Free online resource connects real-life phenomena with science

The University of Colorado’s Physics Education Technology project (PhET) provides an extensive online suite of simulations that covers the majority of high school and introductory college physics; it also illustrates the concepts behind advanced topics such as semiconductors.

The simulations create animated game-like environments where the visual and conceptual models that physicists use are made accessible to students. They often animate what is invisible to the eye, such as atoms, electrons, photons and electric fields. You’ll find around 35 simulations at www.colorado.edu/physics/phet/ and because this is an active project, the website is regularly updated with newly developed or improved simulations.

User interaction is encouraged by PhET’s engaging graphics and intuitive controls that include click-and-drag manipulation, sliders and radio buttons. By immediately animating the response to any user interaction, the simulations are particularly good at establishing cause-and-effect and at linking multiple representations. For example, in the Moving Man (figure 1) simulation, you can use the mouse to drag a little man back and forth on a pavement, watching as graphs of position, velocity and acceleration appear. Alternatively, you can ‘play back’ graphs to see the resulting motion of the man.

For quantitative exploration, the simulations have measurement instruments available, such as a ruler, stop-watch, voltmeter and thermometer. All the simulations are extensively tested for usability and educational effectiveness, and a rating system (gold star, beta or alpha) is used to indicate what level of testing they have received. The tests involved student interviews and use of the simulations in a variety of settings, including lectures, group work, homework and lab work.

The PhET simulations are easy to use. They are written in Java and Flash, and can be run using a standard Internet browser as long as the latest Flash and Java plug-ins are installed. Instructions on the PhET site make it easy to download these free plug-ins for those who do not already have them. The simulations can be run online, or can be downloaded to your machine, which is particularly convenient for users without high-speed Internet connections.

**Figure 1.** The Moving Man is the first of the Motion simulations listed on the PhET website. Others include Masses and Springs and Projectile Motion.

**Electricity and circuits**

When you visit the website, you’ll find the simulations organized under seven partially overlapping topics: Motion, Work, Energy & Power, Sound & Waves, Heat & Thermo, Electricity & Circuits, Light & Radiation, Quantum Phenomena and Math Tools. The PhET simulations range from the quite simple to the highly elaborate. For example, John Travoltage in Electricity & Circuits is a simple sim-
ulation, where the user rubs John’s foot on a rug and sees how he picks up electrons that will create a spark if his hand is moved too near a doorknob – all with accompanying sound effects. This shows the relationship between the size and extent of the spark, the amount of charge accumulated and the distance from the doorknob.

Another quite simple but useful simulation, Balloons and Static Electricity, involves the classic demonstration of rubbing a balloon on a sweater (figure 2), but with the electric charges made visible. After rubbing, the user can observe the Coulomb attraction between the sweater and balloon and the shorter range attraction when the balloon is stuck to a wall, which explicitly shows the electron motion polarizing the wall.

Examples of much more elaborate simulations from the Electricity & Circuits category include the Circuit Construction Kit (CCK) and Radio Waves simulations. In CCK (figure 3), you construct arbitrarily complex circuits involving light bulbs, switches, batteries, resistors and wires, adjust any component resistances or battery voltages, and simultaneously observe the effect on the motion of electrons through the circuit and the brightness of the bulbs. Realistic looking voltmeters and ammeters measure voltage difference and current. This simulation has been very effective at helping students to grasp the concepts of electric current and voltage.

In Radio Waves (figure 4), the user can move electrons in the broadcasting antenna via the mouse or by setting the frequency and amplitude of oscillation, and simultaneously observe the electromagnetic wave that is produced, how it propagates away from the transmitting antenna, and its effect on the electron in a distant receiver antenna.

Other simulations in Electricity & Circuits include Signal Circuit, Electric Field of Dreams, Electric Field Hockey, Battery Voltage, Battery-Resistor Circuit, Ohm’s Law, Resistance in a Wire, Conductivity and Semiconductors.

From motion to maths
The Motion topic includes The Moving Man, Masses & Springs, 2D Motion, Maze Game and Projectile Motion (a favourite of instructors, particularly when they realize that they can launch pumpkins, bricks, and more, to see how air resistance affects them). The Work, Energy & Power category includes Conservation of Energy and Ideal Gases & Buoyancy. Heat & Thermodynamics has simulations of The Greenhouse Effect, Friction, Blackbody Spectrum and Ideal Gases & Buoyancy.

The Ideal Gas simulation is rather elaborate. It begins with the usual capabili-
ties of being able to put atoms in a box and view behaviour while their volume, number and temperature are altered. However, you can also control gravity, make mixtures of heavy and light atoms, investigate the physics of helium and hot-air balloons, turn atom–atom interactions on and off and examine diffusion, all while quantitatively measuring relationships between temperature, pressure, velocity and energy distribution.

The Light & Radiation section features Colour Vision & Filters, Microwave Oven, Radio Waves, Geometric Optics and Blackbody Spectrum. Sound & Waves has only two simulations: Sound, and Waves on a String (figure 5). Both have been found to be effective for teaching and learning – the latter being engrossing for student and instructor alike.

The Quantum Phenomena section takes a number of advanced topics and provides useful visual models of the concepts behind them, making these subjects accessible to the introductory student by hiding the complex mathematics in the depths of the program. These simulations deal with subsections including Nuclear Physics (radioactive decay and weapons), Lasers, Conductivity and Semiconductors.

Finally, the Math Tools category containing Vector Addition, Equation Grapher, Ohm’s Law and Resistance in a Wire are experimental attempts to help students obtain a conceptual feel for mathematical operations and relationships.

When used in their simplest form, these PhET simulations enable any teacher with an LCD projector to replace the traditional static pictures they use in lectures with lively animated views of the phenomena. Varying the controls to show the animated response can provide strong visual images of the cause-and-effect relationships between various physical quantities. A more pedagogically powerful use of these simulations is for the students to control the simulations themselves in discovery activities, designed with guiding questions from the instructor to allow them to develop a robust conceptual understanding of physics.

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