www.concord.org vol. 13, no. 3 Fall 2009

@Concord.org

REALIZING THE EDUCATIONAL PROMISE OF TECHNOLOGY

Inside

The Deeply Digital Texts Initiative

The Concord Consortium's initiative starts with seven new projects.

BY CHAD DORSEY

The latest educational trend is to jettison textbooks in a quick switch to alternative technology. A prep school in Massachusetts has proudly announced the dismantling of their entire school library in favor of digital books. Parents are searching for alternatives to buying college texts, the cost of which often tops $1,000 per year. Amazon is hoping to capture part of the $5.5 billion textbook market with their Kindle reader.

At the Concord Consortium, we welcome the interest in technology, but take a different view. Digital texts require a huge, but exciting investment in technology. However, there is a real danger that they could fall into the trap of simply delivering the same old education. Digital texts should instead take full advantage of the new medium to exploit five unique advantages offered by networked computers:

Interactivity Technology opens up powerful ways of learning by guided exploration of real and virtual worlds. Instead of being told, students can be guided to discover for themselves how the world works. Compelling and personal immersive environments offer enticing ways to do this.

Assessment Interactive materials provide opportunities for new kinds of assessment, including monitoring the performance of individuals and groups of students. Student

continued on page 4

Teaching Beyond the PDF

BY CHAD DORSEY

The call for digital texts is loud and clear. Fueled by perceived cost savings and tantalizing examples of available e-readers, nonprofit and commerical organizations alike have been touting various descriptions of such textbooks and have begun to produce examples. Amazon and Sony's e-readers have jockeyed for starting position for years already, and Barnes and Noble has just sprung out of the gate to join them. Governor Arnold Schwarzenegger has launched a campaign to bring digital textbooks to many California schools.

Digital texts are indeed coming—in many respects, they're already here—and they bring with them the possibility of **revolutionizing teaching and learning.**

We at the Concord Consortium are pleased to see such a movement finally picking up steam. Its advocates are clearly onto something important. But they also have it dangerously wrong.

For more than a decade, we have argued that free digital resources will transform education. Those calling for digital texts today describe a similar vision. But current programs and prescriptions often don't do justice to the true promise of digital resources. Proponents usher in the convenience of text-filled iPods, eulogize the overstuffed student backpack, and imagine district budgets flush with saved cash, all elements that hold some basis in truth. But hearing advocates hawk these as the promise of digital texts is like hearing Henry Ford rave about the advantages of time saved no longer shopping for buggy whips.

Digital texts are indeed coming—in many respects, they're already here—and they bring with them the possibility of revolutionizing teaching and learning. This revolution offers potency far beyond the simple PDF document, a power that most existing examples miss almost entirely. Instead, they offer shallow examples of digital texts that run a real risk of selling the concept short. Using the analogy of textbooks is helpful for those working to relate to this new medium, but it is also a perilous paradigm. Examples that hew too closely to existing models of what textbooks provide are destined to also repeat their failures. By taking advantage of technology's capabilities, digital texts can offer experiences that run much deeper than shallow presentations of text and images.

Digital texts can contain highly interactive, model-based simulations that allow students to engage in deep and powerful inquiry. They can help students visualize the unseen and conduct experiments that would otherwise be impossible. They can bring the power of probes, sensors, and real-time data analysis into every student's hands. They can help teachers tailor their own curriculum, share resources across oceans, and address individual student needs. It is these traits, far more profound than mere portability, that demonstrate the real advantages digital texts can offer.

With this issue, we launch our Deeply Digital Texts Initiative, a multi-year program highlighting examples of what digital texts can do. We describe current work in labs and pilot classrooms that demonstrates many of these promising methods. In the coming years, the Concord Consortium will focus on polishing frameworks and bringing the best examples to schools. We acknowledge that existing public experiments with this first generation of digital resources are an important initial step. We must, however, guard against being lulled into complacency by their relatively minor improvements when the true possibilities of digital resources can already be witnessed. We invite you to read about them in the pages that follow—and to experience them online yourself.

At the start of another school year, we look forward to helping teachers think about how technology can help students learn. We are pleased to do this in our favorite way—through a set of lessons highlighting the many ways that Concord Consortium resources can be used in the classroom. With this set of five lessons, we describe a week of some of the best that educational technology has to offer, ranging from an elementary school lesson on the scientific basis for evolution to a college-level lesson on the internal workings of transistors. We've also included something just for teachers, knowing that the hectic teaching life makes it all too easy to miss taking time for yourself to consider how you approach the craft of teaching.

Monday's Lesson, Inquiry in the Digital Classroom, sets the stage for helping teachers think differently about curriculum and instruction involving technology. This lesson reflects our ongoing commitment to professional development for teachers and draws from our experience with statewide reform efforts in Rhode Island. Teachers will find tested strategies to bring both technology and a student-centered inquiry approach to their classrooms.

Tuesday's Lesson, Teaching Evolution to Fourth Graders, describes how interactive, model-based simulations can help elementary students learn the underpinnings of the most important and unifying concept in all of biology. Students use models to explore adaptation, variation, and inheritance and see for themselves the mechanism of evolution. The Evolution Readiness project does not presume to teach all of evolution to these young students. The activities are designed to cover standards-based material and answer the "why" questions students ask. Teachers in our research classrooms in Massachusetts, Missouri, and Texas began using these activities this fall.

Wednesday's Lesson, Visualizing Energy, provides an example of how combining several technology-based approaches can yield multiple perspectives on an idea. The four methods described in this lesson engage students in data collection and analysis, give them opportunities to compose their own visual representations of energy flow, and make them authors and storytellers describing their own narratives about energy flow in the world around them.

Thursday's Lesson, The Greenhouse Effect, describes ways to use models to teach about the environment and sustainability, among today's most relevant science and social science topics. Students explore the factors involved in global warming by varying parameters and running short experiments. Perhaps the most powerful part of this lesson is the description of how the activity can be modified easily by teachers to create their own versions customized for their students' needs. This lesson is drawn from our Information Technology in Science Instruction project, which resulted in over 1,000 technology-embedded lessons that incorporate models, simulations, and data from probes and sensors to support student science understanding.

> Digital texts can contain highly interactive, model-based simulations that allow students to engage in **deep and powerful inquiry.** They can help students **visualize the unseen** and conduct experiments that would otherwise be impossible.

Friday's Lesson, How Transistors Work, shows how models can assist early college students who are training to be technicians in fields involving electron-scale processes and phenomena. This lesson is one of 16 from our Electron Technologies project designed to further students' molecular-level understanding of important science concepts and extend this understanding to processes involving electrons. This project supports faculty at two-year colleges in teaching these concepts and connecting them directly to the work students will perform as technicians.

For a new vision of the power of digitizing curriculum, try one or all of the above lessons at *http://www.concord.org/fall2009/lessons*.

Chad Dorsey *(cdorsey@concord.org) is President of the Concord Consortium.*

Deeply Digital—*continued from page 1*

performance data can be streamed to teachers who can use the results to match each student's prior knowledge and skills.

Currency For many reasons, textbooks resist change. Often their content is out of date as soon as they are released. Some states even require them to remain unchanged for at least a decade. Technology-based materials can be updated and connected to current research and thinking.

Plasticity Textbooks are designed for average students and they often fail to engage most learners. Electronic media can be customized and adapted to meet different students' needs.

Community Texts are part of a top-down authoritarian model of education, where a few experts dictate what the masses must learn. Electronic media development can take place within an online community of educators and students, provided that design criteria and reviews are in place to maintain quality.

The Concord Consortium is dedicated to **providing the innovations and answers,** so that courses that take better advantage of technology can be created, refined, and studied. To hasten the day when this is possible, we have just launched a new "Deeply Digital Texts Initiative."

We envision courses that rely on community-generated and customized materials based on guided inquiry. Digital resources of the future will generate formative feedback to teachers and students and support differentiated instruction. The materials will be constantly improving because the community of subject and pedagogy experts will integrate current research results and tools.

Unfortunately, we are not there yet. Some fundamental questions have yet to be answered about how students learn with highly interactive materials and how to take full advantage of the features of digital texts. Furthermore, innovative materials are needed to explore new ways of using technology. More topics need to be covered so that fully electronic courses can be developed and evaluated.

The Concord Consortium is dedicated to providing the innovations and answers, so that courses that take better advantage of technology can be created, refined, and studied. To hasten the day when this is possible, we have just launched a new "Deeply Digital Texts Initiative." This initiative consists of seven new projects that each addresses one piece of the puzzle.

New strategies

Two of our new projects explore new applications of software. The first, "SmartGraphs," is based on intelligent software that can recognize important features in graphs. It has implications for any teaching that relies on graphs. SmartGraphs "know" about themselves and students' interactions with them. By providing scaffolding tailored to each student's interactions with the graph, SmartGraphs help students learn about graphs and support them to analyze graphs in various contexts. Pennsylvania's Classrooms for the Future program is a partner in this project. It provides a unique opportunity to test SmartGraphs, since it has deployed over 140,000 laptops in classrooms serving more than a half-million high school students. This allows us to determine whether the software intelligence can be harnessed to improve student graph skills acquisition and to improve the assessment of these skills.

A second project explores applications of advanced computational models to simulate complex situations involving fluid flow. We use the same methods used in current research to model everything from global climate patterns and ocean currents to blood flow. This project examines the fundamental question of whether pre-college students can master such complex systems and understand the relationship between a 3D model and physical models. The project focuses on designing and building an energy-efficient house as both a virtual model and a fully instrumented physical one. In partnership with Tufts, Purdue, and Hofstra universities as well as the Museum of Science in Boston, this project is developing new curriculum materials and conducting a controlled study to determine whether simulations and hands-on projects are mutually beneficial. We are especially excited about this project's ability to promote awareness of sustainability issues among high school students.

Stronger proofs

There is broad belief that guided student exploration of virtual systems holds great value, enabling experiments with systems (entire galaxies down to individual atoms) and across time scales (femtoseconds to millennia). But more proofs are urgently needed that might convince cash-strapped schools to invest in these approaches. Two new projects are designed to provide these proofs in areas that have broad implications.

The first of these undertakes a longitudinal study of student retention and application to supplement our ongoing Science of Atoms and Molecules project. This project uses computer models of atoms and molecules to clarify molecular explanations throughout secondary science courses. The research focuses on retention across grades, looking at whether this emphasis on the atomic scale in chemistry can help biology students a year later. This study provides critical data about whether students can transfer important concepts across years, a vital look at how technology-enhanced curriculum used over time can support the development of deep conceptual understanding.

A second study explores how curriculum and assessment based on dynamic, interactive visualizations of complex phenomena can ensure that all students learn significant science content. Educational researchers have raised troubling questions about the value of visualizations. They seem to indicate that sequences of drawings are more valuable for students. The VISUAL project will clarify when and how to use dynamic visualizations, taking into account factors such as student prior knowledge, the amount of interaction, and the clarity of the model itself. This project continues a longstanding collaboration between the Concord Consortium and Marcia Linn's research group at the University of California, Berkeley, and carries on the work of our joint TELS Center.

Linking research to classrooms

Two new projects explore the ability of electronic media to link classrooms with areas of current science research. High-Adventure Science injects contemporary earth and space science into the classroom, engaging students in thinking about important unanswered questions that scientists around the world are actively exploring. For example, one topic is so-called "dark matter" discovered by Dr. Vera Rubin of the Carnegie Institution for Science in Washington, D.C. Students use models to discover why Rubin found it necessary to propose dark matter to explain data about galaxy rotation speeds. This project explores whether this kind of new content can motivate students and result in learning that is valued by schools.

The Geniverse project provides a different way to link students to research. In this project students learn firsthand how science knowledge develops in the rapidly changing fields of bioinformatics and DNA science by engaging in collaborative, simulated experiments to solve open-ended problems. Students learn about key experimental methods and the core biological concepts behind them, and then publish short summaries of their results and debate the findings and procedures of others, thus participating directly in the process of scientific investigation. The project studies whether and under what conditions this mix of scientific process, current research, and collaboration can accelerate student learning and motivation.

> By **creating new technologies,** researching their effectiveness and developing and supporting exciting technology-enhanced curricula, we are demonstrating new ways for technology to **support teaching and learning.**

Scaling up and creating a community of practice

In order to study the idea that texts developed by experts can be replaced by materials generated by collaborating educators, we need to create a community that is large enough to be self-sustaining. Our new ITSI Scale-Up project represents a national expansion of prior work that can provide the required testbed. This five-year project provides research-based science materials directly to 264 teachers and 10,000 students in four states in its initial phase. The project has the capacity to reach another 1,500 teachers and 50,000 students nationwide and become self-sustaining in a dissemination phase. The central innovation of this work is that teachers learn new content and approaches by revising and sharing computer-based materials.

With these new endeavors, as well as our ongoing projects, the Concord Consortium is working to help define the future of educational technology. By creating new technologies, researching their effectiveness and developing and supporting exciting technology-enhanced curricula, we are demonstrating new ways for technology to support teaching and learning. By working on many aspects of the problem, these projects shape the development of the coming generation of digital texts, allowing them to integrate deeply and effectively with the best that technology has to offer and to support teachers and students far into the future.

Chad Dorsey *(cdorsey@concord.org) is President of the Concord Consortium.*

Inquiry in the Digital

BY DAN DAMELIN

I hate the phrase 'inquiry-based science'… It's like saying 'immersion-based swimming.' If it isn't inquiry-based, it isn't science.

- DAVID HAMMER, PROFESSOR OF EDUCATION AND PHYSICS

LINKS *Monday's Lesson*

- **RI-ITEST** *http://ri-itest.concord.org*
- **RITES** *http://rites.concord.org*
- **Molecular Workbench** *http://mw.concord.org/modeler*
- **ITSI** *http://itsi.concord.org*

Inquiry is essential in learning and doing science. The nature of science itself is an inquiry-based enterprise, and research has shown that students learn science best by doing science.

All national and state science standards include inquiry and/or the nature of science as prominent elements. The National Academy of Sciences has published a separate text titled "Inquiry and the National Science Education Standards (NSES): A Guide for Teaching and Learning," which highlights the inquiry aspect of the NSES. In Rhode Island, where two Concord Consortium projects are taking place, the state standards, known as Grade Span Expectations, list inquiry and the nature of science as two of the six unifying themes across all science topics.

What is inquiry?

Inquiry has many different meanings. Some definitions include anything that involves a hands-on lab, while others are primarily focused on exploration of topics for which answers are unknown. Inquiry is possible at many levels, and it is this spectrum—from fully teacher centered to fully student centered—that is the source of much variability in defining inquiry. The following table provides a framework for categorizing an activity into a particular level of inquiry.

Level	0	1	2	3	4
Question	Teacher	Teacher	Teacher	Teacher	Student
Procedures/ Design	Teacher	Teacher	Part Teacher/ Part Student	Student	Student
Results/ Analysis	Teacher	Student	Student	Student	Student

Based on Herron, M.D. (1971). The nature of scientific enquiry. School Review, 79(2), 171-212.

Level 0 describes an activity in which the teacher proposes the question, defines the methods and procedures, and analyzes the results for the students—for example, a classroom demonstration or a fill-in-the-blank lab experiment.

Level 4 describes an activity in which the student decides on the question to be explored, determines how to go about answering the question, and performs his or her own analysis of the data, including information from articles, discussions, and computer visualizations—as with a student project.

Depending on the practical limitations of time and equipment, as well as considerations regarding the best way to teach certain content, teachers will likely do activities across the inquiry spectrum.

Digital resources can support various levels of inquiry

A hands-on science lab could fall into any of these categories. But teachers can move even a Level 0 or 1 activity to a more student-centered approach by changing the language of the lab to be less prescribed and giving more control to the student in deciding how to conduct and analyze an experiment. Because digital materials are often not designed or easily modified by the teacher, it may seem less obvious how to use these tools at various levels of inquiry.

In the Rhode Island Information Technology Experiences for Students and Teachers (RI-ITEST) project, teachers do not have the ability to change the activities, which were developed to support an atomic-level understanding of physics, chemistry, and biology. However, teachers can adjust the way the activities are used for a more or less student-centered, inquiry-based approach.

The default mode for delivery of a RI-ITEST activity involves assigning students to complete an activity individually or in pairs. Students proceed through a sequence of pages containing models, instructions, challenges, and assessment items (Figure 1). The driving questions and procedures were created by the activity author. Students analyze the results and draw conclusions individually (or with a partner). Used in this way, an activity is a Level 1 or 2 on the inquiry scale depending on how structured or unstructured the model explorations are.

Class discussion and scientific reasoning

One aspect of the nature of science that is deeply entwined with inquiry is the ability to support an argument with evidence. The RI-ITEST teacher guides suggest models to highlight and discussion questions to facilitate full class conversation. For instance, try stopping the class as students are running the activity and have them support their claims by demonstrating how they came to a particular understanding using the models in the activity. This will reinforce their knowledge, build logical reasoning skills, enhance their ability to present ideas clearly—and move the activity up on the inquiry scale.

Alternatively, rather than having students do the activity individually, project the activity using an LCD projector. (If you don't have access to enough computers for the entire class, this may be the best option in any case.) Show a model, then have students suggest ways to interact with it or invite one or more students to the projector or interactive whiteboard to engage with the model. Students can work together as a class to discover concepts and debate their interpretation of the resulting model behavior. Depending on how much the students contribute, this could be a Level 2 or 3 activity.

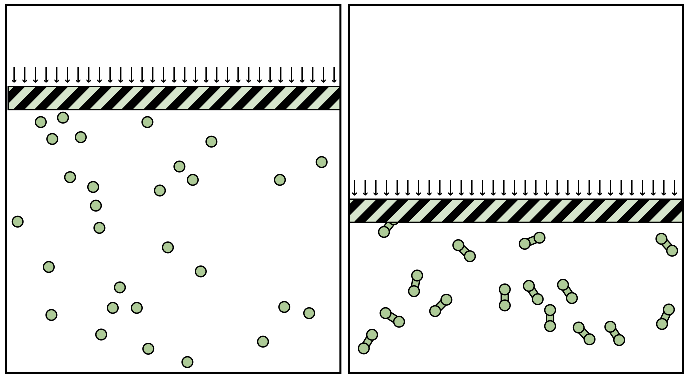


Figure 2. Both models have the same number of atoms at the same temperature and pressure, demonstrating the importance of molecule number rather than atom number in defining the volume of a gas.

Customizing digital activities

Many of the digital resources developed at the Concord Consortium follow the pattern of a multi-page activity with embedded models, supporting text and images, and assessments. In some cases, as with our Information Technology in Science Instruction (*ITSI*) and Rhode Island Technology Enhanced Science (*RITES*) projects, teachers have the ability to edit existing activities or create new activities.

Using the *Molecular Workbench* (the software engine powering many of the molecular models) teachers and students can even design the models. This makes a Level 4 activity possible, where the student chooses a question to explore, designs models, and presents an analysis of the data. By designing her own model, a student was able to demonstrate how the number of molecules—not the number of atoms—is key to understanding volume of a gas (Figure 2).

Benefits of digital resources for inquiry

When I taught chemistry I told students that my most important lab rule was "no unauthorized experiments." Rather than discouraging inquiry, I emphasized that I welcomed suggestions for experiments they wanted to try; they just had to get my approval first. I told them that 95% of the time I would approve any experiment they proposed, and the last 5% we would do together behind the safety shield.

Computer models allow students to have free range to explore extreme limits of the models without safety concerns. They can do many more experiments than in a wet lab, and the results are more immediate and easily shared with other students who can then reproduce the experiment. With the addition of digital resources to a curriculum, many opportunities for increased inquiry become possible.

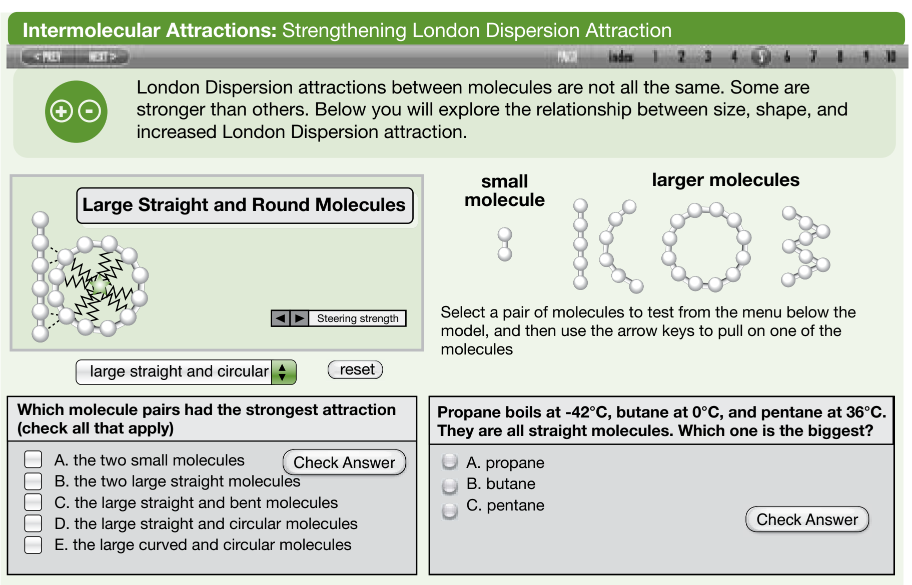


Figure 1. A page from the Intermolecular Attractions RI-ITEST activity. Students read instructions, interact with a model, and respond to embedded questions.

Dan Damelin *(ddamelin@concord.org) directs the RI-ITEST project.*

Teaching Evolution to Fourth

BY PAUL HORWITZ

The year 2009 marks the 150th anniversary of the publication of Charles Darwin's *The Origin of Species* in which he famously described for the first time his theory of evolution by natural selection. Perhaps to mark the occasion, the National Science Foundation recently awarded the Concord Consortium a grant to design curriculum for introducing this difficult concept to elementary students. Try our three Evolution Readiness computer-based activities with your fourth graders and watch plants evolve.

LINKS *Tuesday's Lesson*

Evolution Readiness
http://er.concord.org

Visit *http://www.concord.org/fall2009/lessons* to launch the Evolution Readiness activities.

Activity One: The Virtual Greenhouse

The first activity focuses on the differences between various plants and animals and introduces the concept of a species—a group of organisms that can interbreed. Students see several examples of such groups, some familiar (dogs and cats), some not (exotic plants). Students then use a computer model that introduces adaptation—the fact that every organism possesses certain traits that enable it to live in a particular environment.

Students work with three varieties of plants, distinguished by different leaf types and adapted to different light levels. They plant seeds of each variety and watch them grow in five flower boxes that are illuminated by different amounts of light. The challenge is to figure out which plants grow best in which light level (Figure 1).

You can evaluate student inquiry skills as they attempt this challenge. Roam around the room and watch as your students interact with the model. Do they proceed systematically? Do they try every combination of seed and flower box at least once? Encourage students to record their work by taking snapshots, which are stored in a lab book.

Figure 1. Students are challenged to figure out which plants grow best in which light level. A healthy plant produces a flower. Unhealthy plants wither before producing a flower.

Activity Two: The Virtual Field

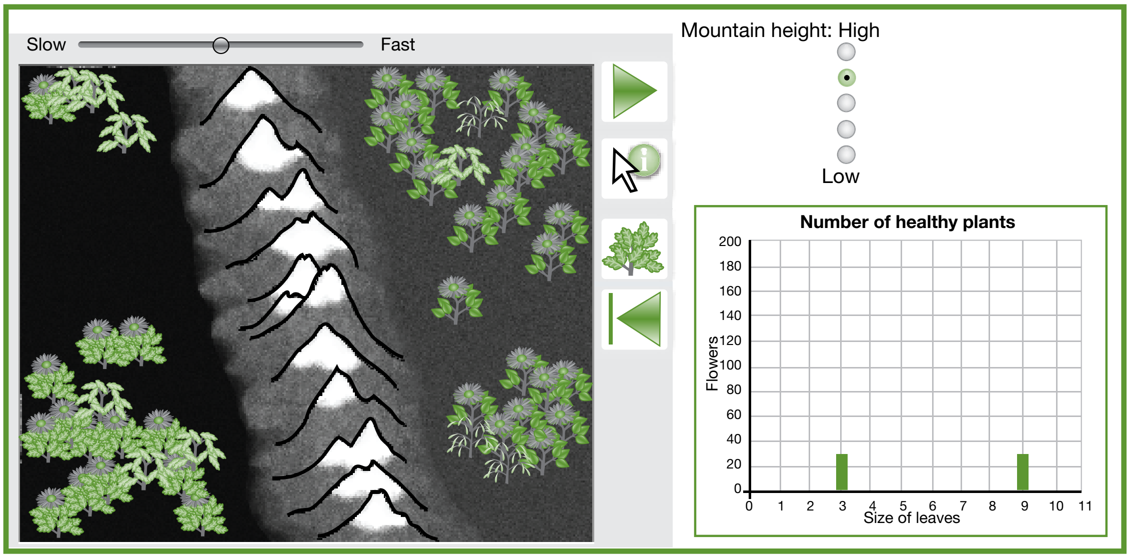
While the first activity begs the question of how adaptations like the leaves-and-light correlation come about, this next activity provides a partial answer by introducing birth and death. Plants that are maladapted to their environment die; those that survive produce seeds that grow into offspring. Some of the offspring differ slightly from the parent plant.

Students are presented with an outdoor field that varies in light level from top to bottom and told to plant the three varieties of seeds where they think they will grow best. If students have planted their seeds judiciously, they grow and produce a flower. But then there's a surprise. Winter arrives and the plants die. If any of the plants have produced seeds, there is a good chance that some of these will grow up to be plants capable of producing their own seeds. The bars on a graph move up and down each year showing the number of healthy plants of each type.

Initially, all the offspring plants look exactly like the parent plant. As each of these plants scatters its seeds randomly, some fall outside

Graders

Figure 2. Students watch mountains grow and affect the environment. Will the plants evolve and adapt or will they go extinct?



the plant's "comfort zone." These seeds will grow, but the plants they produce wither and die prematurely without producing seeds.

Next, students learn about variation—members of the same species can differ, like puppies from the same litter. When students return to the model of the field, the plant offspring differ, too. (Behind the scenes, we have modified the model to allow for this.) And the different offspring have different optimal conditions for growth.

Students are now restricted to planting only "medium" plants—the ones that grow best halfway up the field because they are adapted to medium light levels. This time, however, because of random variation in the seeds, that single plant type evolves and after many generations produces a full spectrum of plant varieties capable of living everywhere in the field.

Activity 3: Changes in the Environment

Evolution is driven by changes in the environment—changes that usually take place over very long stretches of time. For a typical elementary student, this is a difficult concept.

The third activity starts with a uniform field where the light level is intermediate between the very sunny and very dark light levels that previously characterized the top and bottom strips of the field. Medium plants thrive anywhere in this field and although their offspring may include a small number of mutations, these rapidly die out, since the environment is not suitable for them. The bar graph, therefore, shows only one bar.

Students can change this peaceful but static environment using radio buttons to control in seconds a process that normally takes place over millennia—the growth of mountains (Figure 2). The mountains grow in a vertical chain in the middle of the screen. As they do, they have a powerful effect on the environments on either side. To the left of the mountains the environment grows steadily darker; on the right, it gets lighter. If this process takes place too rapidly, it results in an ecological disaster, a mass extinction of life on both sides as the plants cannot adapt fast enough. But if the mountains grow more gradually, the plant population on the right slowly evolves toward plants with thin leaves that are adapted to the increased amount of light, while those on the left adapt to the encroaching darkness by evolving toward large leaves.

The process, while seemingly purposeful and almost miraculous, is a natural—indeed inevitable!—consequence of the two properties of the model that the students investigated earlier, adaptation and inheritance with variability. Any model with these properties will behave the same way. But populations of organisms can only evolve in response to environmental changes that take place very slowly, allowing the random variability from one generation to the next to "keep up" with the change. Abrupt changes tend to have disastrous effects on most species. Forcing students to slow the growth of the mountains so as not to kill all their plants provides them with a reference point for understanding how the evolutionary mechanism works.

Elementary students may not be able to appreciate the vastness of evolutionary time or to conceive of how a series of tiny changes can cumulatively produce the dramatic effects we observe in the fossil record. But that's okay. Our goal is "evolution readiness." By giving young children a basic understanding of how natural selection works, we hope to prepare them to take the next step on an exciting intellectual journey.

Paul Horwitz *(phorwitz@concord.org) is director of the Evolution Readiness project.*

Visualizing Energy

BY ED HAZZARD AND CHAD DORSEY

LINKS *Wednesday's Lesson*

CLEAR
http://clear.concord.org

The concept of energy runs through all topics in science. From the struggles of the tiniest insect to the explosion of the most distant supernova, energy connects the most disparate of scientific ideas together with a tidy coherence. Though the basic notion of energy is simple, it hides a deceptive amount of complexity and nuance. What is energy? What does it mean that energy is neither created nor destroyed? Why is this important?

Teaching students even the most straightforward ideas about energy can be fraught with misconceptions. Conceptualizing an abstract entity that often cannot be seen or felt presents a host of complications, and requires new approaches to teaching. One of the best ways to help students understand such a multi-faceted concept is by using a variety of tools, representations, and strategies. In our Cumulative Learning using Embedded Assessment Results *(CLEAR)* project with the University of California, Berkeley, we are exploring how different representations reveal student thinking about energy.

In this lesson for middle school students, we introduce four activities that apply to the same physical situation. Students begin with a simple hands-on experiment. Then they represent the concepts visually using an online diagramming tool and in narrative through a story. They conclude by describing an analogous real-world situation.

To elicit student ideas and generate interest in sustainable energy, ask students: Where does the energy from your food go? How can you capture this energy for reuse? Next, introduce students to an innovative way to capture "extra" energy: a cafe in the Netherlands collects kinetic energy from its customers*. The action of people walking through the cafe's revolving door generates 4,600kWh of electrical energy per year, enough to power an average house.

* http://www.inhabitat.com/2008/12/10/energy-generating-revolving-door-by-boon-edam/

Now, have your students complete the activities below.

Activity One: The Experiment

Using a hand-crank generator to illuminate a small light bulb, students can observe a series of energy transformations. To focus on the underlying ideas of energy conservation, prompt students to account for the energy flowing through the system by constantly referring to the following energy questions:

- Where does the energy come from?
- Where does the energy go?
- What forms is the energy in?
- Does the energy change from one form to another?

a) Ask students to light a bulb and describe what's going on (Figure 1). In addition to the above questions, students should consider: How does the energy travel from one place to

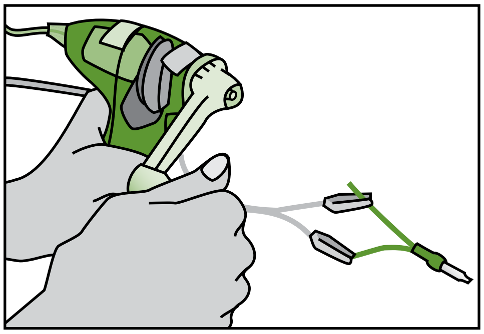


Figure 1. Students light a bulb using a hand generator.

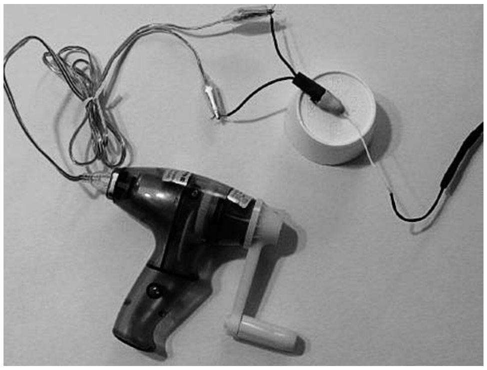


Figure 2. Generator connected to light, with sensor embedded in clay.

Visit *http://www.concord.org/fall2009/lessons* to launch the experiment and MySystem tool used in this lesson.

another? Do you think the same amount of energy came out of the system as was put into it?

b) Instruct students to disconnect the bulb and crank. Notice that cranking is much easier. Why? What's happening with the energy now?

c) Use a temperature sensor to collect evidence about energy. Bury the light bulb and a fast-response temperature sensor in a small amount of clay (Figure 2). Measure the rise in temperature while cranking at different speeds. Why does a bulb produce heat as well as light? Where does the heat energy come from and where does it go? How does the bulb energy get into the clay? Does the rate of temperature rise depend on how fast you crank?

Figure 3 shows a typical set of data for cranking at slow, medium, and fast speeds. (Students can also generate their own data. They should wait between runs for the clay to cool down.) Ask students to interpret the graph. What was the temperature change in the first 30 seconds? What was the rate of temperature increase and how is this shown by the graph? What feature of the graph is related to the heat energy? What happened after the cranking stopped?

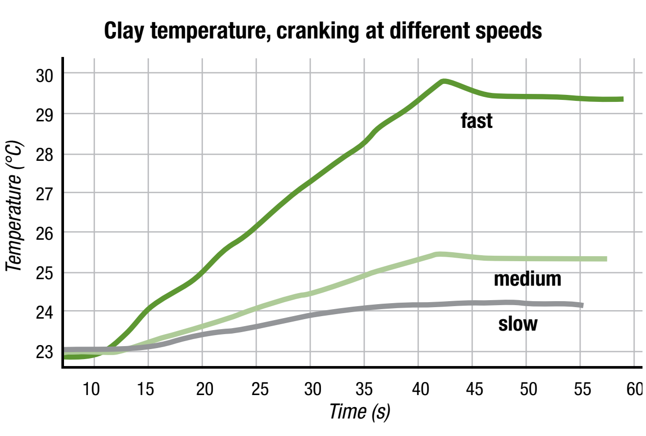


Figure 3. Temperature measurements from the sensor embedded in the clay.

Activity 2: The MySystem Diagram

Using the MySystem online diagramming tool, students can drag icons into a diagramming space to represent objects and connect them with arrows to show the direction and amount of energy flowing between them (Figure 4). Have students construct a diagram depicting the energy flow among the hand, generator, bulb, and clay in the first experiment. Students should keep our original four energy questions in mind as they create their work.

Have students change arrow widths to indicate how much energy is transferred at different locations. Also encourage them to use different colors and/or labels to represent the different forms of energy and energy transport involved at each step (i.e., conduction, convection, or radiation of heat energy).

Monitor diagrams for evidence of student thinking. Do the diagrams indicate that the same amount of energy passes through the system unabated? Do students mark energy that is "lost" as thermal energy? (Students can use the globe icon to indicate energy that has been lost as heat.) Where do students think the energy goes once it leaves the bulb? In what forms?

Activity 3: The Energy Story

Ask students to write a narrative describing what happens to the energy in the experiment. Suggest that they write in first person and create a story line.

Together, the stories and diagrams serve as a combined representation of students' thoughts about energy. What conclusions do your students draw?

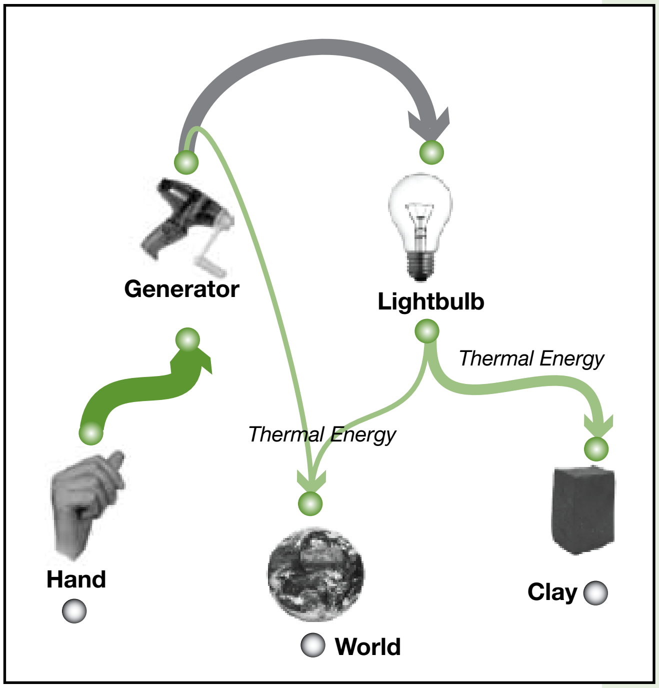


Figure 4. Sample MySystem diagram, indicating energy flow in the first experiment.

Activity 4: Real-world Application

Students are now prepared to apply the same analysis to an analogous real-world situation of their own choosing. For instance, they might diagram the energy flow from a hydroelectric power plant to a light bulb in their house, noting energy transformations and heat loss along the way. Or you may challenge them to invent their own version of the revolving door generator, diagramming the inputs, transformations, and outputs. Students can apply the same fundamental questions to these stories, highlighting and discussing where the energy comes from and where it goes. Through this four-step process, students can visualize energy in a whole new way—and perhaps help experts around the world find new ways to use energy more efficiently.

Ed Hazzard *(ehazzard@concord.org) is a senior curriculum developer.* ***Chad Dorsey*** *(cdorsey@concord.org) is President of the Concord Consortium.*

The Greenhouse Effect

BY BOB TINKER AND CAROLYN STAUDT

Students need to understand the greenhouse effect to grasp the causes of global warming. Studying the greenhouse effect covers many important science topics—light, energy, molecules, heat, and temperature, to start—and supports system thinking.

But understanding the greenhouse effect is challenging. It is complex, involving different kinds of light and their interactions with gases, the earth, and clouds. Students must grapple with both the atomic scale of tiny light particles interacting with atoms and the gigantic scale of the entire earth. What makes the greenhouse effect confusing is that it is the result of the competing effects of incoming energy in the form of light from the sun and infrared light lost to space (Figure 1).

Visit *http://www.concord.org/fall2009/lessons* to launch the Greenhouse Gases activity.

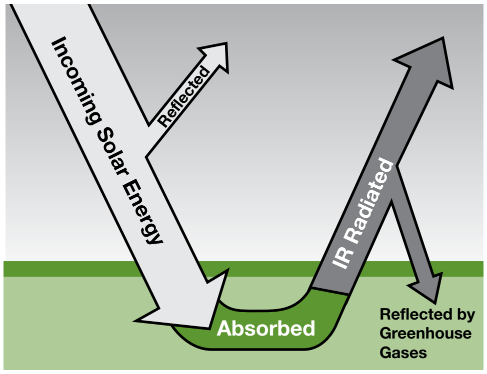


Figure 1: The overall flow of solar energy into the earth is balanced by energy loss to space. When these flows balance, the earth reaches an average temperature.

Greenhouse Gases

You can use the Greenhouse Gases lesson as is or customize it (see sidebar) to teach your students about global warming and perhaps even inspire them to make changes that will have positive effects on the planet.

This lesson, created originally for ninth grade students, features two interactive models created with NetLogo, each designed to support student learning through inquiry. Students should be encouraged to learn how to run the models and experiment with the

Customize the activity

Sign up for an account. You will receive a confirmation email with a web link to activate your account. Go to Investigations and click Global Climate Change to view the Greenhouse Gases activity. To run the activity as a student will see it, click the Run button to the right of the activity name.

In order to customize an investigation, first make a copy of it. Click the gear icon at the top of the page and select copy from the pull-down menu. Rename and save your investigation. You can access this investigation in your home folder.

Review the starter or full model sections and pages by clicking the expansion button next to the activity name in the navigational menu on the left of the investigation window.

View individual pages by clicking the circle icons above the investigation page. To modify content, click the pencil on the top of any box. With tools similar to word processing, you can easily add, delete, and format text, insert lists, or add pictures using existing URLs. Click the Save button when you are finished editing.

To add functionality, click the plus icon at the top of the investigation page. This will display a pull-down menu with various features that are available within that page. You can add text boxes, open response and multiple-choice questions, a draw tool, a data table and graph, models, and a snapshot. Selecting an item will place it at the bottom of the page. Click and drag on its header to move the feature to another location. To remove a feature or page, use the red X next to the item you wish to delete.

Note: These steps are based on a fall 2009 preview version of *ITSI-SU*.

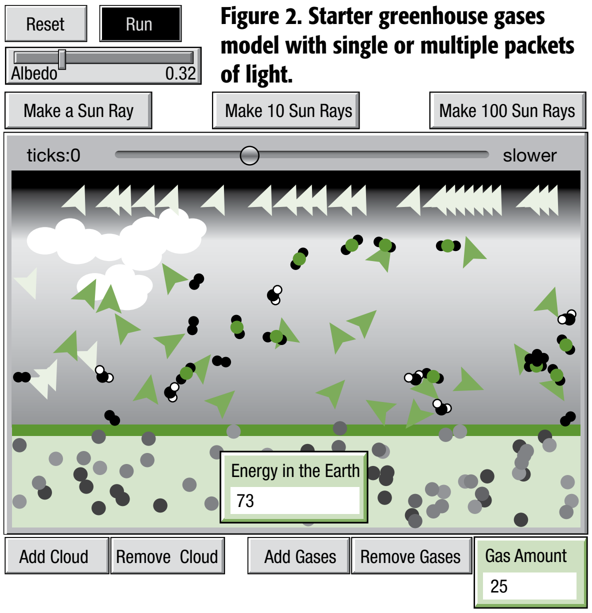


Figure 2. Starter greenhouse gases model with single or multiple packets of light.

different controls, and to observe how the model works.

The first model helps students understand how light, atmosphere, and the earth interact (Figure 2). It introduces the idea that when light energy enters the atmosphere some is absorbed, depending on how reflective the earth is on average (the albedo). Students can send single packets of light and watch where each goes. The light energy can be seen heading to the earth, resulting in infrared (IR) energy radiated back into space. Careful observation reveals that clouds reflect sunlight, but not IR. Conversely, greenhouse gases pass sunlight, but not IR.

The second model puts these all together by supplying a stream of light and allowing the system to reach temperature equilibrium (Figure 3). The new idea is that there is an average global temperature, which is determined by the amount of energy in the earth.

Students can see that the temperature always fluctuates a bit, but that clouds, greenhouse gases, and changes in albedo all impact the global temperature.

Assessing student understanding

After students have worked through the activity, you can assess what they have learned by using the following challenges.

Challenge 1: The snowball earth
Some scientists think that the earth once froze over. Can you adjust the model to show this? Once the earth becomes a snowball, how might it recover?

Challenge 2: Population rise
What happens to the earth if the population increases? How could you set the controls to approximate a crowded earth? Justify your choices. What happens to the temperature?

How accurate is a model?

No model completely captures all of reality. The earth is a complex system of oceans, albedos, light inputs, multiple greenhouse gases, and radiation levels, all of which vary greatly from place to place. Our greenhouse models are simplified and do not include some interactions that could be important, for example, absorption and radiation in the atmosphere. To build fairly accurate models of the earth's temperature and how it will rise over the next decades requires the largest computers that exist.

Given the problems with models, should we ignore them because they are not exact? Not at all. Instead, the limitations of every model need to be understood. Stimulate a discussion about the uses and limitations of models. Ask students: What simplifications have been made? What is the effect of these simplifications on your overall understanding of global warming? Even a simplified greenhouse gas model can make a real impact.

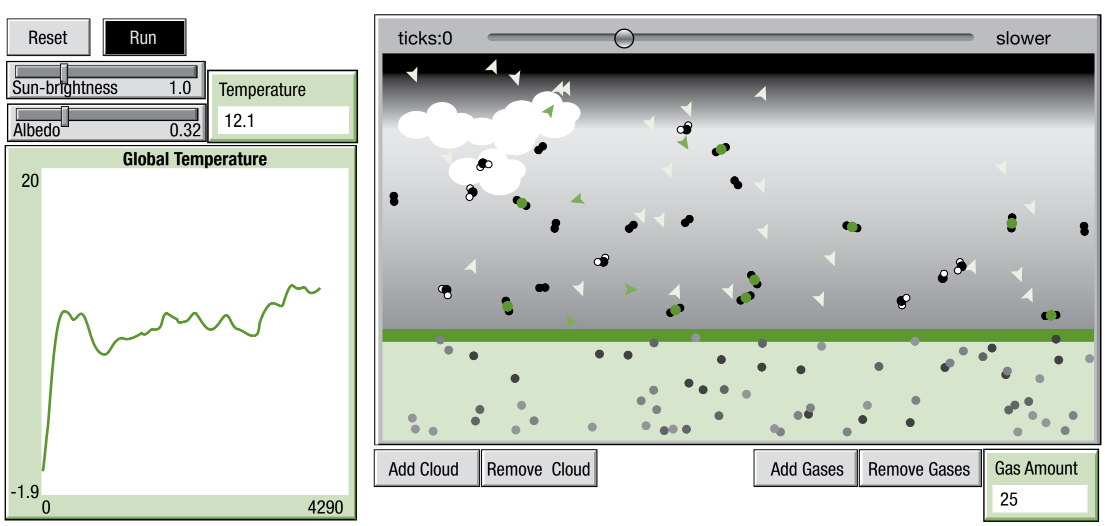
LINKS *Thursday's Lesson*

NetLogo
http://ccl.northwestern.edu/netlogo

ITSI-SU
http://itsisu.investigations.concord.org

Bob Tinker *(bob@concord.org) is President Emeritus of the Concord Consortium.* ***Carolyn Staudt*** *(cstaudt@concord.org) directs the Innovative Technology for Science Inquiry Scale-Up project (ITSI-SU).*

Figure 3. Greenhouse gases model with stream of light. This model shows how the temperature of the earth is determined by a balance between incoming radiation from the sun and outgoing IR radiation to space. Students can see that the amount of solar energy, the albedo, clouds, and greenhouse gases can all shift this balance.



How Transistors Work

BY CHARLES XIE

Microelectronics is a subfield of electronics that studies very small electronic components, circuits, and systems. The foundation of information technology, microelectronics is also central to the current nanotechnology revolution. Many recent innovations, such as system-on-a-chip, microelectromechanical systems, gene chips, and lab-on-a-chip are either a direct outgrowth of microelectronics or a blend of it with other disciplines.

Although technology and engineering courses at the high school and college level now include microelectronics, teaching this subject is no small matter! The pedagogical challenge arises because microelectronics is a synthesis of many high-level fields, including solid-state physics, quantum mechanics, thermodynamics, statistical mechanics, electronics, and signal processing. Most curriculum materials employ mathematical formulation and didactic instructions. While this approach may work for advanced college students, the learning curve is far too steep for most high school and community college students.

The NSF-funded *Electron Technologies* project is exploring novel ways to make microelectronics more accessible to a wider audience. Our strategy utilizes computational modeling and visualization of electron dynamics in micro systems. If seeing is believing, we hope seeing is also understanding as the invisible world of electrons becomes visible and dynamic.

In this lesson, we present an activity for teaching transistors, which was created using our *Molecular Workbench* software.

LINKS *Friday's Lesson*

Molecular Workbench
http://mw.concord.org

Electron Technologies
http://et.concord.org

The importance of transistors

Transistors are the building blocks of digital electronic devices. Your cell phone, MP3 player, and computer all depend on them to operate. Transistors can be made very tiny and massively produced using advanced microfabrication technology. You are probably using millions of them if you are reading the electronic version of this article—as of 2008, an Intel microprocessor contained nearly 2 billion transistors.

Visit *http://www.concord.org/fall2009/lessons* to launch the Transistors activity.

Exploring the field effect

In a physics course, students may have learned: 1) electric fields cause the flow of electrons and 2) changing electric charges can affect the distribution of electric fields. Few students, however, understand that electric fields not only drive but also obstruct electric currents. The first model (Figure 1) in the activity is designed to show these field effects.

The model shows the flow of electrons, represented by the small circles with arrows that indicate their velocities around a negatively charged "island," represented by the large gray circle in the middle. Students can change the total charge on the island and observe how it affects the flow of the electrons. Due to the Coulombic repulsions between the electrons and the island, there is an area around the island which the electrons are prohibited from entering. This forbidden area is shown as a green circle with a dashed outline.

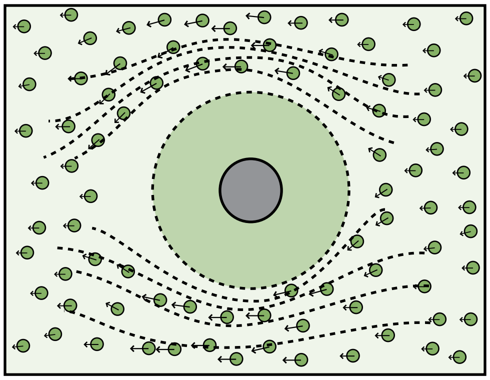


Figure 1. This interactive simulation demonstrates how a static electric field obstructs an electric current. The dotted lines are the trajectory lines of some of the electrons.

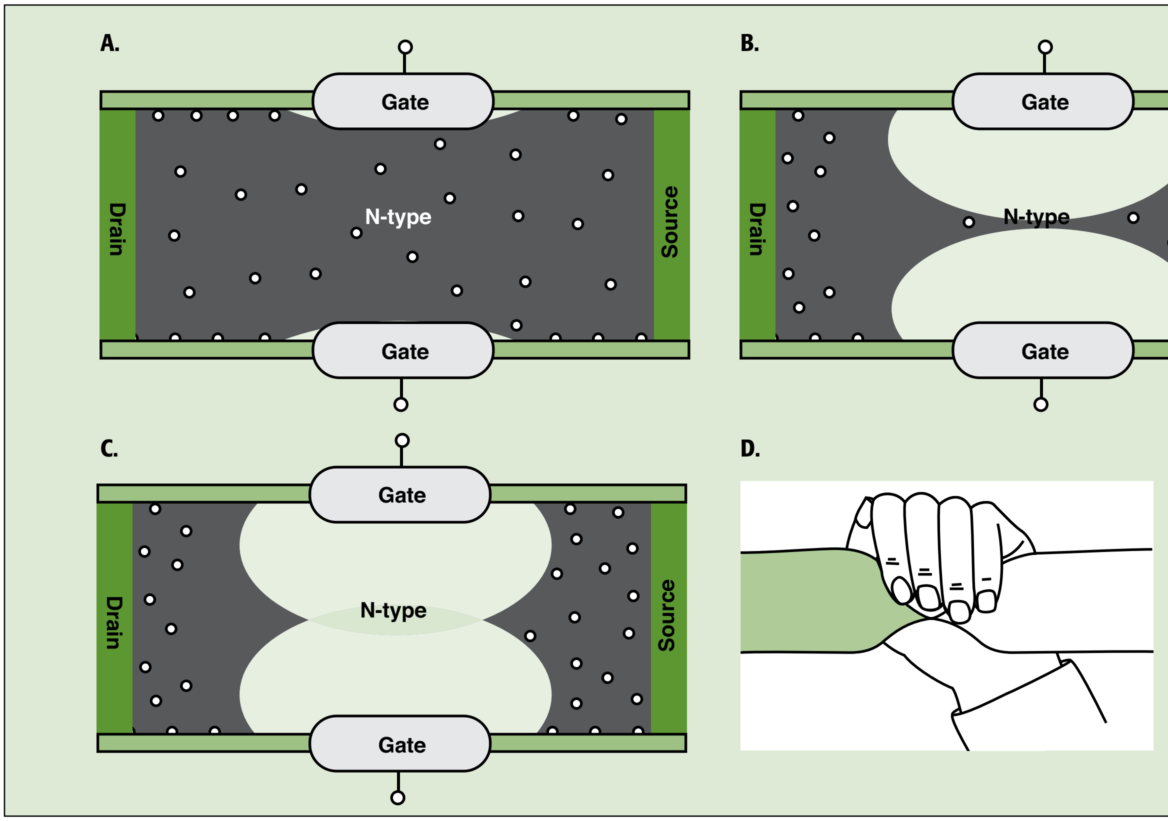


Figure 2. This sequence of images shows how an electric current in a junction field effect transistor is turned off.

Before manipulating the model, consider the following questions:

- What would happen to the forbidden area if the amount of charge on the "island" increases or decreases?
- What would happen if the island moves to a different location?

The size of the forbidden area determines the extent of constriction and, therefore, where the electric current can flow.

Experimenting with the junction field effect transistor

Having obtained a concrete picture about the field effect, students explore how this effect can be used to turn an electric current on and off like a switch in a junction field effect transistor (JFET) (Figure 2).

A JFET consists of a bulk semiconductor that provides the charge carriers, a source from which electrons flow in, a drain through which electrons flow out, and two gates that control the current flowing from the source to the drain. A voltage can be applied between a gate and the source to generate the field effect. When there is no voltage or the voltage is low, the electrons flow through the bulk semiconductor. When the voltage increases, the flow can be impeded. When the voltage reaches a certain value, the flow is completely pinched off. Like a garden hose, which you can squeeze to slow or stop the water flow, a JFET uses an electric field to achieve a similar effect.

Building logic gates

In the rest of the activity, students explore an AND gate and an OR gate built from two JFETs, thus understanding how transistors can be used to build integrated circuits (chips).

From microelectronics to nanoelectronics

The smaller a single transistor can be made, the more we can build into a chip and the faster it will compute. The last four decades have witnessed the reign of Moore's Law in the computer industry, which states that the number of transistors on a chip doubles approximately every two years. The trend is not expected to stop for at least another decade, thanks to the advent of nanoelectronics.

When transistors become as small as a few nanometers, we enter the realm of nanotechnology. Sciences are rapidly converging, blending, and unifying in this fertile field, which may well be the main locomotive for the next Industrial Revolution. Today's high school and college teachers must prepare students for future nanotechnician jobs.

Charles Xie *(qxie@concord.org) is the creator of the Molecular Workbench software and the director of the Electron Technologies Project.*

The Concord Consortium
25 Love Lane
Concord, MA 01742

NEWS at Concord Consortium

Happy 15th Anniversary, Concord Consortium

The Concord Consortium is pleased to announce that 2009 marks our 15th anniversary. To celebrate, we plan to redesign our website to improve the ways our readers learn about and use our software and activities. Your input as a reader of *@Concord* is extremely valuable, and we invite your opinions and feedback.

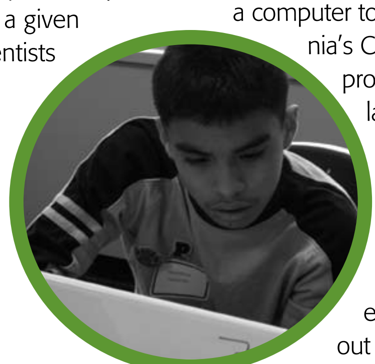
We have designed a brief survey, which takes only a few minutes to complete and automatically enrolls you in a drawing for a new iPod Touch! Please visit ***http://concord.org/survey09***

New Photos of Electrons

In atoms and molecules, the state of an electron is described using an electron cloud, which represents the probability of the electron being found at a given location. Earlier this fall, scientists photographed for the first time the electron clouds around a single carbon atom using a field-emitting microscope.

These unique and groundbreaking pictures of electron clouds prove what probability theory had claimed—electrons exist as "clouds." But today's ultrafast microscopy is still too slow to capture how they move (the mechanism that governs a large part of the physics and chemistry of atoms and molecules). The Electron Technologies project *(http://et.concord.org)* has developed an innovative computational engine with which students can further explore the movement of electron clouds. A part of the Molecular Workbench software, this engine provides a dynamic, interactive environment that allows students to discover the interaction of electron clouds with nuclei, the formation of covalent bonds, the origin of chemical polarity, electron transfer, ionization, and more.

The fact that the engine is based on solving the time-dependent Schrödinger equation—the equivalent of Newton's equation of motion in the microscopic world—demonstrates the tremendous potential of computational physics in transforming educational media from static animations to interactive simulations.



Research on 1:1 Computing

There is a growing number of 1:1 school laptop programs, in which every student has a computer to use each day. Pennsylvania's Classrooms for the Future program is now the nation's largest statewide deployment of computers, with more than 140,000 laptops serving high school students in English, social studies, science, and mathematics classrooms throughout Pennsylvania.

How does teaching and learning change when every student has a laptop? To help answer that question, the Concord Consortium's Andy Zucker studied the Denver School of Science and Technology, a highly successful public charter high school where more than 40% of the student body comes from low-income families. Findings from that study are available in two new articles. In its June/July 2009 issue, *Learning and Leading with Technology* published "Assessment Made Easy: Students Flourish in a One-to-One Laptop Program." And in its December 2009 issue, *The Science Teacher* will publish "Teaching Physics with Laptops." Andy says about these articles, "I wish there were more articles about teaching with laptops because as prices keep decreasing, more and more teachers and students will have daily access to computers. Teaching and learning, especially in science, can benefit greatly from ubiquitous access to computers—but only when best practices are more widely shared."

@Concord

Editor: Chad Dorsey
Managing Editor: Cynthia McIntyre
Design: Susan W. Gilday
www.concord.org
The Concord Consortium
25 Love Lane
Concord, MA 01742
978-405-3200 | fax: 978-405-2076

@Concord is published two times a year by **The Concord Consortium,** a nonprofit educational research and development organization dedicated to educational innovation through creative technologies.

This material is based upon work supported by the National Science Foundation under several grants (DRL-0946582, DRL-0929774, DRL-0929540, DRL-0918449, DRL-0918522, DRL-0918642, DRL-0918743, ESI-0737649, DUE-0831974, DRL-0822213, DRL-0822388, DUE-0802532). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.