



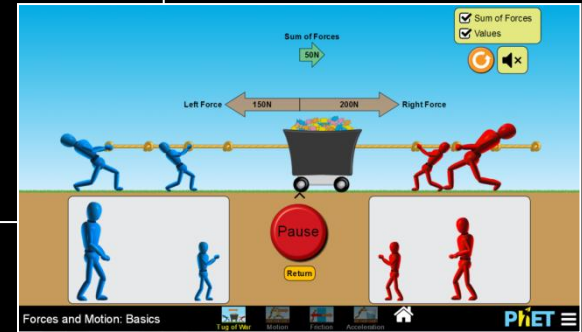
Tug of War



Motion



Friction



PhET Interactive Simulations for Active Learning in STEM

Yuen-ying Carpenter



University of Colorado
Boulder

Goals for today

- Describe how certain **simulation features** facilitate student learning and exploration
- Describe the **range of sim uses**, focusing on types of learning goals and facilitation
- Outline **best practices** that leverage sim features in classroom and for the creation of **sim materials and activities**

What is PhET?

130 free interactive science & math simulations

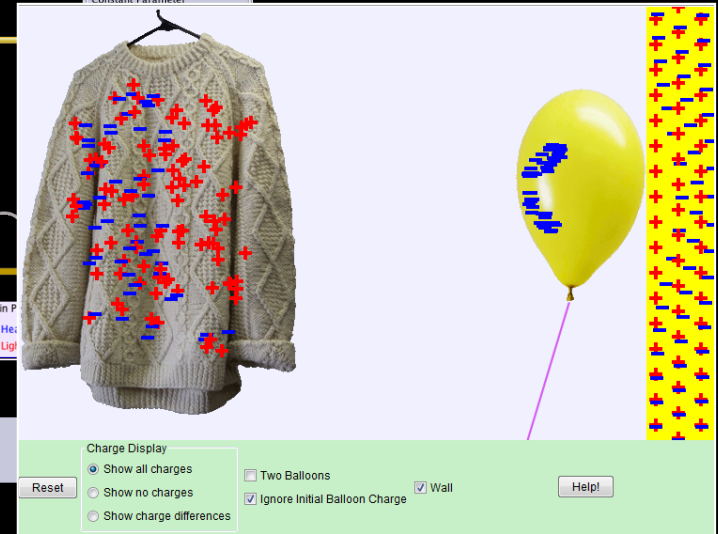
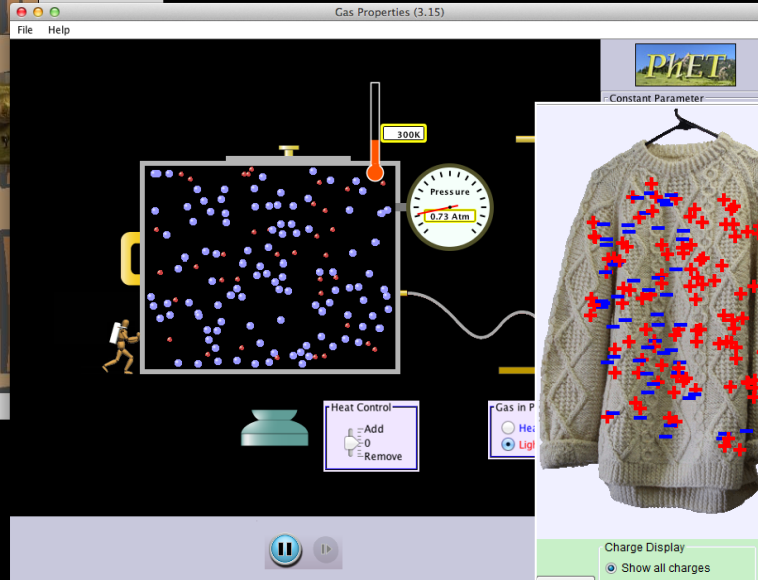
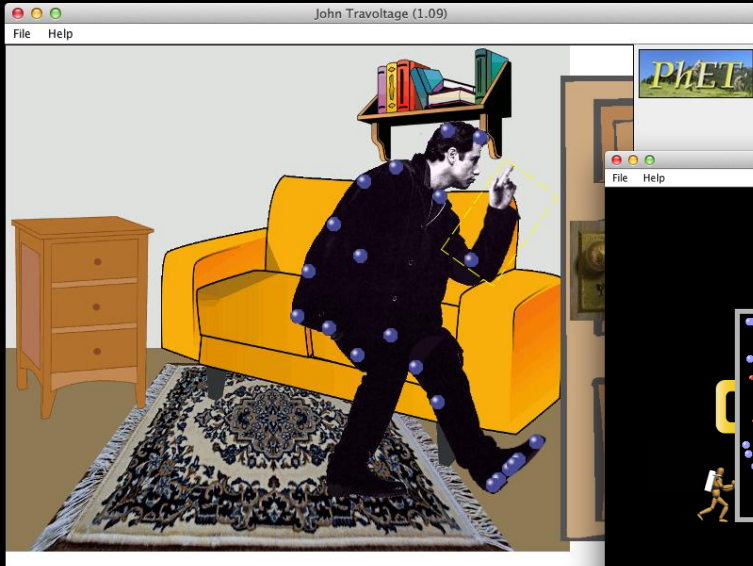
This screenshot shows the 'Molecules' simulation interface. At the top, there are tabs for 'Make Molecules', 'Collect Multiple', and 'Larger Molecules'. The main workspace contains a 'Water' molecule (H₂O) and an 'Oxygen' molecule (O₂). On the right, a 'Your Molecules' panel lists goals and progress: 'Goal: 2CO₂ You have: 1CO₂', 'Goal: 2O₂ You have: (empty)', 'Goal: 4H₂ You have: (empty)', and 'Goal: 2NH₃ You have: 2NH₃'. At the bottom, there are buttons for 'Hydrogen', 'Oxygen', and 'Nitrogen' and a 'Kit #3' indicator.

This screenshot shows the 'Real Molecules' simulation interface. The central 3D model displays a trigonal bipyramidal molecule with bond angles of 90.0° and 120.0°. On the right, a 'Bonding' panel shows options for single, double, and triple bonds, and a 'Lone Pair' panel shows an option to add a lone pair. Below these are 'Options' for 'Show Lone Pairs' and 'Show Bond Angles'. At the bottom, a 'Name' field is set to 'Molecule Geometry' and 'Electron Geometry' is set to 'Trigonal Bipyramidal'.

This screenshot shows the 'Beer's Law Lab' simulation interface. It features a central beaker containing a pink liquid. To the left, a light source is set to a 'Wavelength: 508 nm' with 'preset' selected. To the right, a detector measures 'Transmittance' and 'Absorbance'. Below the beaker, a 'Solution' dropdown is set to 'Drink mix' and a 'Concentration' slider is set to 100 mM. A ruler at the bottom left shows a scale from 0 to 2 cm. The PhET logo and navigation icons are visible at the bottom.

Elementary —————→ *College*

The Evolution of the PhET Interactive Simulations Project



Physics

2000

2002

2004

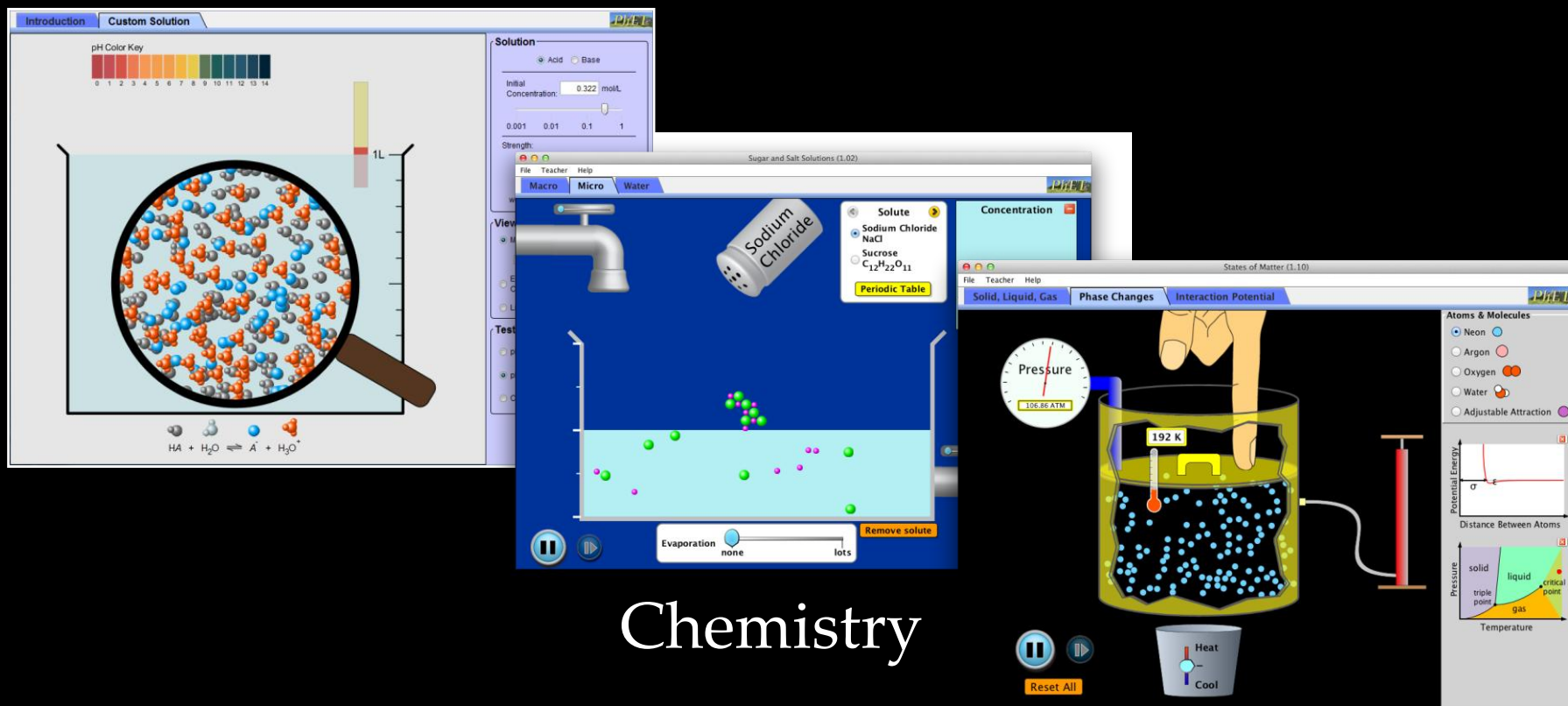
2006

2008

2010

2012





2000

2002

2004

2006

2008

2010

2012



Build an Atom (3.02)

File Help Build Atom Game

Protons:
Neutrons:
Electrons:

Element

H	He																		
Li	Be	B	C	N	O	F	Ne												
Na	Mg	Al	Si	P	S	Cl	Ar												
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr		
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe		
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs												

Model:
 Orbits
 Cloud

Show element name
 Show neutral/ion
 Show stable/unstable

Protons Neutrons Electrons

A 3D simulation of a skier on a curved track. A speedometer at the top shows the skier's velocity. A pie chart indicates energy distribution.

Kinetic Energy
Potential Energy
Thermal Energy

Bar Graph
 Pie Chart

A simulation of the Moon's orbit around Earth. The Sun is shown as a large yellow circle. The Moon's path is a purple line. A control panel on the right allows for adjusting gravity, velocity, and path. A 'Sim Speed' slider is at the bottom, showing '67 Earth Days'.

Physics
Gravity on off

Show
 Gravity Force
 Velocity
 Path
 Grid

Star
Our Sun
Planet
Earth

Reset
Reset All

Sim Speed: slow fast
67 Earth Days
Clear

Middle School

2000 2002 2004 2006 2008 2010 2012



Fractions Intro (1.02)

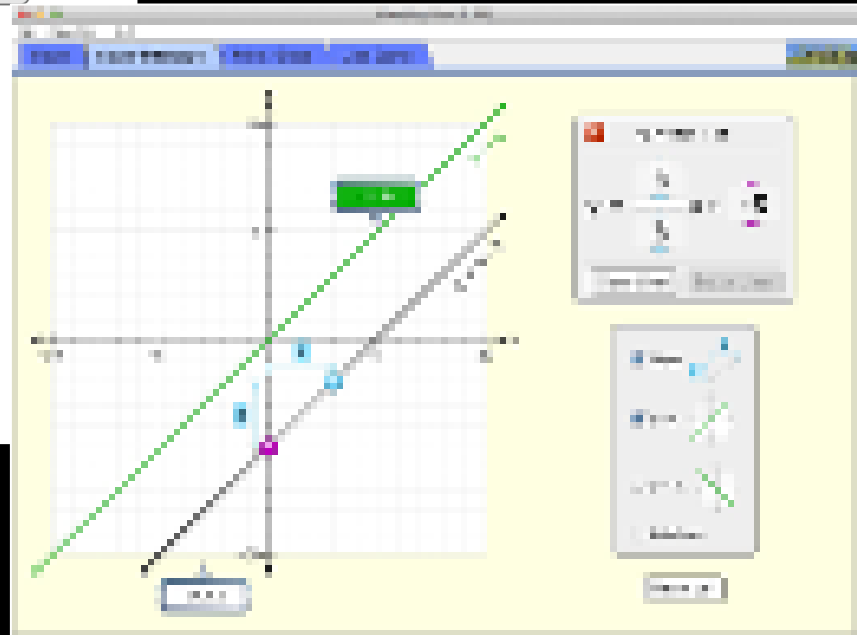
File Help

Intro Build a Fraction Equality Lab Matching Game

Max 3

6
—
3

$\frac{1}{3}$



Mathematics

2000

2002

2004

2006

2008

2010

2012



Next Generation PhET Sims



=



+



Inclusive Features: Sonification,
Captioning, Haptic Devices

2000

2002

2004

2006

2008

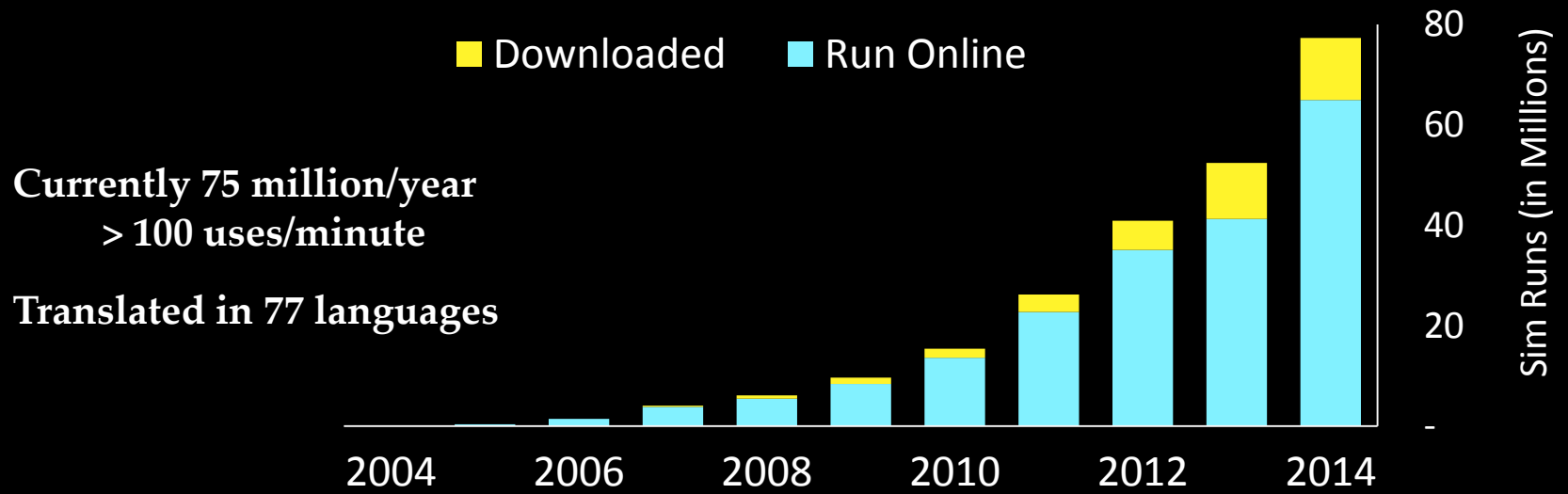
2010

2012



Who uses PhET?

- Teachers and students worldwide
 - Designed and researched to support productive inquiry-based learning



Our goals

PhET Accessibility Goals

- Freely available (online/offline)
- Flexible for use across diverse environments

PhET Pedagogical Goals:

Support students to...

- Engage in scientific exploration
- Take ownership of the learning experience
- Develop conceptual understanding
- Make connections to everyday life
- View science as accessible and enjoyable

Enable More
Student Centered
Pedagogies

Time to explore!

- <http://phet.colorado.edu>



Over 200 million simulations delivered



University of Colorado
Boulder

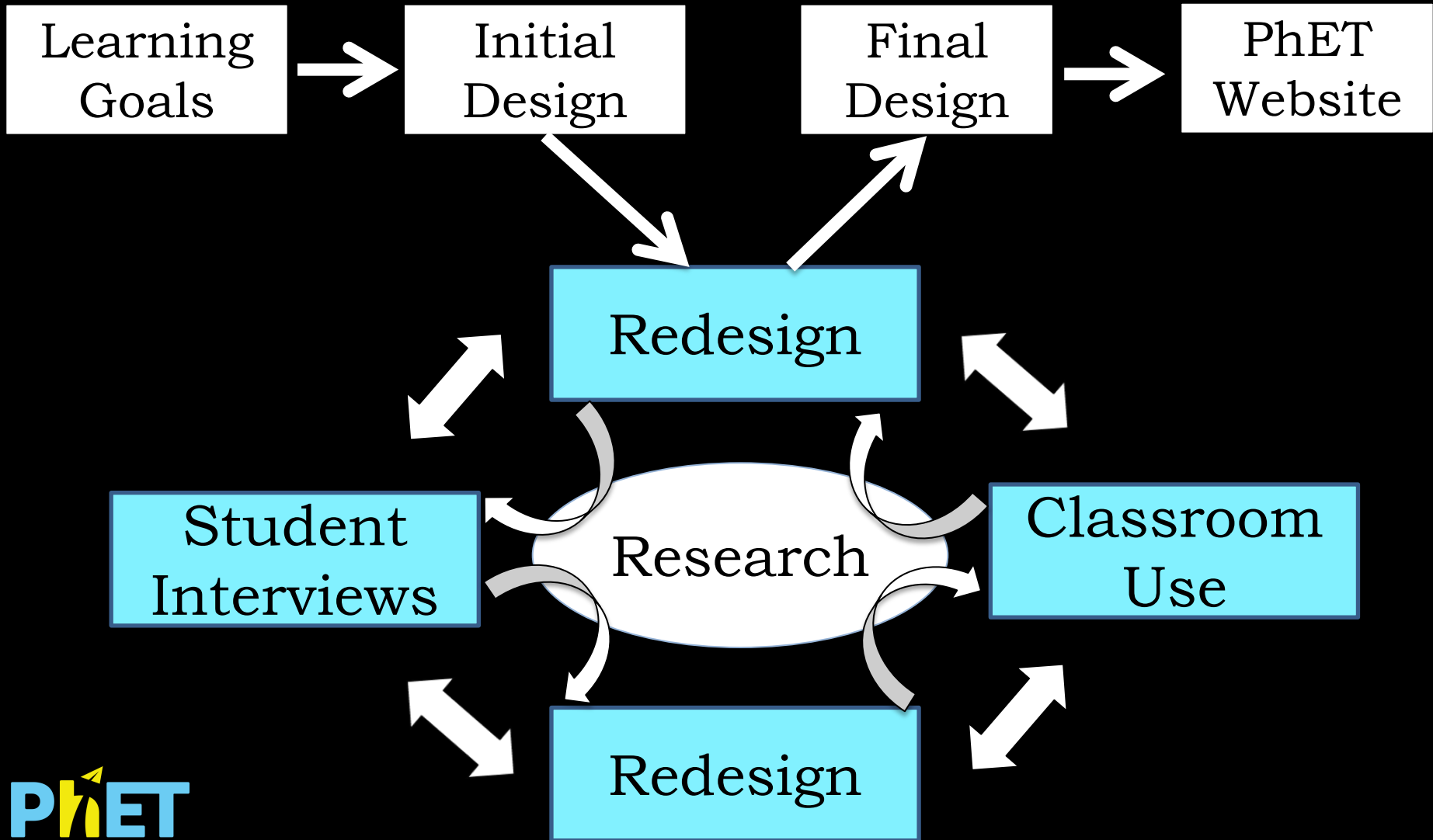
Support PhET's Annual Campaign:

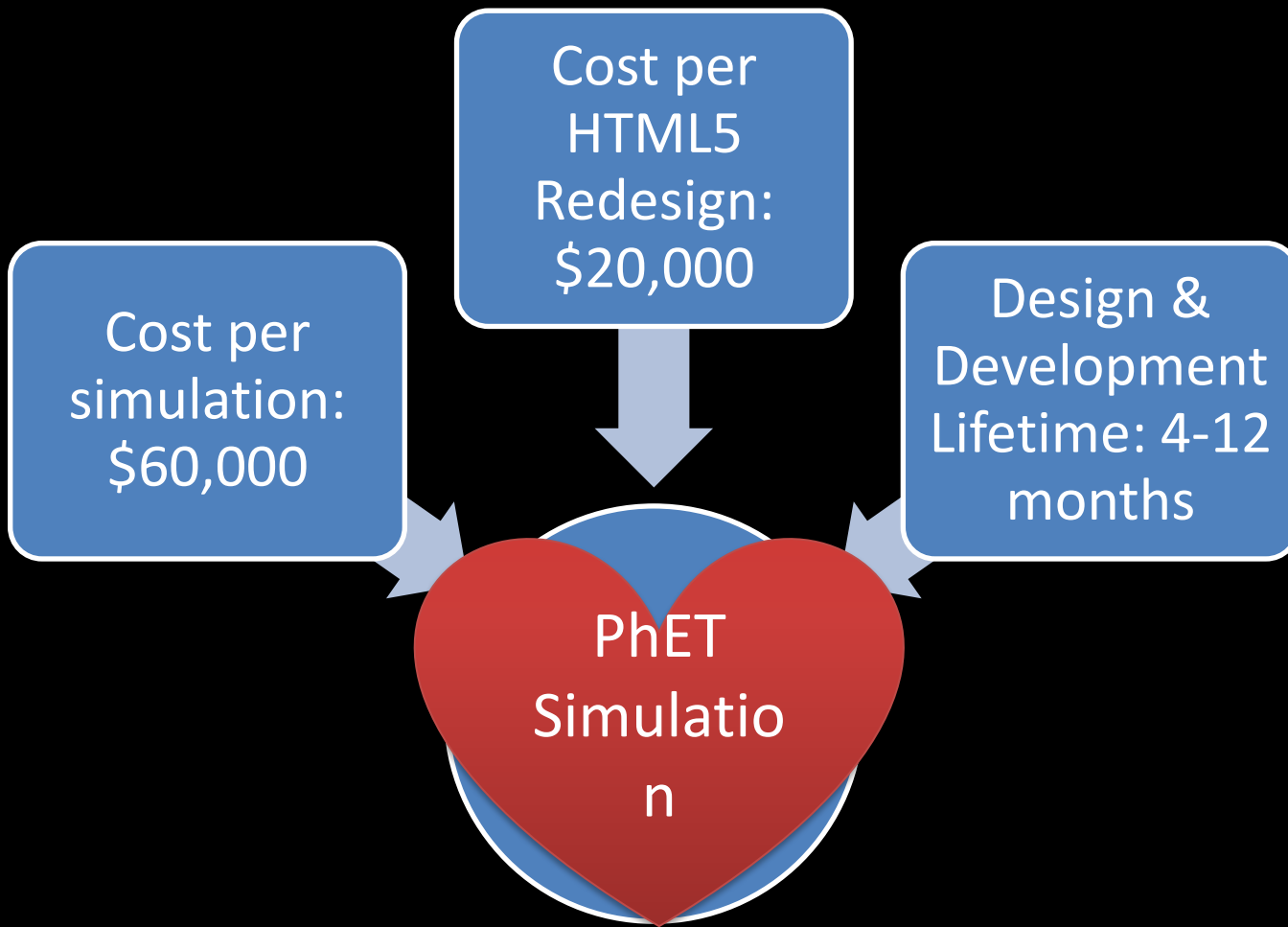
Donate Today

[HTML5 Sims](#)



Development Cycle





Research-Based Design

- Extensive design feedback on each sim



- Research over many sims shows what works
 - *Affordances* What actions are cued by the design?
 - *Constraints* What limitations focus or frame attention?

Real-world connections

Highly interactive,
Game-like

Implicitly scaffold inquiry

Molecule Polarity (1.02)

Options Help

Three Atoms Real Molecules

Atom A Electronegativity less more

Atom B Electronegativity less more

Atom C Electronegativity less more

View

Bond Dipoles

Molecular Dipole

Reset All

$\delta+$ A

$\delta-$ B

$\delta+$ C

Show the invisible

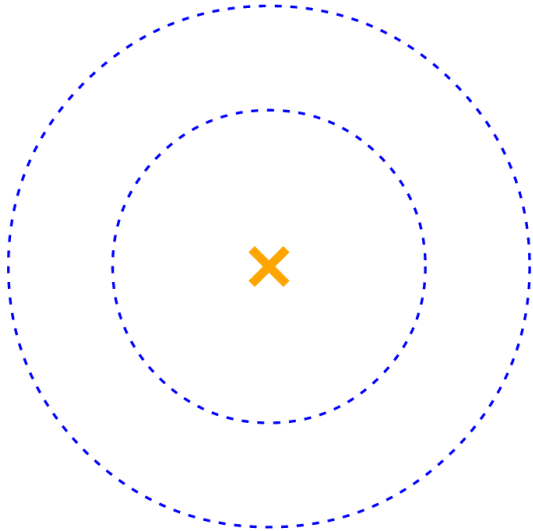
Intuitive interface

Real-time feedback

Multiple representations

Allow difficult or impossible actions

Protons:
Neutrons:
Electrons:



Protons Neutrons Electrons

Model:
 Orbits
 Cloud

Element -

H																	He				
Li	Be															B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar				
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr				
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe				
Cs	Ba	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf				
Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At									

Net Charge +

Mass Number +

- Show
- Element Name
 - Neutral/Ion
 - Stable/Unstable

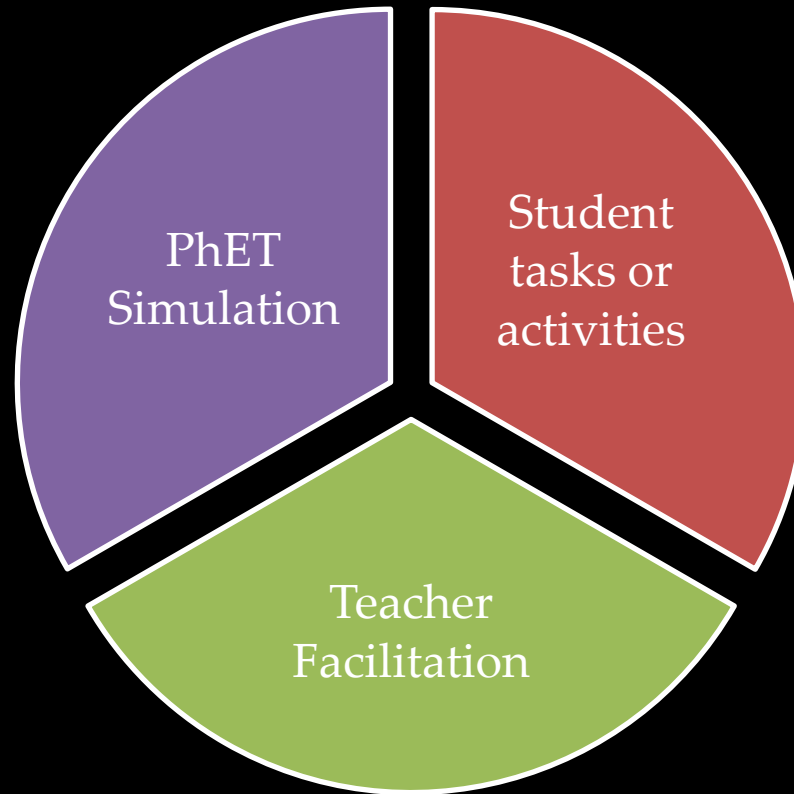


Implicitly scaffold inquiry

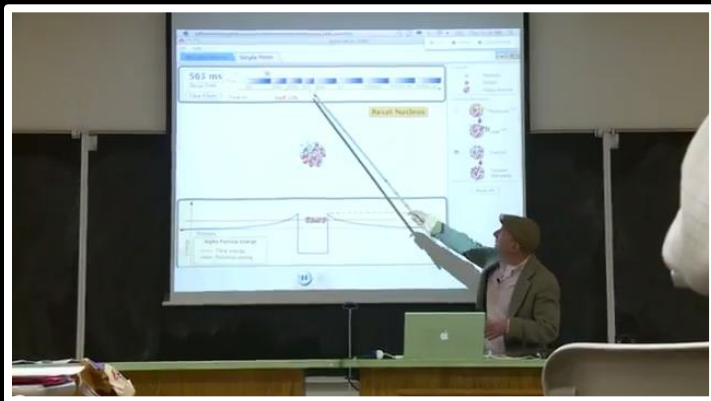
Build an Atom

Atom Symbol Game Home PhET

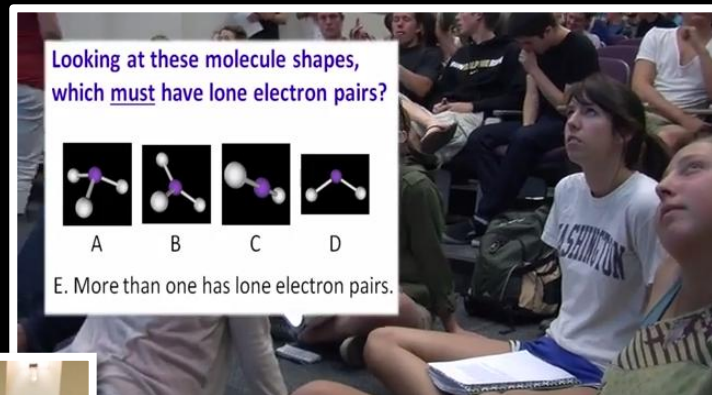
PhET sims don't exist in isolation



Classroom Contexts



Lecture Demo



Clickers



Guided-Inquiry Activity

Learning Contexts

Instructor-led

e.g. Lecture or lab demos
+ discussion
+ clicker Qs

Student-led

Group / individual work

e.g.

- In-class guided-inquiry
- Recitation / Tutorial
- Lab or pre-lab activities
- Homework

Guiding Questions for Sim Use

Based on how you use the sim...

1. What do students think they should be doing?
2. Are you leveraging the sim design for...

Student learning

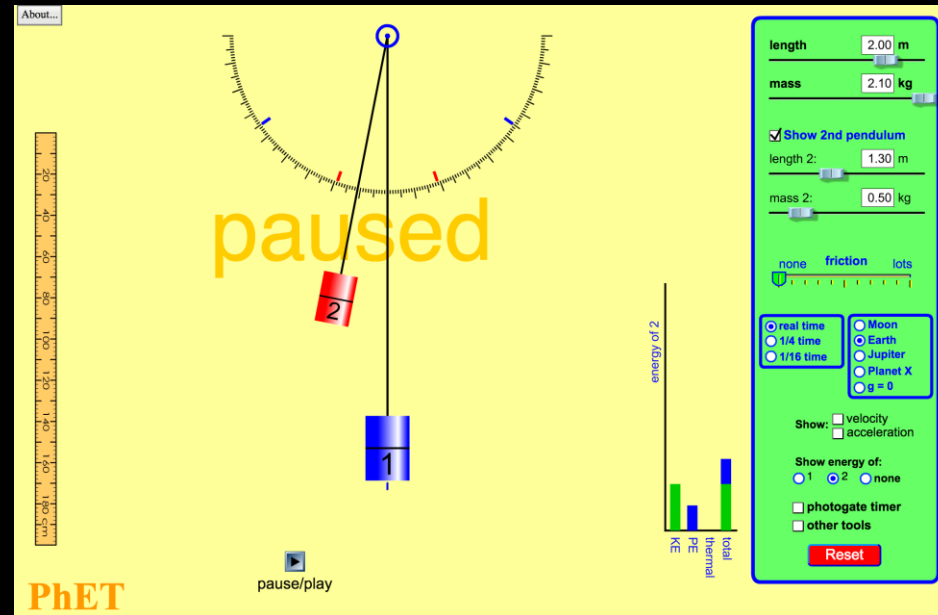
Concepts
Practices

Student motivation

Interest
Ownership
Sense of progress

Goals

- 2-3 focused learning goals per activity
- Consider whether those goals target practices/skills or concepts (or both!)



Framing

Instructor-led

- Open-ended guiding question or an initial prediction
- Basic orientation to the relevant sim features
 - what are we looking at
 - what can we alter

Student-led

- Allow for 5-10 min of open exploration
 - Student ownership
 - Orients students towards exploration and sense-making

Guidance

Student-led

C LENSES

C lenses (this designation does not appear on the lenses) can be used with the 500C, 500C/M, 500EL, 500EL/M, 2000FC, and 2000FC/M (see also the Instruction Manual for the 2000FC/M).

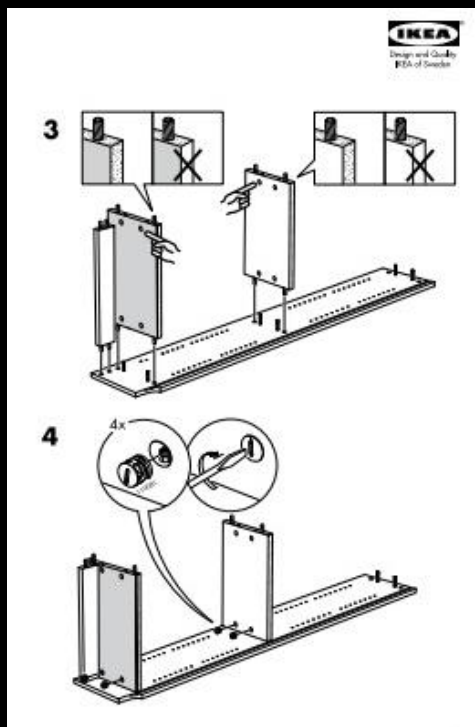
They all feature a built-in Synchro-Compur leaf shutter, an automatic diaphragm, an exposure value scale, automatic depth-of-field indicators, M and X flash synchronization at all speeds, and a self-timer V. The C lenses attach to the camera via a bayonet mount.

Diaphragm (Fig. 62)

The aperture ring (13) and shutter speed ring (14) are cross-coupled. Both rings are operated with the grip ring (15). For independent setting of the aperture or shutter speed, press the cross-coupling release (4) to the rear and rotate the ring until the desired value is opposite the central index (12). The lens is normally focused wide open. The diaphragm automatically closes down to the working f /stop at the moment of exposure. Press the depth-of-field preview catch (5) to check out the available depth of field. This will stop the lens down to the working aperture. The diaphragm is reopened to the maximum aperture by turning the aperture ring (13) to the maximum aperture or tripping the shutter (with a detached film magazine) and winding the camera.

Shutter speeds (Figs 63—64)

The shutter speed ring (14) has three different scales with white (black on chrome finish lenses), green, and red numerals. Only the white (black) numerals and B can be set opposite the central index (12).



P&ET Computer Simulation Activity: Isotopes and Atomic Mass

10. Lithium (Li) has only two stable isotopes. Use the simulation to determine the following.

- Atomic mass of lithium-6 = _____ amu
- Atomic mass of lithium-7 = _____ amu

c. Complete the following table using the simulation.

	Number of ${}^6\text{Li}$ atoms	Number of ${}^7\text{Li}$ atoms	% composition of ${}^6\text{Li}$ in sample	% composition of ${}^7\text{Li}$ in sample	Average atomic mass of sample (amu)
Sample 1	3	2			
Sample 2	6	4			

c. What do you notice if you compare the average atomic mass of the two samples? Explain.

d. Is the average atomic mass you just determined closer to the mass of lithium-6 or lithium-7? Explain.

11. Without the simulation, write out a method to calculate the average atomic mass of a mixture of lithium-6 and lithium-7 atoms if you were given the **number of atoms** of each.

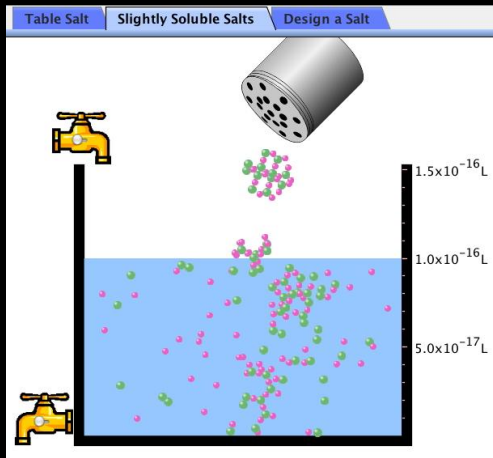
12. Without the simulation, write out a method to calculate the average atomic mass of a mixture of lithium-6 and lithium-7 atoms if you were given the **percent composition** of the mixture.

Treat student activities as structured guidance not instructions

Prompts

Add 100 silver bromide pairs to the water.
How many silver and bromide ions dissolve in the water?
Repeat this for all salts.

Task completion + Answer making



Investigate different salts.
What features do salts have in common, and how do salts differ from each other?

Sense making

Prompts

1. Use minimal words
2. Focus on sense-making and reasoning
(not just on answers)
3. Use sim features and examples
4. Ask students to reason with both words
and diagrams
5. Help students monitor understanding

Tables

- Use tables to cue and organize without need for explicit directions
 - Comparisons
 - Effects of variables
 - Classifications

Big Table of Electronic and Molecular Geometry

of e^- domains - 1

2-b min. 2

Electron Domains	Bonded e- regions (bonds)	Non-bonded e- regions (lone pairs)	Electron Domain Geometry	Molecular Geometry	Bond Angle
2	2	0	Linear	Linear	180°
3	3	0	Trigonal Planar	Trigonal Planar	120°
4	3	1	Tetrahedral	Trigonal Pyramidal	109.5°
4	2	2	Tetrahedral	Bent	109.5°

8. Use the simulation to complete the following table:

Element	Mass of 1 atom	Average atomic mass of 2 atoms	Average atomic mass of 3 atoms	Average atomic mass in nature*
Beryllium (Be)	9.012 amu	9.012 amu	9.012 amu	9.012 amu
Fluorine (F)	18.998 amu	18.998 amu	18.998 amu	18.998 amu

* The average atomic mass in nature can be found in the simulation OR on a periodic table

9. Why are all the values in each row of the table above the same?

Integration & Follow-through

- More consistent, integrated usage encourages students to engage with the sim

Instructor-led

- Screenshots in lecture summaries, clicker Q
- Using the sim to answer student Q

Student-led

- Use available sim examples so that students use the sim for feedback and communication

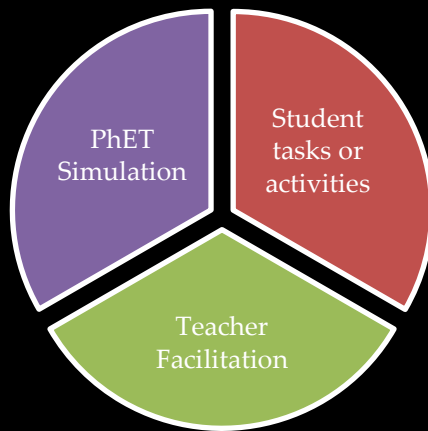
Summary

Goals

Framing

Guidance

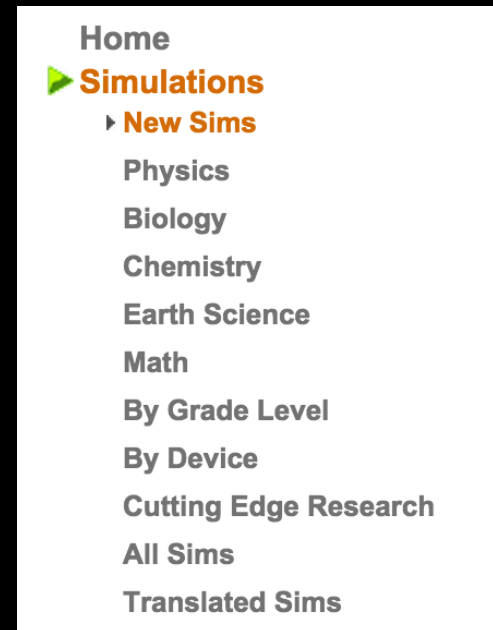
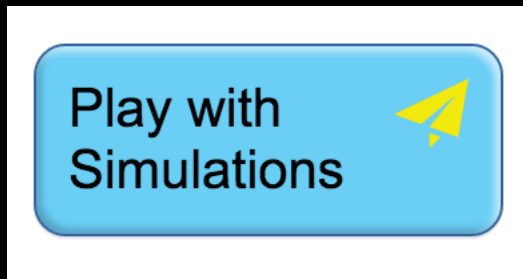
Integration



- Facilitation and activity design influence student perceptions with simulations
- Focus on engaging students in sense-making

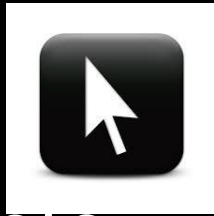
How can I get started?

- Get to know the sims



- Website teaching resources
 - **For Teachers** (videos, strategies, tips, etc.)
 - Activities

How to Get Involved



<http://phet.colorado.edu>

- ✓ Donate
- ✓ Share activities, clicker questions, or demo materials
- ✓ Follow:



Acknowledgments

