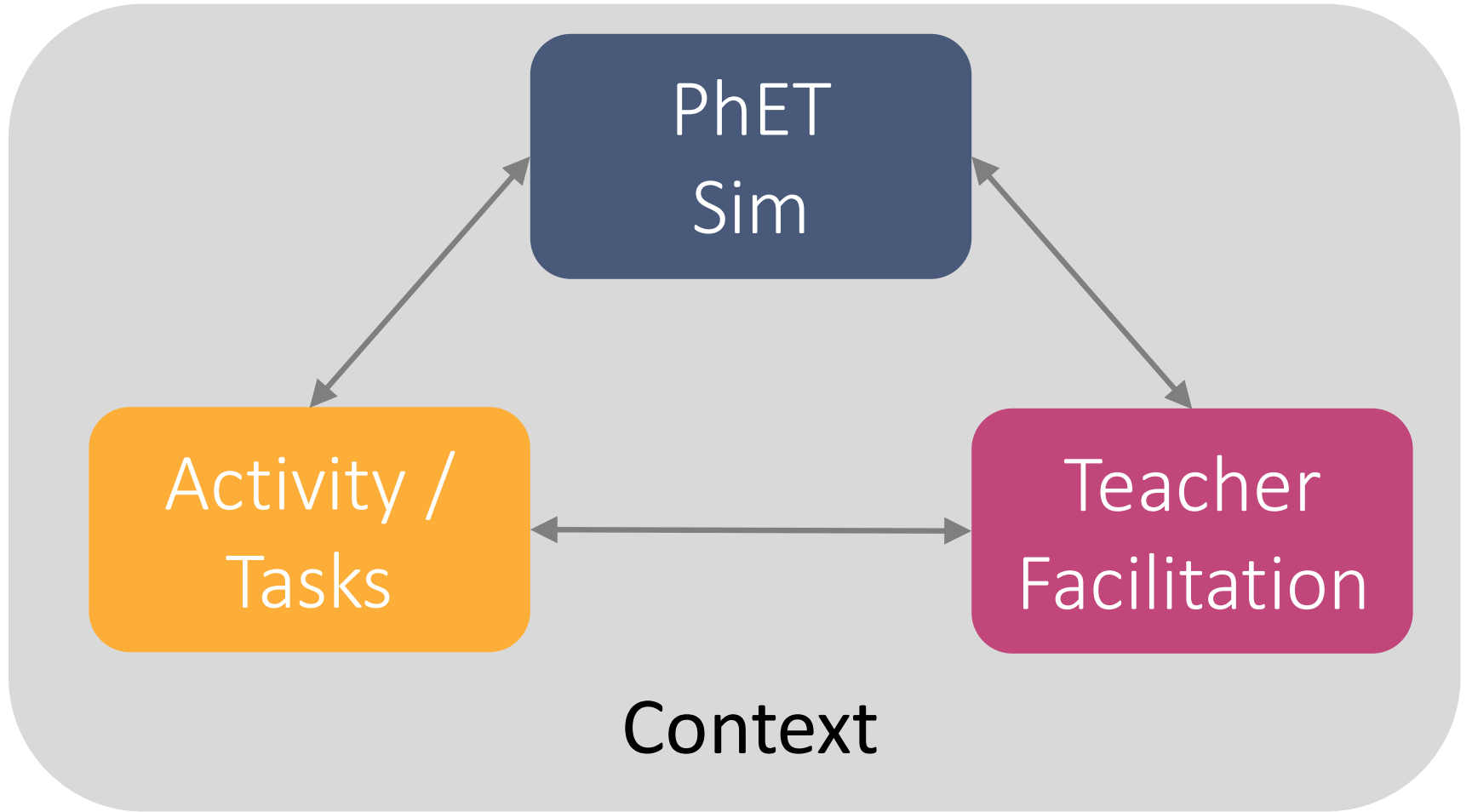
## Creating Sim-based Learning Environments



Distributed Scaffolding

# Sim-based Learning

## Creating Sim-based Learning Environments



# Sim-based Learning

## Strategies for designing sim-based activities

Start with open play

Avoid explicit instruction

Leverage affordances of the sim

Use open, investigative questions and challenge prompts

More at: <https://phet.colorado.edu/en/teaching-resources/tipsForUsingPhet>

# Sim-based Learning

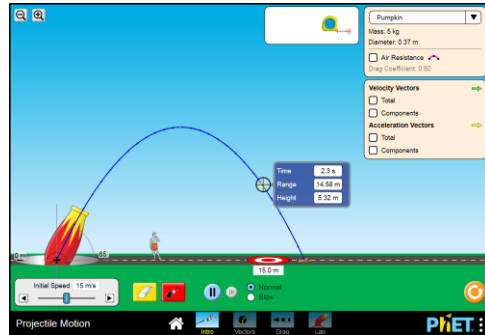
## Strategy: Use Challenge Prompts

### Not this

Set the canon angle to 45 degrees ...

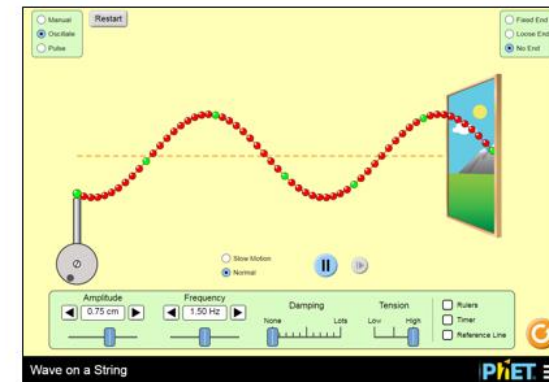
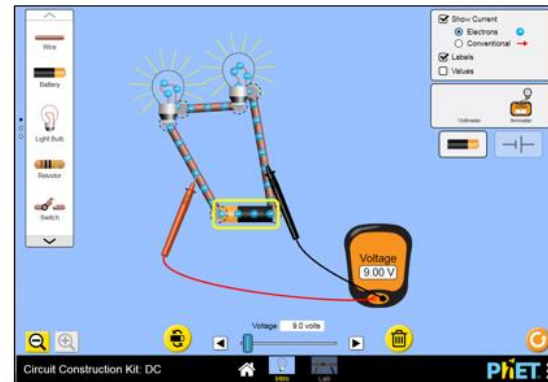
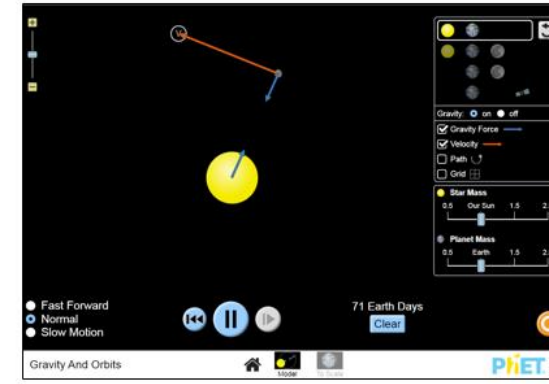
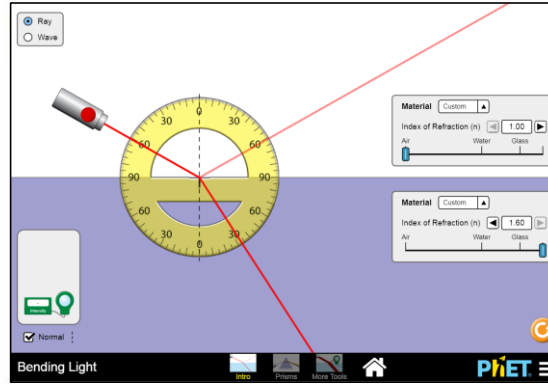
### This

What are all the ways to affect projectile distance?



# Mini design task

Pick one sim and write a challenge prompt



# Example Activity

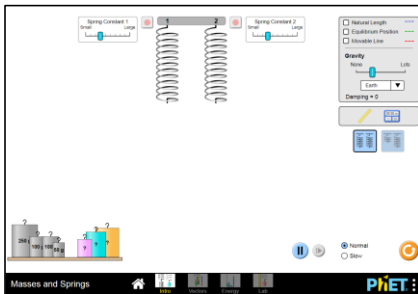
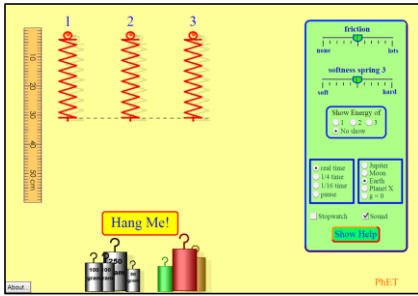
## Masses and Springs

5-10 minutes of play – No instructions.

**Challenge 1:** Using data from the sim, make a graph that shows whether or not the springs obey Hooke's Law.

**Challenge 2:** What is the mass of the red weight?

**Challenge 3:** Determine the spring constant in two different ways: with your graph from (1) and with the stopwatch.






# Sim-based Learning

# Activity Design and Facilitation Resources

Video Series

**Video Series: Facilitating PhET Activities in K12 Classrooms**

A video series that discusses key things to consider when preparing to use and then facilitating activities with PhET simulations. Focused on K12.



[1] Facilitating Activities in K-12: Preparing for a PhET acti...

Designing PhET Activities for the K12 Classroom | Facilitating Activities with PhET: An Overview | [1] Facilitating Activities in K-12: Preparing for a PhET

Course Alignment Documents

**PhET** Plans for using PhET simulation activities in Loeblein's HS Physics

IC In-Class Activity: CQ (clicker questions); HW (homework); Demo: teacher centered group discussion

**Semester 1**

Unit 1: **Introduction to Motion:**  
Moving Man IC/CQ  
Calculus Grapher HW/CQ

Unit 2: **More on motion and Measurement**  
Vector Addition IC/CQ  
Projectile motion IC/CQ

Unit 3: **Forces and the Laws of Motion** Publishing skills: curve fit, drawing, tables  
Forces and Motion: Two activities IC/CQ  
Ramp- Force and Motion: Two activities IC/CQ  
Maze Game: HW/CQ  
Curve Fitting: HW

Unit 4: **Work, Energy, Momentum and Collisions**  
Energy Skate Park: Four activities IC/CQ  
Masses and Springs: IC/CQ  
Collision: HW

Unit 5: **Circular Motion and Semester Project**  
Pendulum: HW/CQ  
Gravity Force Lab: IC/CQ  
Pendulum: HW

Activity Writing Guide

**Prompts and Tables**

**Prompts to Encourage Targeted Inquiry:**

- Find all the ways to... make a complete circuit.
- What's the largest... molecule you can make?
- How many... collection boxes can you fill in 5 minutes?
- List all the essential items to...make a circuit.
- What are two ways to...get the sleepy dog to move?
- How can you make...the gravity force...bigger?
- Develop a procedure for... comparing the densities of two objects with different mass.

**Effective Table Structures:**

**Cueing Variables:** This structure cues students to make comparisons between variables.

Environment	Selection Factor	Material	Basis 1 Take Over?	Basis 2 Dis-Over?	Observations
			<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No	

**Cueing Cause/Effect Relationships:** This structure cues students to notice important effects of an action within the sim.

Action	Gravity Force
Put one and ghost closer together	<input type="checkbox"/> Increases <input type="checkbox"/> Decreases
	<input type="checkbox"/> Increases <input type="checkbox"/> Decreases
	<input type="checkbox"/> Increases <input type="checkbox"/> Decreases

**Cueing Classification:** This structure cues students to classify objects into distinct categories and is useful for organizing cause/effect relationships.

Good Conductors	Weak Conductors	Insulators
How can you tell something is a good conductor of electricity in the sim?	How can you tell something is a weak conductor of electricity in the sim?	How can you tell something is an insulator of electricity in the sim?

Facilitation Guide

**PhET** Facilitation Strategies for Inquiry-based, In-class Activities using PhET Simulations <http://phet.colorado.edu>

Here we describe effective strategies for facilitation of activities using PhET simulations (sims) in elementary and middle school classrooms. These strategies are derived from observations of teachers using a range of PhET sims in a classroom setting. These strategies are not meant to be strict "step-by-step" directions, nor do they include all possible effective strategies. Rather, these strategies can be adapted to the particulars of different grades, teacher preferences, and classroom environments.

Overall, this collection of strategies aims to support inquiry-based learning. Through the use of PhET sims, students explore new ideas, take ownership of their own learning, and cultivate positive attitudes toward science.

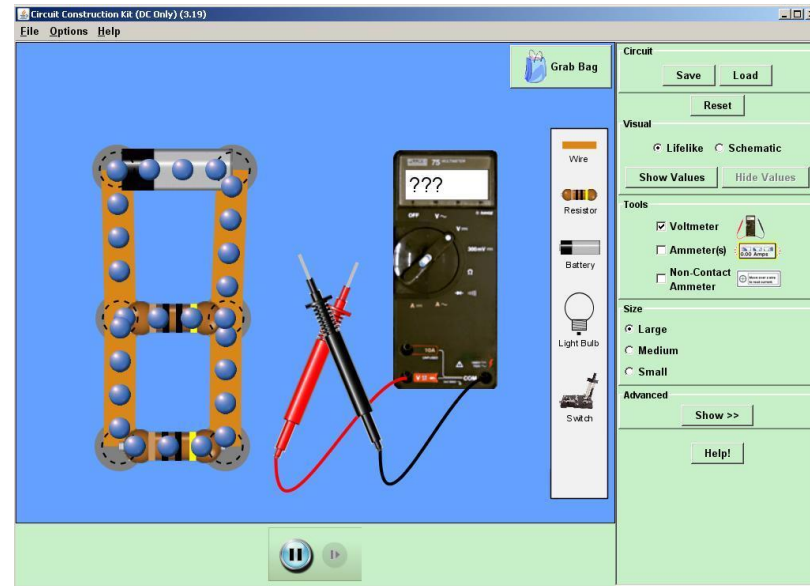
**Outline:**

1. **Goals for Teachers:** Describes what teachers can achieve through implementation of these strategies.
2. **Facilitation Objectives and Strategies:** Introduces 6 objectives of sim-based activity facilitation and suggests specific facilitation strategies.
3. **Monitoring and Measuring Student Learning:** Discusses strategies for monitoring understanding throughout sim use, and the optional use of written assessments.
4. **Example of Activity Facilitation Sequence:** Demonstrates facilitation strategies and sequencing within an example lesson.
5. **Preparation:** Provides a summary of important preparation steps, including creating the lesson, preparing the classroom, and preparing to teach.
6. **Teacher reflection:** Suggests approaches for reflecting on teaching and learning, including a rubric for characterizing lesson qualities.

<https://phet.colorado.edu/en/teaching-resources>

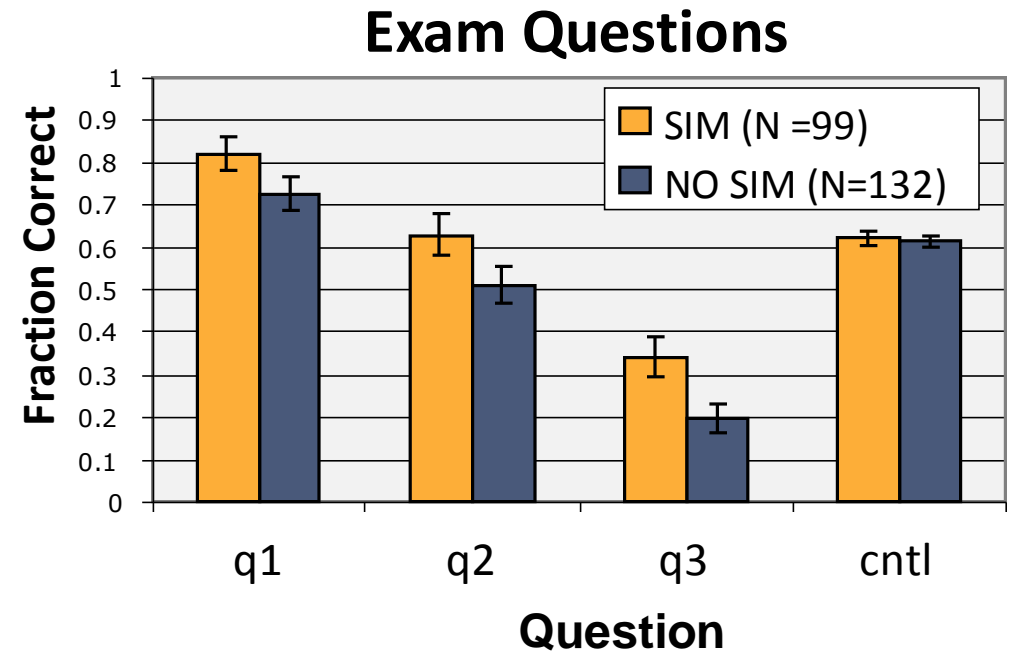
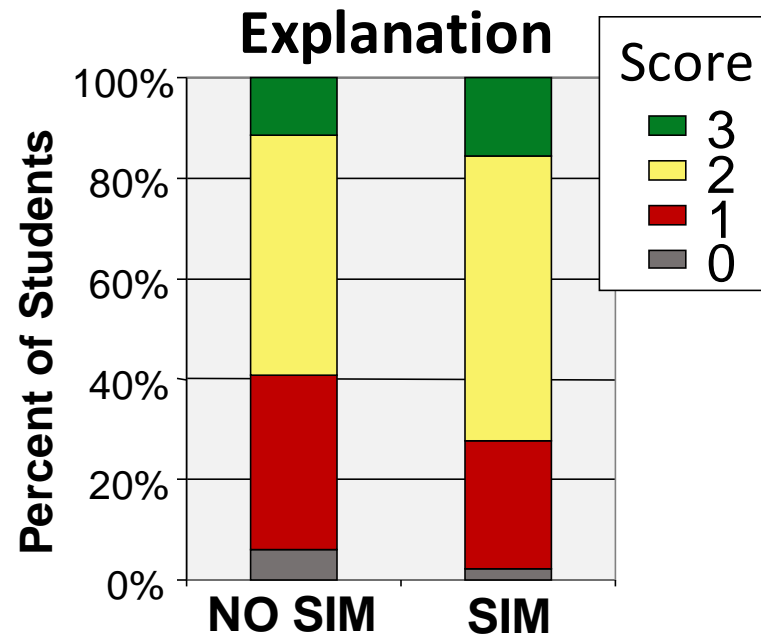
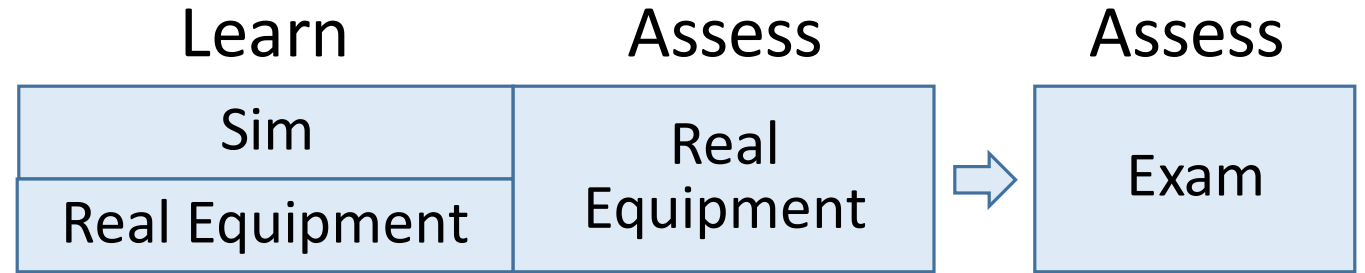
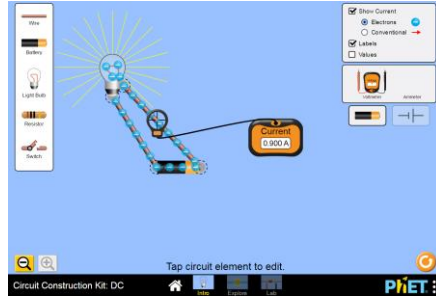
# Sim-based Learning

## Compare and Contrast



# Sim-based Learning

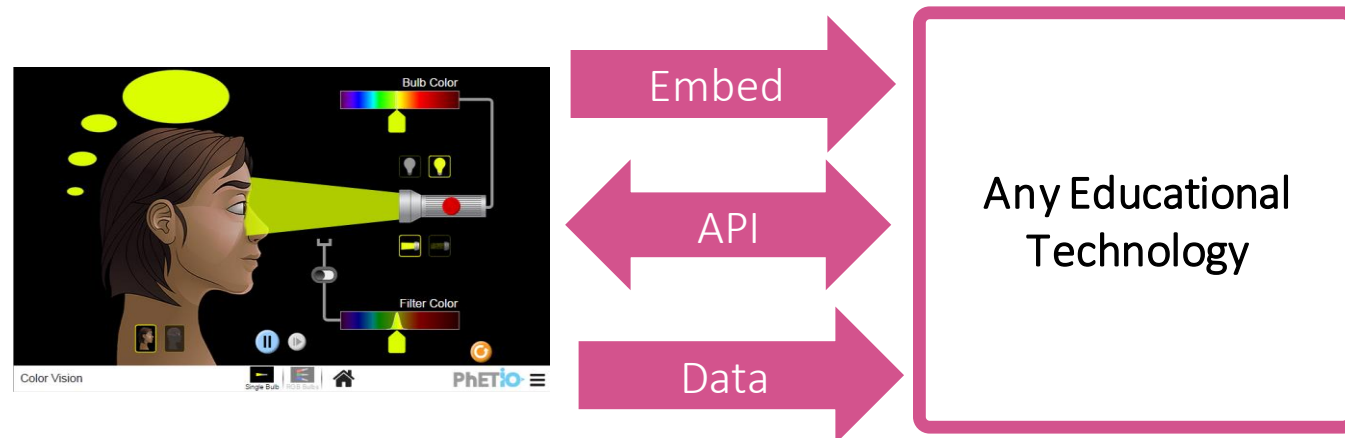
## Impact on learning



# Frontiers: PhET-iO

## PhET-iO Simulations

Customizable and Interoperable with Back-end data



<https://phet-io.colorado.edu>

# Frontiers: PhET-iO

## PhET-iO Simulations

Customizable and Interoperable with Back-end data

**NOTES**  
Take notes on the experiment here

**Simulation**

Wavelength: [Color Spectrum]

Absorbance: 0.07

Solution: CuSO<sub>4</sub> Copper sulfate

Concentration: 100 mM

Light Absorbance Lab PhET-iO

**RECORD DATA**

**Data Table**

Trial	Wavelength	Width (cm)	Concentration (mM)	Absorbance	Restore Trial	Add to Graph	Delete
1	Yellow	1.00	100.00	0.04	[Icon]	[Checkbox]	[X]
2	Yellow	1.27	100.00	0.05	[Icon]	[Checkbox]	[X]
3	Yellow	1.48	100.00	0.05	[Icon]	[Checkbox]	[X]
4	Yellow	2.00	100.00	0.07	[Icon]	[Checkbox]	[X]

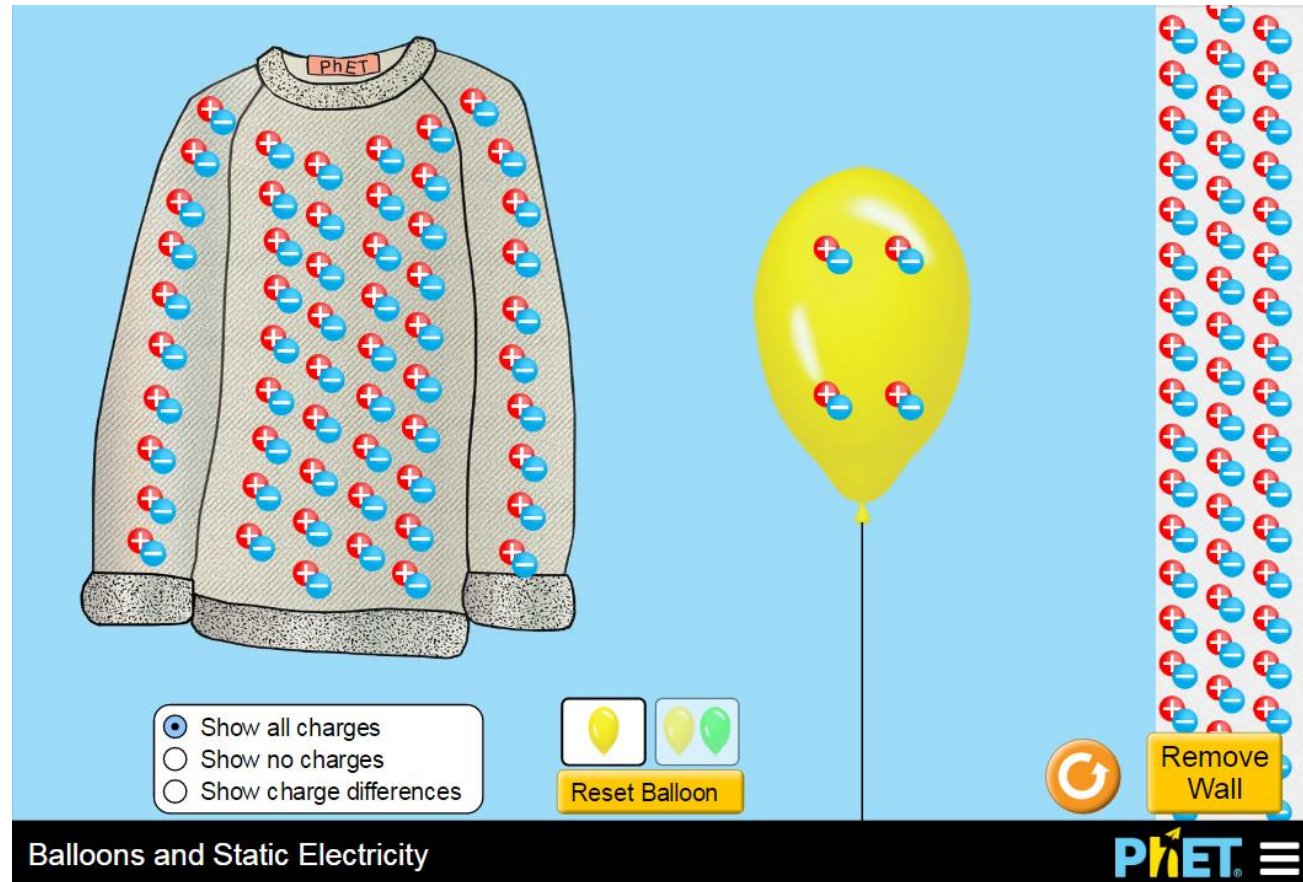
# Frontiers: Accessibility



Emily Moore

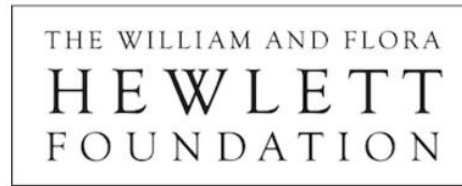


## PhET Sims for Students with Disabilities



<https://phet.colorado.edu/en/accessibility>

# Funders



# Deep Dive

Planning use across course

Writing clicker questions and activities

Applying strategies



# Invitation

FIND PHET

<https://phet.colorado.edu>

USE SIMS

In lecture, lab, homework

CONTRIBUTE

Lessons

Register at <https://phet.colorado.edu>



SEND IDEAS

[phethelp@colorado.edu](mailto:phethelp@colorado.edu)

CONNECT

 [@PhETsims](https://twitter.com/PhETsims)  [/PhETsims](https://facebook.com/PhETsims)

