

# SIMS FOR SCIENCE

*Powerful tools to support inquiry-based teaching*

— Katherine K. Perkins, Patricia J. Loeblein, and Kathryn L. Dessau —

**E**ducational simulations can be highly engaging and effective tools for helping students learn science and math—but they must be carefully developed and tested (Wieman, Adams, and Perkins 2008; deJong 2006; Finkelstein et al. 2006). Since 2002, the PhET Interactive Simulations project at the University of Colorado has been working to provide learning tools for students and teachers. The project has developed over 85 interactive simulations for teaching and learning science, all of which are freely available online (see “On the web”).

Simulations—or sims—create animated, game-like environments in which students learn through scientist-like exploration. They emphasize the connections between real-life phenomena and the underlying science, make the invisible visible (e.g., electrons, photons, field vectors), include the visual models that experts use to aid their thinking, animate those models, and provide interactive controls and measuring tools. Currently, PhET offers sims for physics (e.g., Energy Skate Park, Circuit Construction Kit, and Gas Properties), chemistry (e.g., Salts and Solubility, pH Scale, and Models of the Hydrogen Atom), Earth science (e.g., Glaciers and Radioactive Dating Game), and math (e.g., Estimation, Equation Grapher, and Vector Addition).

With a highly intuitive interface and little text, the use of PhET sims can be customized to match a teacher's learning environment and learning goals. This flexibility allows for use in the classroom, lab, or as homework—either in groups or individually (see “On the web”). Many sims can also be used across a wide range of grade levels. For example, the Circuit Construction Kit can be used in an elementary or middle school level science unit on circuits and electron flow, or in a high school or college unit on the effects of wire resistivity (Vick 2010).

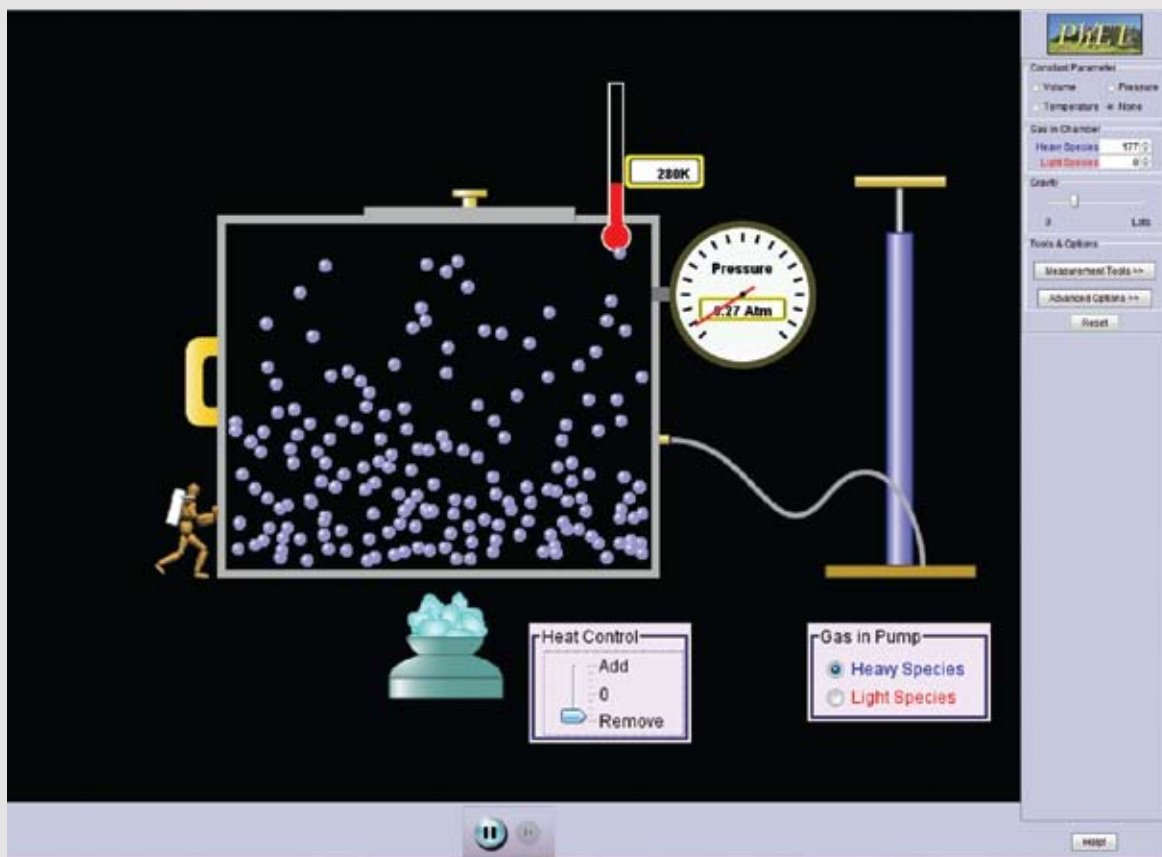
Although these sims can be used in a variety of ways, they are specifically designed to make scientist-like, inquiry-based activities that are productive and fun learning experiences for students. In this article, we focus on the design features of PhET sims that support inquiry learning, highlight their alignment with standards for several science disciplines, and provide examples of inquiry-based activities.

## Background

The PhET project was started by Nobel Laureate Carl Wieman to improve the way science is taught and learned; he wanted to create sims that were aligned with and vetted through educational research. As a result, each sim is developed by a team of scientists, software engineers, science educators, and science education researchers to facilitate learning and address known student difficulties with the content. Each sim is tested through student interviews and observations of use, and the PhET project is actively engaged in research on effective design and classroom use of interactive simulations in general (Adams et al. 2008a, 2008b; see “On the web”).

FIGURE 1

### Gas Properties sim.



Sim design includes implicit guidance to help students direct their own productive exploration (Podolefsky, Perkins, and Adams, Forthcoming). Student thinking is guided and focused by the choice of controls, visual representations, animated models, and immediate feedback provided by visual changes during student explorations.

Folder-like “tabs” along the top of each sim allow scaffolding of content topics or complexity as students move from tab to tab in their explorations (e.g., from a tab with a magnet and compass to a tab with a magnet and a pick-up coil). Connections to the real world are used to anchor students’ thinking to the familiar and pique their interest. Purposeful constraints—that is, what students are *not* allowed to do or

see—are used to further guide productive exploration by reducing or filtering out real-world complexities that can distract from the key ideas.

This approach allows activities and homework assignments to be less directed and use more open, conceptual questions—questions that require students to engage in scientist-like exploration. For example, in the Gas Properties sim (Figure 1, p. 47), students are invited to interact with a familiar bicycle pump—and move their mouse to pump the air out of it. They see a submicroscopic view of air particles, which enter a box, bounce, and collide with one another. Students can use intuitive click-and-drag manipulation, sliders, and radio buttons to change the temperature

**FIGURE 2**

### Sims and benchmarks.

(Note: The following are abbreviated from AAAS 2009.)

Discipline	American Association for the Advancement of Science benchmarks (AAAS 2009)	PhET simulations
Chemistry	The rate of reactions among atoms and molecules depends on how often they encounter one another. 4D/H9a	Reactions and Rates
	Physical properties of compounds reflect the nature of the interactions among its molecules. 4D/H10	States of Matter
	Energy changes in atoms can occur in only fixed amounts (e.g., discrete colors of light emitted by atoms). 4E H1–H10	Models of the Hydrogen Atom Neon Lights and Other Discharge Lamps
Earth science	Gravitational force is an attraction between masses. 4G/H1	Gravity Force Lab
	Knowledge of radioactivity helps understanding of how rocks can be dated and the scale of geologic time. 4C H1–H6	Radioactive Dating Game
	Consideration of the effects that human activities have on the Earth’s surface. 4E H1–H10	The Greenhouse Effect Glaciers
Biology	The variation of organisms within a species increases the likelihood that at least some members of the species will survive under changed environmental conditions. 5A/H1a	Natural Selection
	Protein molecules assist in generally catalyzing and regulating molecular interactions. 5C/H9	Gene Machine: The Lac Operon
Physics	Mechanical forces are produced by electric charges on the atomic scale. 4G H1–H8	Balloons and Static Electricity
	Applied electric forces can cause the electrons to move through the material, producing an electric current. 4G/H4ab	Signal Circuit Circuit Construction Kit
	The interplay of electric and magnetic forces is the basis for many modern technologies, including electric motors, generators, and devices that produce or receive electromagnetic waves. 4G/H5c	Radio Waves and Electromagnetic Fields Faraday’s Electromagnetic Lab Generator
	Semiconducting materials differ greatly in how well they conduct electrons, depending on the exact composition of the material. 4G/H4d	Conductivity Semiconductors

**FIGURE 3****Inquiry tips.**

- ◆ Use open, conceptual questions and minimize directions.
- ◆ Encourage sense-making by eliciting student thinking and requiring reasoning in words and diagrams.
- ◆ Motivate activities through connections to students' real-world experiences.

and box size, or enable a quantitative analysis tool, such as a ruler, pressure meter, or thermometer. As they manipulate these controls, the sim responds immediately—illustrating cause-and-effect relationships and multiple-linked representations (i.e., motion of the objects, graphs, number readouts, and so on).

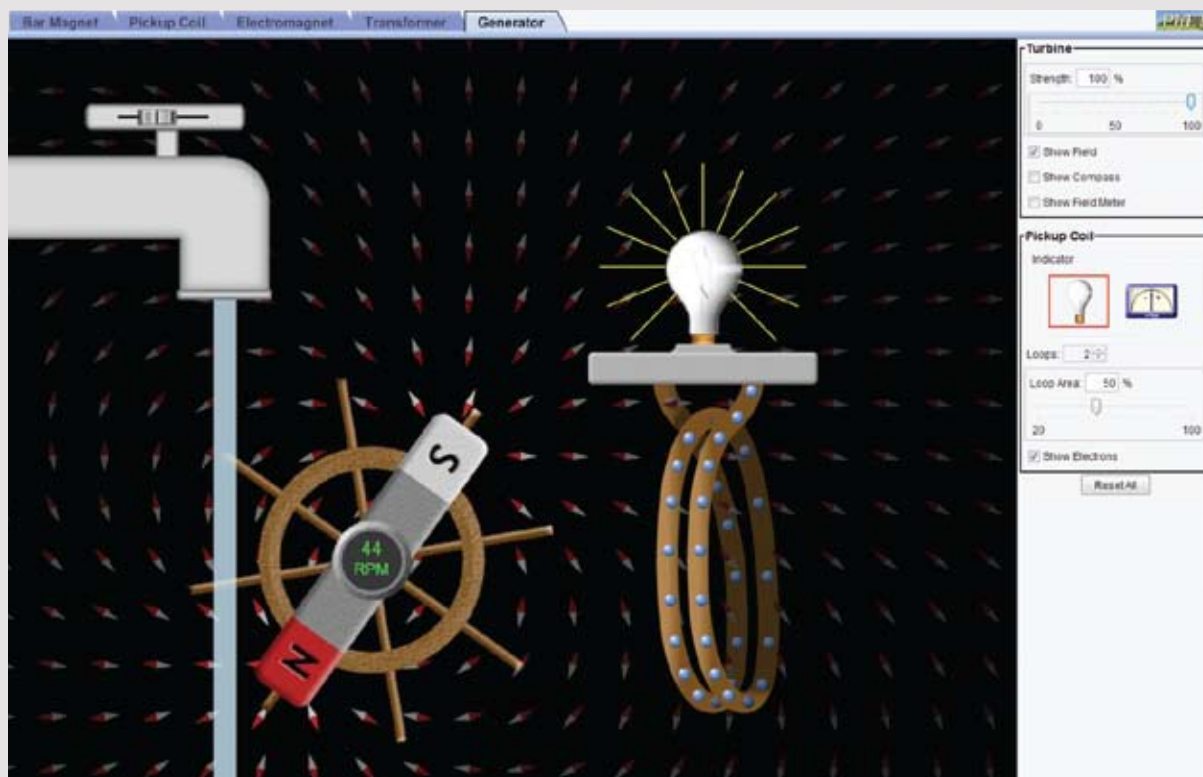
**Sims and inquiry**

Although sims can be highly effective learning tools, even the best sims are not automatically successful. They are designed to supplement an already well-designed curriculum and the efforts of a good teacher, but they cannot replace them. They must be part of an overall instructional design and rely on the timely guidance of a teacher.

Figure 2 illustrates how specific sims align with the American Association for the Advancement of Science benchmarks (2009). Because many sims cross over a variety of grade levels, they can support both remedial and gifted programs. The basic strategies for using sims effectively match those for all effective teaching (Bransford, Brown, and Cocking 2000). These strategies are discussed in PhET's Guidelines for Creating Inquiry-Based Activities (see "On the web") and are highlighted in Figure 3.

Both physical and simulated labs can be used with inquiry-based teaching (Vick 2010), but sims offer several advantages:

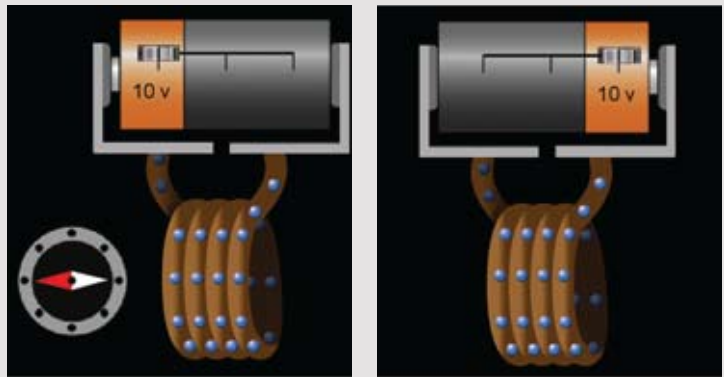
- ◆ They can be used to replace physical equipment that is unavailable or impractical to set up.
- ◆ They can be used to do experiments that are impossible to do otherwise (e.g., sims can immediately show the result of adjusting the amount of greenhouse gas in the atmosphere).
- ◆ They allow teachers and students to change variables in response to student questions.
- ◆ They can show the invisible and explicitly connect multiple representations.
- ◆ They provide a common visualization that facilitates communication and instruction.

**FIGURE 4****The Faraday's Electromagnetic Lab sim.**

**FIGURE 5****Clicker question.**

What will happen if you switch the battery so that the that the positive end is on the right?

- A. The electrons will go faster.
- B. The electrons will go slower.
- C. The compass will switch directions.
- D. The electrons will go the other direction.
- E. More than one of these.



- ◆ They support out-of-class inquiry learning.
- ◆ They put students at ease and allow them to explore (i.e., students do not have to worry about breaking the sim or physically harming themselves).

One approach is to integrate both types of tools. That is, begin student inquiry with sims—supporting students in developing their conceptual framework and model of the science—and then work with physical equipment, so students can apply their conceptual models to predict or explain physical behavior.

The following section provides an inquiry-based activity that is used with PhET sims.

### Faraday’s Electromagnetic Lab

The Faraday’s Electromagnetic Lab sim can be used in a high school level physics class to teach how an electrical current can be “induced” to flow across a closed circuit when placed in a changing magnetic field—Faraday’s law of induction. In this sim (Figure 4, p. 49), students manipulate a bar magnet and coils to make a lightbulb glow. When students move the bar magnet near the pick-up coil, they see the lightbulb light up. The faster they move the magnet, the brighter the bulb glows. Animated graphics show the direction and strength of the magnetic field, and the electron motion in the pick-up coil. Students can explore real-life connections by playing with electromagnets, transformers, and generators. In this sim, tabs (labeled “Generator,” “Electromagnet,” “Transformer,” and so on) are used to scaffold student investigation of ideas.

Patricia Loeblein, a physics teacher at Evergreen High School in Evergreen, Colorado, uses this sim as part of a series of inquiry activities (2009a). In the first activity, students use the “Bar Magnet” and “Electromagnet” tabs. The learning goals are well articulated and provided to students. Students will be able to

- ◆ predict the direction of the magnetic field for different locations around a bar magnet and electromagnet,

- ◆ compare and contrast bar magnets and electromagnets,
- ◆ identify the characteristics of electromagnets that are variables and what effects each variable has on the magnetic field’s strength and direction, and
- ◆ relate magnetic field strength to distance quantitatively and qualitatively.

Students are directed to carry out tasks but are not given explicit directions about which controls to use—this is because research suggests that such directions limit their interactions with the sim (Adams, Paulson, and Wieman 2009). Instead, they are first asked to investigate the “Bar Magnet” and “Electromagnet” tabs, paying attention to what they can change and what tools they can use to make measurements. Then, they are asked to read the first four learning goals, design experiments to accomplish these goals, and be prepared to explain their designs.

Depending on the grade level, students can then go on to learn about Faraday’s law by exploring all of the tabs in the Faraday’s Electromagnetic Lab sim (Loeblein 2009b). Here, students’ goals are to

- ◆ identify equipment and conditions that produce induction,
- ◆ predict how the current will change when the conditions are varied, and
- ◆ compare and contrast how both a lightbulb and a voltmeter can be used to show characteristics of the induced current.

Again, specific instruction is minimized. Students are asked to investigate using the “Pick-up Coil” tab and then to describe what induction means, and how they know when it occurs. The directions state, “Design an experiment to determine how the size and direction of the induced current will change when the conditions are varied. Collect data, make observations, and record your information in a table.”

After students have finished the lab, it is helpful to assess

their understanding of the concepts. Clickers—wireless, personal response systems that allow a teacher to quickly collect an answer to a question from every student—allow rapid formative assessment. We often use clicker questions to probe student thinking, facilitate additional peer discussion, and provide guidance and redirection to student thinking as needed (see “On the web”). Figure 5 is an example clicker question that is paired with this activity.

## Resources for teachers

PhET sims are free and available online for use in 51 different languages. For those without an internet connection, the sims can be downloaded for offline use.

On each sim page, teachers will find a list of main topics, related topics, sample learning goals, and teacher-contributed activities. In addition, the “Teacher Tips” document provides insights into common student difficulties with the material, the modeling assumptions used with the sim, and nonobvious controls. PhET’s Ideas and Activities database (see “On the web”) includes activities written by the PhET team and the community of teachers using PhET. The database can be searched by sim, type of activity, grade level, language, and keywords. All teachers are encouraged to contribute ideas on how they have used PhET sims, or to contribute comments when they have tried an activity with their class. Guided-inquiry activities are marked with a gold star.

Guided by education research and user testing, PhET sims engage students in authentic, scientist-like inquiry and help create a productive learning experience in which students construct their own understanding of scientific concepts. With an intuitive user interface, real-world connections, a high level of interactivity, and animated visual models, sims are a fun, believable, and safe way for students to effectively explore and learn science. ■

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## Author’s note

Please send feedback or suggestions to [phethelp@colorado.edu](mailto:phethelp@colorado.edu).

## NSTA connections

For more information on electromagnetic forces, check out the “Electric and Magnetic Forces: Electric Charges” NSTA Science Object. NSTA Science Objects are online, inquiry-based content modules for teachers that are free of charge. For more information, visit [http://learningcenter.nsta.org/products/science\\_objects.aspx](http://learningcenter.nsta.org/products/science_objects.aspx).

## On the web

Clicker information: <http://stemclickers.colorado.edu>

PhET’s Guidelines for Creating Inquiry-Based Activities: <http://phet.colorado.edu/en/for-teachers/activity-guide>

PhET’s Ideas and Activities database: <http://phet.colorado.edu/en/for-teachers>

PhET interactive simulations: <http://phet.colorado.edu>

PhET research: <http://phet.colorado.edu/en/research>

Using PhET sims in the classroom: <http://phet.colorado.edu/en/for-teachers/classroom-use>

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