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REALIZING THE EDUCATIONAL PROMISE OF TECHNOLOGY

Probes Help Younger Students Learn Science

The TEEMSS project provides evidence of student learning with probes.

BY ANDY ZUCKER

The good news: research demonstrates that using data collection probes helps high school students learn many science concepts better and more quickly. Over 50% of U.S. high school science teachers are using such probes with their students. The not-so-good news: there has been far less use of probes by younger students and little research to determine if using probes can help them, too.

With the completion of the *Technology Enhanced Elementary and Middle School Science* (TEEMSS) project, the Concord Consortium is delighted to fill this research gap and report some good news for younger learners.[1] TEEMSS created, disseminated, and conducted research on 15 technology-based science units for students in grades 3 to 8. We found that, indeed, probes do help these students learn science.

Five units were created for each grade level (3-4, 5-6, and 7-8), targeting NSES standards for Inquiry, Physical Science, Life Science, Earth and Space Science, and Technology and Engineering. Each unit contains two investigations with a discovery question, several trials, analysis, and further investigations. TEEMSS also developed teacher supports, including an online professional development course and teacher guides. Teachers and students could use the activities with just about any combination of computer and probe. Our probeware software technology runs on handheld computers or desktops running Windows or Mac OS, and with interfaces and probes from any major vendor (Data Harvest, Fourier, ImagiWorks, Pasco, Texas Instruments, and Vernier). The National Science Foundation provided funding for TEEMSS.

continued on page 4

Inside

Download FREE software to run five lessons from our website:

www.concord.org

The Power of Plumbing: Infrastructure Supports Electronic Activities

BY ROBERT TINKER

Once every student has a networked computer, what will instructional materials look like? They better be more than simply texts-on-screen. The material should be compelling and thought provoking, and should take full advantage of the flexibility and computational power computers offer.

This issue of *@Concord* features five classroom-ready lessons from our work that represent a sneak peek at what could replace texts: free computer-based materials that provide interaction, guidance, assessment, and flexible formatting. And, unlike texts, these materials are entirely electronic and can be distributed freely to colleagues, kids, and parents. After using these, textbooks will seem impossibly antique.

Instructional materials should be **compelling and thought provoking,** and should take full advantage of the **flexibility and computational power** computers offer.

Monday's Lesson, "Motion Two Ways," illustrates how hands-on experimentation can be incorporated into electronic media. It is one of hundreds of activities using probes and sensors that we and participants in our workshops have produced. This particular activity is a great way to introduce force and motion. A motion sensor is needed, but we give teachers the option of using most commercial motion detectors or one that can be built from an inexpensive DC motor. Constructing the sensor is itself a valuable introduction to electronics, magnetism, and IT careers.

Tuesday's Lesson, "The Color of Light," demonstrates how useful it is to embed different models in the same platform. This lesson is a sequence of three short model-based activities that address the atomic basis of color. The first uses a simple model built using NetLogo to get students thinking about the role of absorption and re-emission in determining the color of objects. The second uses our Molecular Workbench to focus on the way atoms can be excited by light and then decay, releasing heat or light. The third uses an open source Java model developed by the Physics Education Technology (PhET) group at the University of Colorado. These three activities were easy to develop using a web-based template we are developing.

Wednesday's Lesson, "Friction," demonstrates how electronic media will adapt to individual student differences, the goal of our Universal Design for Learning (UDL) project. Soon the graphs and models will be able to explain their important features. If students have earphones, the text and, eventually, the graphs and models can be vocalized. Colors, layout, and the language used can be modified. When there are questions for students to answer, help will be adjustable for top-down or bottom-up thinkers and the kind of scaffolding will be variable from highly specific to open-ended. Eventually, we will provide different paths through a learning activity and entirely different activities for the same instructional goals, but designed for students with different strengths.

Thursday's Lesson, "Genetics," shows how guided inquiry can combine a game-like environment with serious, difficult content learning. Games alone can be unproductive and waste time, but these problems can be overcome by guiding students through explorations of challenges, interesting interactions, and a simplified system modeled after the real thing. This lesson is part of a much larger set of activities that introduce most genetics concepts—including evolution—at multiple levels from molecules to populations.

Friday's Lesson, "Chemical Reactions," allows students to make sense of the notation used for chemical equations by getting a feel for chemical reactions at the atomic level. The activity is one of 24 under development as part of the Science of Atoms and Molecules project. The goal is to supplement introductory physics, chemistry, and biology courses with a coherent treatment of atoms and molecules. The activities all feature our incredible Molecular Workbench system that generates highly interactive models of atomic-scale phenomena.

OPTIMISTS have been predicting the demise of textbooks for a long time. Why has it taken so long? Why think it might happen now? One reason has to do with plumbing—of a software kind—and investing in an infrastructure.

Around 1980 we made the first probeware—software that read sensors of various kinds and graphed the results in real time. In those early days, our software was designed to be a pure tool, modeled after a word processor or spreadsheet. We believed that students would master the tool and use it for independent explorations. Naturally, teachers and learners needed instructions, so we produced print materials to complement the tools. As the tools got more sophisticated, the options multiplied and the instructions ballooned. We resisted mixing our "constructivist" tools and models with electronic instructions, because that sounded too much like "instructivist" computer-assisted learning (CAI) and that was considered a *bad thing*.

Theory finally collided with reality in 1995 with GenScope, a genetics software tool. Paul Horwitz's careful classroom research found that kids could master GenScope by treating it like a game, but that this did not improve their scores in standardized tests of genetics. The obvious fix was to create a "surround" for GenScope called Pedagogica. This was a programmable environment that provided all the pedagogical support needed: scaffolding, guidance, instructions, and assessments. The result was BioLogica, with the same genetics software now embedded in a series of learning activities that provided an environment for guiding student learning through exploration of various aspects of genetics. A script that Pedagogica runs determines the actual content, whether it is simple dominance rules, or how to interpret a Punnett square. It also determines how open-ended or didactic the activities are.

There are many advantages to this approach. Students do not need to learn the tool before using it. Their attention is not on the tool as such, but on the content, in this case genetics. Teachers do not have to master the tool either, so extensive professional development is not required prior to use. Many different activities can be based on the same tool, but aimed at different content and grades, and employing different instructional strategies. With a good authoring system, developers and teachers can easily change an activity based on classroom feedback or make multiple versions for different students.

A surprising amount of software "plumbing" is needed to make this work. Like plumbing, this software is relatively invisible, but essential. SAIL, the Scalable Architecture for Interactive Learning, the latest version of Pedagogica, grows out of TELS, a collaboration that includes programmers at the University of California, Berkeley, and the University of Toronto. SAIL is the plumbing behind the first four lessons that links together the various parts of each lesson—from text and images to models and data collection, plus open response areas for students to type or draw—and connects all of them to a server.

> The **Scalable Architecture for Interactive Learning** is the plumbing that links together the various parts of each lesson—from text and images to models and data collection, plus open response areas for students to type or draw—and connects all of them to a server.

SAIL is the key to a set of functions that all educational tools and models need:

Editing. Simplifying the creation and modification of highly interactive learning materials by non-technical educators.

Deployment. Delivering materials that students need, when students need them, suitably modified for their level and learning style.

Assessment. Tracking student progress and thinking by monitoring their choices and responses and making this information available to researchers and teachers.

Extensibility. Making it easy to add new functions and link them into the system.

SAIL is modular, free, and open source. Perhaps the advantages SAIL offers will tip the balance in favor of electronic media.

Robert Tinker *(bob@concord.org) is President of the Concord Consortium.*

Probes—*continued from page 1*

Extensive testing

Almost 70 teachers in 18 school districts worked with the project. Teachers used TEEMSS units in 2004-2005, 2005-2006, and 2006-2007. School year 2005-2006 was the one in which the largest numbers of teachers and students used project materials. Participants that year included 24 grade 3-4 teachers, ten grade 5-6 teachers, and eight grade 7-8 teachers, teaching a total of 1,183 students. Data were also collected in 2004-2005 from 21 teachers who taught the same topics as many of the TEEMSS units, but without using the TEEMSS materials, including probes and computers. Data from those classes provided a non-TEEMSS comparison group.

Positive opinions

Not surprisingly, teachers and students discovered that probes are terrific tools for inquiry-based teaching and learning. One teacher wrote,

As computers become more common in schools, the **smart use of technology** has a much better chance than ever to **enhance the teaching and learning** of science for tens of millions of students.

"I was amazed at how the students made predictions that I was not even thinking about. On the temperature lesson, a student noticed that there was more humidity on the other side of the room than where he was due to the amount of students that were working on the other side of the room. That was very interesting to them."

And another said,

"The aha moment that comes to mind is seeing the kids' reactions when they discovered on their own the voltage of parallel versus series circuits and how they related to the battery voltage. This is a very exciting way to teach and extremely motivating to students."

According to one student,

"The thing I liked most about the activities was that we actually got to see what would happen rather than just learning about it."

The teachers rated various features of TEEMSS. As a group they reported that TEEMSS is useful for teaching science, and they and their students liked doing the investigations. Among the features they most appreciated about using the probes was that students were able to figure things out for themselves, and see graphs immediately as they did the experiments. Students, too, reported that they liked doing science using probes and computers, and being able to design their own experiments.

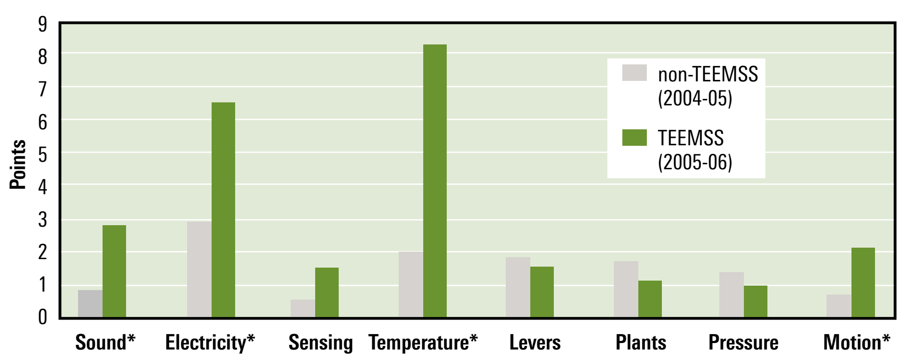
After using TEEMSS, teachers reported that the probes were easy to use, and in the future they would be more likely to use technology to teach science.

Teaching science effectively

Among the research questions we wanted to answer was whether students learned science using the TEEMSS units. For all 12 units that include pre- and post-tests, the answer is clear; they did, as demonstrated by significant gains between students' scores on the two tests.[2]

An important but more difficult question is whether students who used probes and computers learned more science than students who studied the same topics without using probeware. To answer that question, we combed through our data looking for groups of teachers who taught particular science units without the TEEMSS materials one year (in other words, teaching as they usually taught) and who then taught the same topics using TEEMSS the following year. For those cases, the big difference from year to year is whether or not the teachers used TEEMSS units, including probes. Because the same teachers are being compared from year to year, any difference in results would *not* be due to the teachers.

Because participating teachers were able to make choices about what they taught, only some of the topics were taught that way, i.e., *without* using probes one



Students' gains on tests by the same teachers in successive years.
* indicates a statistically significant difference

year and then the following year *with* TEEMSS and probes. We found such cases for eight of the topics and were eager to analyze those data.

What we discovered was that there were statistically significant differences favoring the TEEMSS students for four of the eight units (Sound, grades 3-4; Electricity, grades 3-4; Temperature, grades 5-6; and Motion, grades 7-8).

On the other hand, there were no significant differences between TEEMSS and non-TEEMSS students for the other four units (Sensing, Levers and Machines, Plants, and Pressure). For those units, using probes seemed neither to increase nor decrease what students learned, compared to those students not using probes.[3]

For the units favoring the use of TEEMSS, we wanted to know how *much* more the students learned when they used probes. "Effect size" is the accepted measure one uses to answer this question. An effect size of 0.2 standard deviations is considered small, 0.5 standard deviations is medium, and an effect size of 0.8 standard deviations is considered large. An effect size of 0.5, for example, means that, on average, students in the experimental group (in this case, those who used probes) perform at about the 69th percentile compared to students in the non-experimental group. In other words, instead of the average student performing at the 50th percentile, an effect size of 0.5 means that the average student performs at the 69th percentile—a considerable improvement.

For the four units showing significant gains, the effect sizes favoring TEEMSS were 0.58, 0.94, 1.54, and 0.49, respectively. Gains are shown in the figure on page 4. Effect sizes were computed based on the gains, the numbers of students taking each test, and other factors.

Conclusions

Many studies have reported positive impacts of using digital technology to teach science.[4] But there have been only a limited number of earlier studies of the use of probes in elementary and middle schools, and those studies were often done with small numbers of students. The TEEMSS results are newsworthy both because they are based on a greater number of students (over 1,000) and because the effect sizes we found are larger than in prior studies; for the four TEEMSS units on which statistically significant differences favored TEEMSS students, the effect sizes were quite impressive (two medium and two large).[5]

As computers become more common in schools, with entire states (including Maine and Pennsylvania) adopting "one-to-one" laptop programs for students, the smart use of technology has a much better chance than ever to enhance the teaching and learning of science for tens of millions of students. It is time to harness the incredible riches of probes and other digital technology to challenge students and allow them to learn science by collecting and analyzing data from real-world experiments, not only by reading textbooks.

LINKS ***Probes Help Students***

Technology Enhanced Elementary and Middle School Science
http://teemss.concord.org/curriculum

Andy Zucker *(azucker@concord.org) is the lead researcher for the TEEMSS project and the author of* Transforming Schools with Technology: How Smart Use of Digital Tools Helps Achieve Six Key Education Goals*, to be published by Harvard Education Press in January 2008.*

NOTES

[1] A longer research paper about this TEEMSS research is available on the Concord Consortium's website, and a peer-reviewed article will be published by the *Journal of Science Education and Technology.*

[2] There were no associated tests for the three TEEMSS "design units."

[3] Comparison data are not available for Weather, Seasons, Adaptation, and Water Cycle.

[4] Bayraktar, S. (2001). A meta-analysis of the effectiveness of computer-assisted instruction in science education. *Journal of Research on Technology in Education,* 34(2), 173-188.

[5] An effect size of 0.94, for instance, means that a typical student in the experimental group performs at the 83rd percentile of the comparison group.

Motion Two Ways

CAROLYN STAUDT AND ED HAZZARD

Get Java

Windows

Our software requires Windows XP, 2000, or Vista.

Install Java (*http://java.com/download*).

Mac OS X

Our software requires Mac OS X 10.4 or greater.

1. Update to the latest Java version using Software Update from the Apple Menu.
2. Fix your Java Web Start if you haven't already done so (*http://itsidiy.concord.org/FixJavaWebStart.dmg*).

The concept of motion—the rate of change of distance and velocity over time—is a very difficult topic for students to understand. For instance, give this challenge to your students:

A car starts rolling up a ramp. It slows, stops and rolls down under the force of gravity. Graph the position and velocity of the car against time.

Because it is quite common to think that the car stops for a significant time at the top, learners regularly make a prediction that is immediately contradicted by the data. To better understand this motion, students need firsthand experience collecting the data. When they do, and the real motion of a car is represented in a graphical form, math comes alive.

The *Information Technology in Science Instruction* (ITSI) project allows for the integration of a challenge or discovery question with instructions, data collection, and analysis, along with student input in the form of typed or drawn responses to questions. We have created over 100 activities that use probes and models for middle school physical science, earth science, and life science, and high school biology, chemistry, and physics. Most models are open source, so they can be modified. And the probes can be purchased or handmade.

In this "Monday's Lesson," we describe two side-by-side motion activities, one with a commercial probe and one with a motion sensor built by students using inexpensive parts.

Figure 1. Ramp experiment with a commercial sensor.

Commercial probeware

The following probeware is compatible with ITSI activities:

- Fourier Ecolog
- Data Harvest EasySense Q
- Pasco Science Workshop 500
- Pasco Airlink SI
- Texas Instruments CBL2
- Vernier Go! Link
- Vernier LabPro

Motion on a ramp (commercial probe)

To explore motion with your students using any of several commercial ultrasonic motion sensors, go to the following website: www.concord.org/resources

You can preview (Show) the "Motion on a ramp" activity on the Web, but to collect and save data, click the Run link, which opens a .jnlp file to your desktop. Choose your probeware interface from the pull-down menu before running the activity (see list above). For setup, see figure 1.

Motion on a ramp (DIY probe)

Commercial probeware is fabulous. It allows students to collect real-time data literally at their fingertips. But since some schools simply have no budget for equipment, we developed an alternative—a second motion lesson that supports a "Do It Yourself" (DIY) approach to probeware.

By creating probes used in science investigations, students learn about electronics and information technology, while also saving schools a bundle on hardware. For the cost of a $70 interface and $25 in parts, students can build simple circuits that measure temperature, light, magnetic field, motion and more than 14 different parameters in all. This requires some facility with wiring, but in return, it gives students a valuable introduction to electronics and computer interfacing (see figure 2).

Go to: www.concord.org/resources

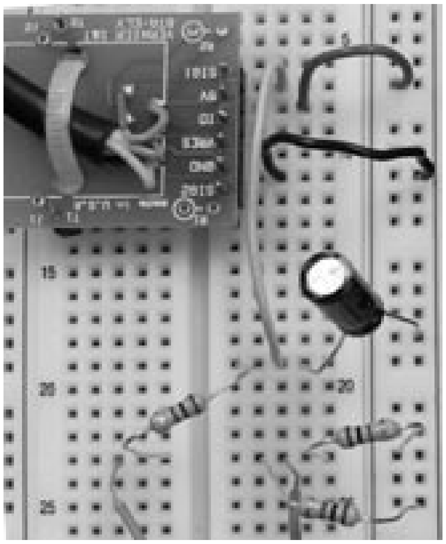


Figure 2. **Do-it-yourself probe electronics.**

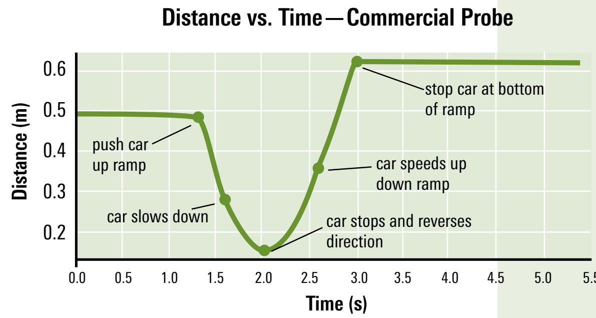
First, follow the directions to build your own motion sensor, and then run the "Motion on a ramp" activity with your hand-made motion sensor. For setup, see figure 3.

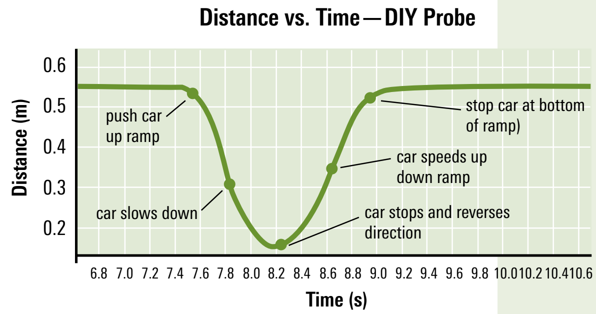
Prediction and analysis

The initial challenge above asked students to make a prediction: graph the motion of a car moving up and then down a ramp. With both the commercial and the DIY probe motion activities, students are encouraged to predict the motion of the car in words and in graphical form. As students test their predictions and collect real data, the lines they draw remain as a background image on the graph, allowing students to assess how good their predictions were.

All student data is retained automatically when the activity is closed. Students or the teacher can review the data as the basis for a class discussion. A careful examination of the velocity graph shows that the effect of friction is different on the way up and on the way down. Students can also notice that "changing direction" is represented by the velocity graph passing through zero.

The final analysis of student data is a vital part of each activity. Students consider questions such as:





- What is the relationship between a distance vs. time graph and a velocity vs. time graph?
- How would you predict the velocity graph if you knew the shape of the distance graph?
- How would you predict the distance graph if you knew the shape of the velocity graph?

Students explore these questions by comparing the distance and velocity data they have collected.

Using commercial probes or building their own motion sensors, students are able to gather, analyze, model and communicate data to help them easily visualize motion. And that's certain to get your students moving in the right direction!

Carolyn Staudt *(cstaudt@concord.org) directs the ITSI project.* ***Ed Hazzard*** *(ehazzard@concord.org) is a senior curriculum designer.*

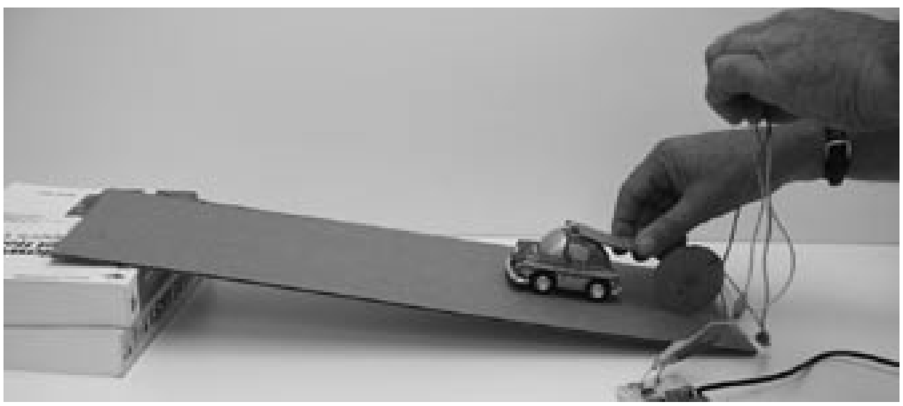


Figure 3. **Ramp experiment with a do-it-yourself sensor.**

Build your own motion sensor

A $1 DC motor generates a voltage that is proportional to its rotational speed. By attaching the shaft of the motor to a wheel on the cart, you generate a voltage proportional to the cart's speed. This is fed into a voltage sensor to generate a graph of velocity. An integrator can convert this into a distance graph.

LINKS *Monday's Lesson*

Information Technology in Science Instruction
http://itsi.concord.org

The Color of Light

ROBERT TINKER

Why do we see a red rose as red and its leaves as green? What's different about yellow and purple polka dots? What determines the colors we see? Questions like these thoroughly baffled Aristotle, Newton, and many other early scientists. Now, using a few simple models, even young learners can outsmart these great thinkers.

Newton was the first to realize that to understand fully the color of things, we need to consider separately the colors in light and the effect of roses, leaves, and other objects on the light. Use the following short activities with your students to explore the color of light. Each activity was developed in our "Do It Yourself" system and exploits a different model: Molecular Workbench, NetLogo, and Physics Education Technology. Newton would certainly have liked them!

Part 1: Light reflection

The first activity introduces a particle model of light and the idea that white light is a collection of packets of energy called photons. Photons are, of course, unusual particles because they have no mass. Light is not usually represented this way—it is usually described as a wave. A rain shower of colored particles is also a legitimate representation and much easier to understand than waves. Of course, if students ask about waves, you have the perfect opportunity to talk about wave-particle duality and the incredible idea that both representations are valid.

Go to _www.concord.org/resources_ and run the "Light reflection" activity.

This activity features a simple NetLogo model. View the model by clicking the buttons marked "Setup" and then "Run." This model depicts photons as red, green, and blue arrowheads (see figure 1). Encourage students to explore how reflection and absorption of photons determines the colors of objects.

1. Have students follow individual photons by slowing down the model (use the slider above the model).
2. Ask students to make predictions about the color that will be reflected as they use the red slider to absorb red photons.
3. Try the same with the green and blue sliders.

The big idea is that photons are absorbed and then some are re-emitted in random directions. The color we see is determined by these re-emitted photons. If a majority of the photons coming from a spot are red, we say that the spot looks red. If they are all absorbed, it looks black.

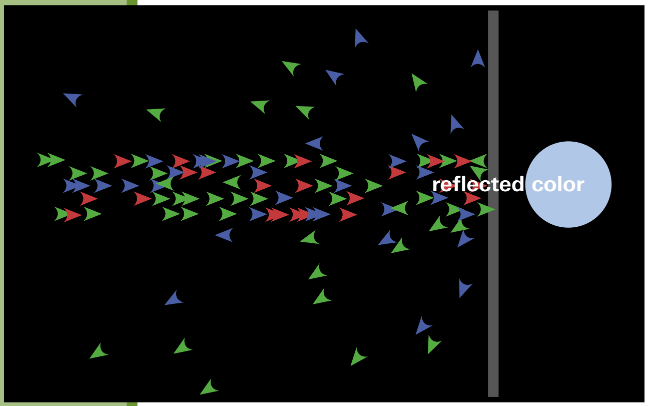


Figure 1. In this NetLogo model, a beam of white light comes in from the left that consists of equal numbers of red, green, and blue photons. Sliders (not shown) determine what fraction of each type is absorbed. The others bounce off in random directions, determining the color we see.

Part 2: Light and atoms

In the second activity, students look more closely at what happens when photons hit a solid. If the solid is colored, some photons vanish and others get re-emitted. Why?

Run the "Light and atoms" activity at _www.concord.org/resources._

This activity uses a _Molecular Workbench_ model in which atoms can be bombarded with photons (see figure 2). The big idea is that atoms sometimes absorb energy from photons and become excited. Have students explore what happens to that energy. It can result in an emitted photon or it can be converted into heat energy. Students should understand that the fates of different colored photons that interact with atoms determine the color we see.

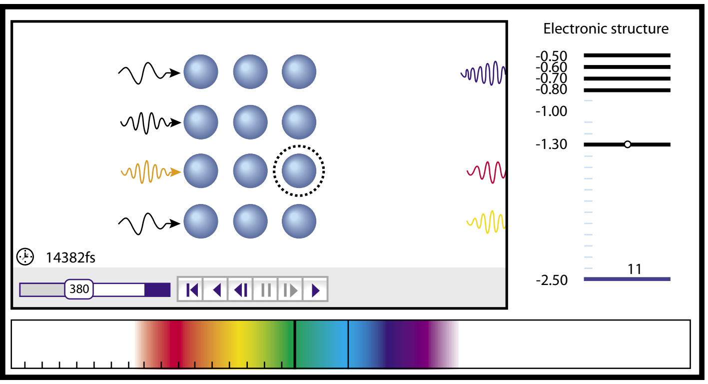


Figure 2. This Molecular Workbench model shows what happens when a beam of photons of mixed energy bathe these atoms. Most go through, but some have just the energy required to excite an atom from its ground state. Excited atoms are represented by the dotted "halo." Excited atoms can emit a photon in any direction, which is what we see when we look at a substance.

Part 3: Neon and fluorescent lights

In this final activity, which uses one of the *Physics Education Technology* (PhET) models created at the University of Colorado, students look at how colored photons are made. They explore different gases in "neon" lights and watch as a single atom that is bombarded with electrons can be excited and then emit a photon if the electron has enough energy (see figure 3).

Run the "Neon and fluorescent lights" activity at *www.concord.org/resources*.

Ask students to make a prediction and then experiment with the model.

The big idea here is that electrical energy from a battery is converted into light by interactions between electrons and gas atoms. The detailed properties of the gas atoms determine the color of the light emitted.

It is a complex chain of events. Electrons boil off a heated electrode in one end of a tube. Inside the tube are gas atoms. If there is an electric field created by a battery, the electrons are accelerated and slam into the gas atoms, giving them energy. The amount of energy that an atom can absorb is determined by the available empty electron states.

An excited atom can lose its energy by emitting a photon of light. If that photon carries away energy in a certain range, we perceive it as colored. Thus the available excited states determine the color we see.

Ask your students to describe how they think "neon" or gas discharge lights work, and why they come in different bright colors.

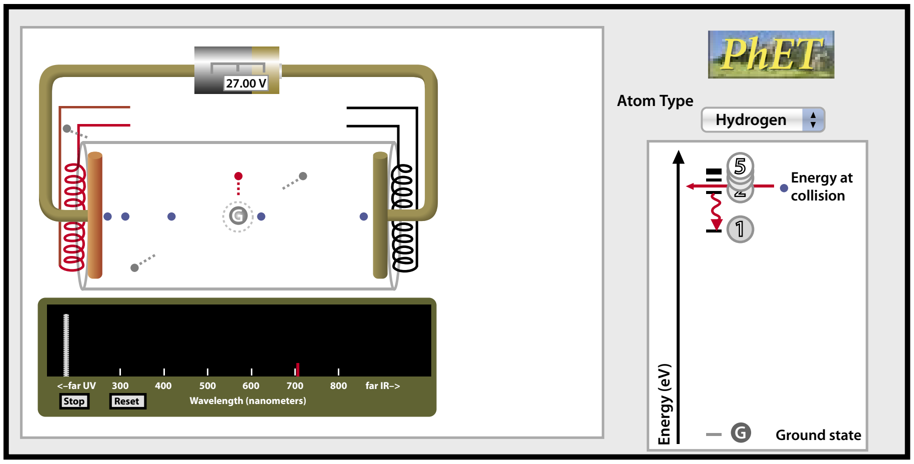


Figure 3. The term "neon light" is used for any light source that relies on electrons hitting gas atoms, though not all such tubes use neon gas. In this case, a hydrogen atom is used. Electrons bombard one hydrogen atom and excite it to a higher energy level. The atom then drops to a lower energy and emits a photon. In this illustration, we caught the atom just after it dropped from the second excited state to the first, emitting a red photon.

LINKS *Tuesday's Lesson*

Information Technology in Science Instruction
http://itsi.concord.org

Physics Education Technology
http://phet.colorado.edu/new/index.php

Molecular Workbench
http://mw.concord.org/modeler/index.html

1. Have students experiment with different battery voltages and atoms to create different colors.
2. Challenge students to use the configurable option for atom type and make an atom with no visible spectrum, or one whose main color is blue, green, or red.

Customizing activities

While Newton would surely have liked these activities, chances are he would have wanted to make some changes to address his own students as well as the local curriculum. You may, too. For instance, you may want to explain the idea of "wavelength," which is avoided in our treatment.

It is easy to customize these activities or create new ones.

1. First, register at *http://itsidiy.concord.org* (it's free!).
2. Load one of these activities—or any of hundreds of existing activities—in your browser.
3. Click "Copy," which generates your own copy of the activity. You can then edit, save, and run your revised version.

This system epitomizes the decentralized "Do It Yourself" approach of our *Information Technology in Science Instruction* project. Student activities of the future will not be handed down from a distant expert. Instead, teams of teachers, educators, scientists, and even students themselves will develop them collaboratively.

Robert Tinker *(bob@concord.org) is President of the Concord Consortium.*

Teaching Friction in Multiple

CYNTHIA MCINTYRE

Science units

- What if there were no friction?
- Why are there clouds?
- What do plants eat?
- What is electricity?
- Why does water boil?
- Is it getting hotter?
- How do we hear sound?

Your new group of fourth graders is scheduled to arrive for the start of school next week, so you scan through the roster of 23 names: 14 boys and 9 girls. You recognize three or four surnames as siblings of students you've had in class in previous years, and you know that while a younger sibling may resemble the older in appearance, their learning styles and abilities will undoubtedly differ: each child is unique. You also read four *IEPs*, carefully noting the details about a student's hyperactivity disorder, another's visual impairment, an English Language Learner, and one student with autism. It's daunting—to say the least—to think about meeting all their needs.

UDL Science

The Concord Consortium's *Universal Design in Science Education* project is developing software so that elementary teachers can meet each student's needs when science is taught. Universal Design for Learning (UDL) educational materials are created with multiple means of representation, multiple means of engagement, and multiple means of expression. In a word, UDL software represents choices: opportunities for teachers and students to select ways to approach a topic; to choose how that topic will be presented (for instance, in English or Spanish, in a larger or smaller font size, with different background colors, or to be read aloud); and to decide how best to demonstrate what the student has learned.

We are designing seven units around the theme of energy for students in grades 3-4 and 5-6. A variety of inquiry activities both on and off computer address a number of driving questions (see Science units sidebar).

Try it out

This lesson explores the question: *What if there were no friction?*

Go to: *www.concord.org/resources*

Try the sample friction units for grades 3-4 and for 5-6. The software opens in a Java Web Start File, which automatically saves student information—for example, a probe measurement, a written or drawn response to a question, or a snapshot of a model. The student's information is available when she reopens the program. The teacher can also access this information at the end of a work session.

Students start with a short pre-test, which allows the teacher (and the researchers at the Concord Consortium) to assess each student's prior knowledge of friction. At the completion of the pre-test, links to six activities—four in science, one in math and another in language arts—become available. As with all facets of UDL, the more flexibility, the better. Thus, students are not required to complete the activities in any particular order, though they cannot take the post-test until the teacher permits them to do so.

Smart graphs and models

Each activity starts with a discovery question and uses probes to support lab investigations or computational models to explore virtual environments. In "Dragging shoes" students use a force sensor to measure friction values of shoe soles (see figure 1) and in "Hot stuff" they experiment with a model to observe the effects of friction at the molecular level (see figure 2).

We are currently developing "Smart Graphs" and "Smart Models" that will provide meta-analysis. That is, a graph will be

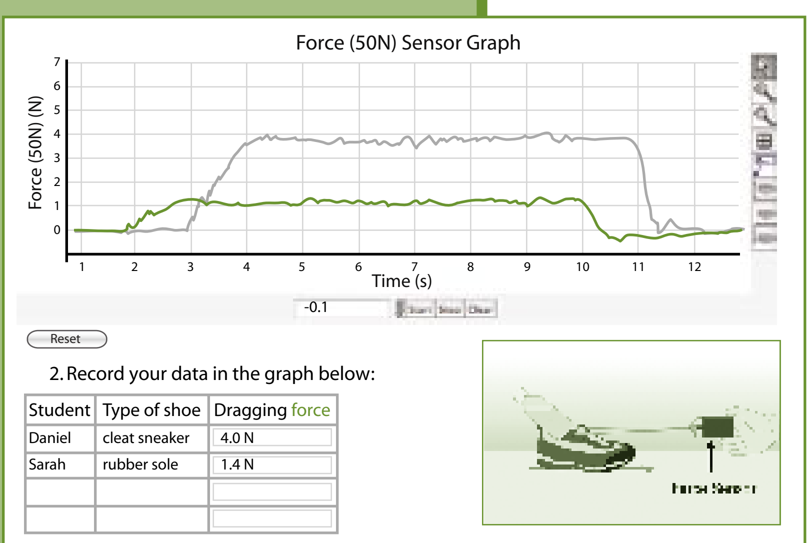


Figure 1. Students use a force sensor to measure the friction of different shoes.

Ways

able to describe itself in words while highlighting the feature being described, for instance the maximum, minimum, slope, time between two measurements, difference of two measurements, or the average *y*-value of a segment of the graph. And a molecular dynamics model will be able to communicate important features of the display, including number and kind of atoms and molecules, average potential and kinetic energy, or the states of matter—liquid, solid and gas—that are present.

Scaffolded assistance

Students are asked to explain their learning and are often given the choice of using text or a drawing. Assistance is available with various levels of support. For example, students are asked, "Which caused more heating, rubbing the penny on the wood or rubbing on the waxed paper? What is your evidence?" The student sees an open text box plus one or more of the following scaffolds:

Level 5: *(No extra hints or scaffolding is provided.)*

Level 4: Think about your graphs and what they show. *(Clues are given for data or information that students should use.)*

Level 3: When the penny and the wood are rubbed together, the graph of temperature _____. When the penny and the waxed paper are rubbed, the graph of temperature ____. Using the _____ caused more heating. *(Parts of a response are provided, and the student is asked to fill in missing content.)*

Level 2: Data show that: a) the temperature graph was higher when the penny was rubbed on the wood, so wood caused more heating, b) the temperature graph was higher when the penny was rubbed on the waxed paper, so waxed paper caused more heating. *(The student selects the best of several suggested responses.)*

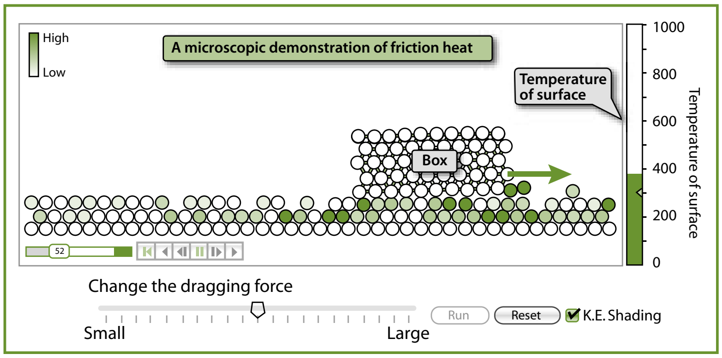


Figure 2. Students experiment with a molecular model of an object being dragged over a surface.

Level 1: The temperature graph was higher when the penny was rubbed on the wood, so wood caused more heating. *(One or more examples of good responses are provided.)*

Such scaffolding provides clarity to students. For some, a quick metacognitive reminder to re-read the question suffices, while for other students, more structure is necessary, sometimes in the form of model responses.

Coaches

The *Center for Applied Special Technology* (CAST) has done significant work studying brain networks and has identified three primary networks and how they function in learning, which they have applied to reading comprehension. Our science coaches—animated robots that address the student with prompts, hints, and models—align with the affective, strategic, and recognition networks and help students by sparking ideas and questions around the science content. The affective coach seeks to engage and motivate students by linking scientific knowledge and exploration to their real-world experiences and goals. The strategic coach helps students focus on what they need to know and how they can go about finding that out. The recognition coach guides students in gathering facts through exploration, observation, and experimentation and helps them both to display and interpret their results.

Design options

Our UDL software is designed so the look can be modified to match a student's tastes or learning style. For example, a student who is easily distracted may require a high-contrast screen, with each feature prominently displayed; on the other hand, a student who would most benefit from a low-stimulus environment may need calm colors. Additionally, an advanced reader may choose to read in a smaller font, allowing him or her to see more text per screen, while an English Language Learner or one with a visual impairment may require a larger font and can also choose to have the text read aloud. English and Spanish versions of each activity are available, and we are designing the underlying technology to support additional languages in the future.

Conclusion

Just like the variety of fourth grade names on your class list, you know that students learn in countless unique ways. New universally designed software provides the flexibility to accommodate learner differences. Our hope is that by designing a set of UDL exemplars in elementary science, others will follow and create even more opportunities for all students to learn—no matter what their style.

Cynthia McIntyre *(cynthia@concord.org) is the Director of Communications and Online Learning. She assists with coordination and editing of the UDL science curriculum.*

LINKS *Wednesday's Lesson*

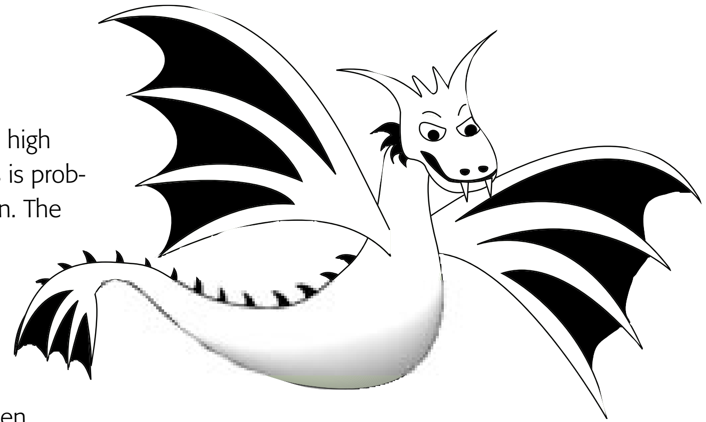
Universal Design in Science Education
http://udl.concord.org

Center for Applied Special Technology
http://www.cast.org

Individualized Education Program
http://www.ed.gov/programs/specediep/index.html

Exploring Genetics with

PAUL HORWITZ



Of all the topics in the middle and high school life science curricula, genetics is probably the hardest to teach and to learn. The reasons for this are obvious: genes, proteins, chromosomes, and all the rest of the machinery responsible for genetic phenomena are not visible to the naked eye, nor is there any obvious connection between them and the observable phenotypic variations to which they give rise. In fact, the evidence for that connection is indirect and depends on statistical and probabilistic reasoning that is itself unfamiliar to most students. No wonder so many students, faced with the ubiquitous Punnett square, manage to master the mechanical process of entering letters into each cell of the matrix without ever understanding how that matrix represents meiosis and fertilization, or what it has to do with predicting the statistical outcome of random processes such as chromosome segregation and gamete selection.

Nor are these students helped much by invoking the name and recounting the story of Gregor Mendel. Mendel discovered the outlines of the genetic basis of life by observing variation in multiple generations of plants, but it took him eight years to do it and he was a genius. Surely it is asking a great deal for an adolescent to recapitulate the process in a matter of days!

BioLogica™ (and its predecessor program, GenScope™, which has been rendered obsolete by the Mac OS X operating system) enables us to approach the problem of teaching genetics from the other direction. Instead of starting with the data and working backwards, as Mendel did, BioLogica operationalizes Mendel's famous laws in the form of a manipulable computer model; the software allows students to experiment with the model and work out its consequences for themselves. Admittedly, this pedagogical approach does not capture the subtle and multilevel reasoning that led to the original discovery, but that lofty goal is probably unattainable for most beginning students and can arguably be postponed until later in their biology education.

Exploring genetics

The activity, called "Exploring Genetics," is adapted from a five-day project entitled "A Dragon Named Meiosis" developed by Beat Schwendimann, a fellow of the *Technology Enhanced Learning in Science* (TELS) Center, in which the Concord Consortium is a partner.

Go to *www.concord.org/resources* to download an exploratory activity based on BioLogica[1].

The activity was designed to last approxi-

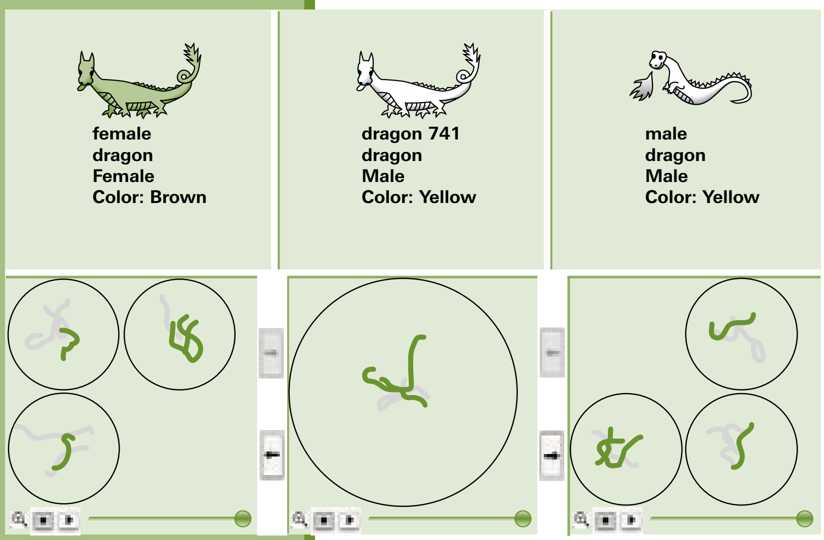


Figure 1. A view of the meiosis level of BioLogica. The dragons in the right and left panels are the father and mother, respectively, of the dragon in the middle, whose phenotype is determined by the genes it received from its parents.

BioLogica

mately one class period, but is broken into three independent parts so that it can be revisited without becoming repetitious. No previous experience with BioLogica is assumed, but we recommend that students be introduced to Mendelian genetics prior to tackling the activity.

After an introductory screen explaining its purpose, the activity presents a standard BioLogica model consisting of two dragons[2]—a male and a female—and two sets of chromosomes, one for each dragon.

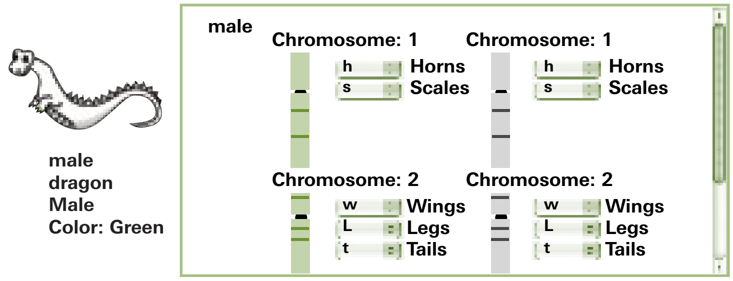
Have students explore the model by changing genes in order to determine the rules governing dragon traits: the presence or absence of horns or wings, tail shape, number of legs, color, and so forth. Many of these traits are governed by the interaction of dominant and recessive alleles as prescribed by Mendel's First Law, while others are incompletely dominant, X-linked, and polygenic. Beware: one of the color genes is a recessive lethal—you could kill your dragon!

Challenge: make (particular) dragon babies

After responding to a few embedded questions about the model, students run germ cells from a male and a female dragon through meiosis, examine the resulting gametes under a virtual "magnifying glass" to determine which alleles they carry, select one gamete from each dragon, and pair them in a simulated fertilization process that results in a zygote and a full-fledged baby dragon. Because the phenotype of the offspring is determined by the particular allelic combinations it carries, one can ensure the presence of any trait for which the appropriate alleles are

LINKS *Thursday's Lesson*

Technology Enhanced Learning in Science Center
http://www.telscenter.org



Change a gene and watch what happens to the dragon. See if you can figure out the rule that links a dragon's genes (its "genotype") to its appearance (its "phenotype").

Figure 2. A view of a dragon's chromosomes. When a gene is changed from one allele to another, the image of the corresponding dragon changes in accordance with Mendel's Laws.

present in the parental genotypes by selecting gametes judiciously. And that's the challenge: students must put into practice the phenotype-to-genotype rules they learned earlier.

The final three screens in the activity contain challenges of increasing difficulty:

Make a winged dragon.

Make a dragon with four legs.

And the Platinum challenge:

Make a green dragon with a plain tail.

Efficiency in choosing gametes is rewarded. When a student exits the activity, we report on how many attempts were made on each challenge, and how often the gametes were inspected to determine their alleles.

What's missing?

Detailed though this activity is, it still leaves out several crucial aspects of the inheritance of traits through sexual reproduction: the essential randomness of the process and the statistical analysis made necessary by that randomness. In the BioLogica model, students have complete control over chromosome segregation and gamete selection prior to fertilization[3] and the parent organisms are pre-selected. In nature, of course, neither chromosome segregation nor gamete selection can be controlled, and mate selection has a significant random component. Consequently, the genotype of any particular offspring can only be predicted statistically. In dealing with the underlying causes for differences between offspring of the same parents, this activity offers an explanation for the non-uniform distribution of phenotypic traits that formed the basis for Mendel's laws. It does not take the next step of demonstrating how those laws actually emerge from the model.

BioLogica includes a pedigree level that is designed to help students make the intellectual leap between the randomness of the underlying processes and the statistical patterns that emerge from their repeated application. And in BioLogica's population level, simulated organisms roam around the screen, mating randomly and surviving differentially, subject to selective pressures that are phenotypically determined.

From Punnett squares on paper to changing dragons' genes in a model-based environment, students can learn about genetics one allele at a time—even if you can't produce multiple generations of Mendel's pea plants in your classroom!

Paul Horwitz *(phorwitz@concord.org) is Co-Principal Investigator on the TELS project and the developer of GenScope, the precursor to BioLogica.*

NOTES

[1] Although GenScope only ran on Macintosh computers, BioLogica, which is written in Java, runs on both Macs and PCs.

[2] BioLogica is capable of handling species other than dragons, but the dragon species is by far the most developed and has been used in the overwhelming majority of BioLogica-based activities. One might say the dragon is the fruit fly of educational genetics. Download BioLogica here: http://mac.concord.org/downloads/

[3] They can control crossing over as well, although we don't make use of that feature of the model for this activity.

Visualizing Chemical

ROBERT TINKER

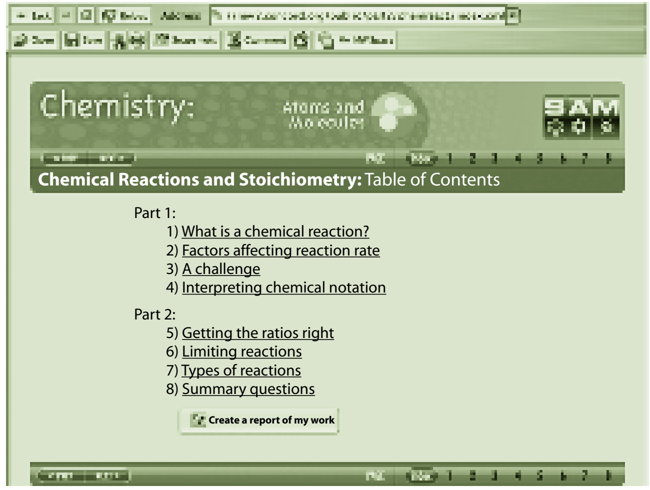


Figure 1. Molecular Workbench opens in a special "browser."

One of the reasons some students never really get started in chemistry is because they fail to grasp the notation used for reactions. Those funny symbols surrounded by large and small numbers seem like a foreign language and their connection to atoms is hard to grasp. If a student is stumped by chemical reactions, too often the teacher will emphasize the symbols and how to balance an equation, without really addressing the source of student confusion. More likely, a stymied student fails to understand that the reaction equation summarizes a rearrangement of a few atoms that is repeated many, many times.

Focusing on atoms and their interactions is a powerful way to overcome these problems. Once students understand a reaction for a representative group of atoms, then the notation used for standard chemical reactions begins to make sense.

The *Science of Atoms and Molecules* (SAM) project at the Concord Consortium is designed to provide just such an atomic perspective across the secondary curriculum. SAM is developing 24 activities that can be used in introductory physics, chemistry, and biology courses. SAM activities introduce a coherent collection of ideas about the properties of atoms and molecules that provide explanations for many phenomena that otherwise must be taken on faith and memorized. For instance, "Chemical Reactions" addresses chemical reactions at the atomic scale using the powerful Molecular Workbench system.

Getting started

Open Chemical Reactions at:

www.concord.org/resources

For more information about Molecular Workbench, click on the "home" icon, which looks like a house, in the Molecular Workbench browser command bar. For a database of hundreds of activities that use Molecular Workbench, use your regular Web browser to access *http://molo.concord.org*.

Part 1: Chemical reactions and a challenge

The unit consists of eight activities that are linked from an index page (see figure 1). Have students become familiar with chemical reactions and how they are influenced by temperature and concentration by going through the first two activities. Then ask students to complete the short challenge based on this introductory material.

Students start with ten separate atoms, which begin to join together as molecules as

Technical help

Molecular Workbench requires several megabytes because it provides a sophisticated computational model that closely matches how atoms and molecules interact and react. The software also supports editing, authoring, and delivering the materials.

The first time you launch the Chemical Reactions activity it will take some time, but subsequent launches from the same computer will be fast, since Molecular Workbench and this activity are automatically cached.

If you do not see the index page (shown in figure 1) after a short delay, go to *http://mw.concord.org/modeler/* for help. The most likely problems involve the version of Java you have, local firewalls, and security precautions.

It is well worth the wait to download!

Reactions One Step at a Time

LINKS *Friday's Lesson*

Science of Atoms and Molecules
http://sam.concord.org

the temperature is increased. As the simulation runs, pairs of atoms form molecules (see figure 2). The bar on the right shows the percentage of the atoms that are part of molecules. Students must get 80% of the atoms to become part of molecules by increasing or decreasing the temperature of the molecular chamber.

Students discover by direct experimentation with the model that an intermediate temperature is best. Too cold, and the atoms seldom get close enough to react; too hot, and the random motion is so violent that the molecules break apart and 80% completion is rarely achieved.

Part 2: More reactions, plus ratios

In the second part, students experiment with other reactions. One model involves making water from hydrogen and oxygen. Have students select different numbers of molecules of oxygen and hydrogen and watch what happens. If they select two molecules of hydrogen and one of oxygen, they will observe the sequence of steps that follow, starting with figure 3 (A).

1. The oxygen breaks into atoms and then one of the hydrogen atoms exchanges its partner for a free oxygen (B).
2. Later (C), the other hydrogen finds the other free oxygen, creating two OH radicals.
3. After a long time (D), the hydrogen molecule breaks apart.
4. Soon (E), one free hydrogen finds an OH to make one molecule of water.
5. A bit later (F), the reaction is complete, with two water molecules.

Note: To get a sense of the relative time of each step, notice the clock measured in femtoseconds (fs) in the lower left of each screenshot. One femtosecond is 10^{-15} seconds.

The details of the partial reactions are not as important as the fact that the overall reaction $2H_2 + O_2 \leftrightarrow 2H_2O$ involves several steps that rearrange the atoms. Thus, the overall reaction hides a lot of details of what actually happens to atoms. When students look carefully, it is clear that no atoms disappear or are created. It is also clear that a sequence of simple events happens at random and requires the right temperature.

Assessment

Like all our SAM activities, this one includes embedded student assessments.

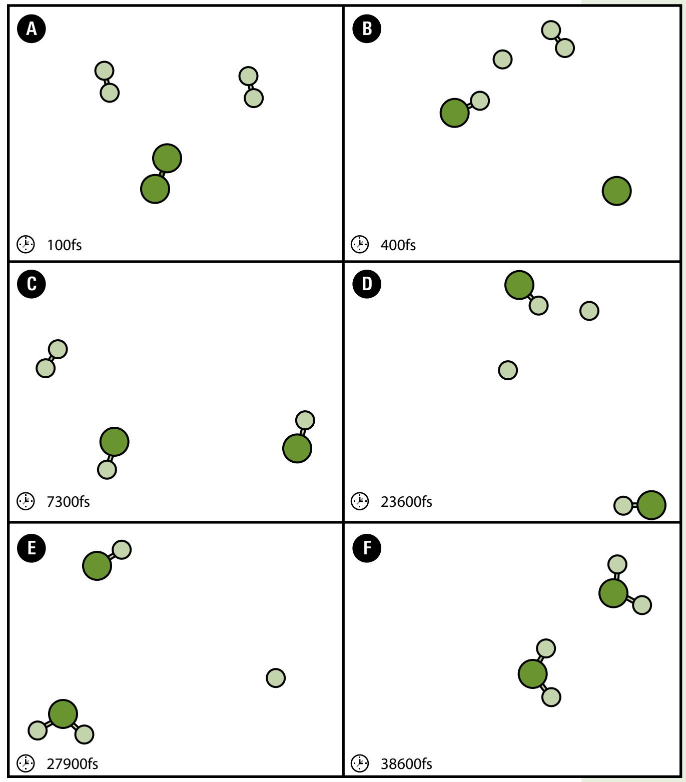


Figure 3. Six frames from the simulation that forms water. The larger atoms are oxygen and the smaller are hydrogen.

Almost every page has a few questions in either multiple-choice or open response form. The multiple-choice questions are intended for self-testing and have a "Check Answer" option. In addition, the final activity has both types of question, but no way for students to check their answers. All student responses and any snapshots they make are collected in an electronic lab book. Students can draw from these to make a report.

Use this report writing capacity by giving a specific assignment. For example, you might ask "What is the minimum number of hydrogen molecules that are required to synthesize ammonia (NH_3) by reacting with 300 nitrogen molecules? Explain your reasoning and use evidence from Molecular Workbench models."

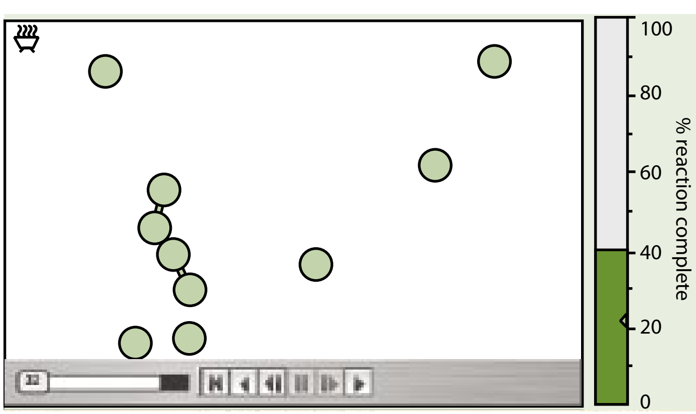


Figure 2. The bar on the right shows the percentage of atoms that have joined as molecules. Students are challenged to reach 80%.

Robert Tinker *(bob@concord.org) is President of the Concord Consortium.*

NEWS at Concord Consortium

Teachers Need Feedback LOOPS

The National Science Foundation has awarded the Concord Consortium $3 million for a new five-year project, Logging Opportunities in Online Programs for Science (LOOPS). LOOPS will collect data on student progress—what activity each student is working on or has completed, plus student responses to questions and scores on various explicit assessments. The major innovation of LOOPS will be data on student inquiry skills obtained by monitoring how students learn from their explorations of models and probes. LOOPS will extract in real time a few key indicators of inquiry skills and present them in a format that teachers can use.

LOOPS will put teachers in a feedback loop of data, which will help inform their choice of assessments, actions, and curriculum customizations. These feedback loops will be classroom-tested with inquiry-based materials using probes and models focused on eighth grade physical science.

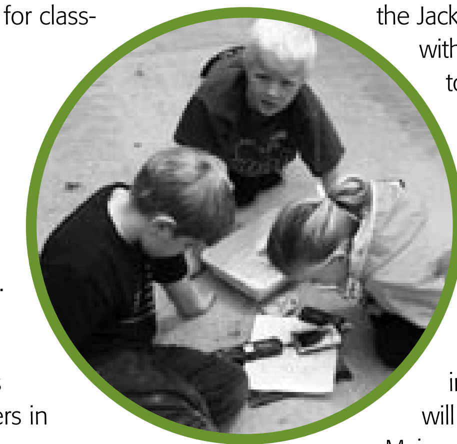
The LOOPS project is part of a long-term collaboration with the University of California, Berkeley, the University of Toronto, and North Carolina Central University.

Physics First in Rhode Island

The Concord Consortium is excited to collaborate with Rhode Island's statewide Physics First movement, which switches the order of required secondary science courses to a physics-chemistry-biology sequence. The National Science Foundation has funded the Rhode Island Information Technology Experiences for Students and Teachers (RI-ITEST) project, which will provide 100 teachers over 120 hours of activities and full support for classroom implementation.

The revised course sequence will add new content drawn from the science of atoms and molecules, which our Molecular Workbench models in powerful ways. Using computational modeling like Molecular Workbench also prepares students for related careers in information technologies.

Over two years, participating teachers will meet in summer and school year workshops, take an online course, and be mentored. Student progress will be determined using qualitative and quantitative techniques that include measuring students' gains in modeling and molecular reasoning skills.



Student Inquiry with Biological Data Sets

The Maine Mathematics and Science Alliance, the Concord Consortium, and Jackson Laboratories have partnered to conduct a new project: GENIQUEST (GEN*omics* I*nquiry through* QU*antitative Trait Loci* E*xploration with* S*AIL* T*echnology*): Bringing STEM Data to High School Classrooms. The project's long-range goal is to improve student understanding of science, scientific research, and the use of evidence in reaching scientific conclusions.

The focus is the development of an application enabling students and teachers to investigate biological data sets using a research-based instructional model. By integrating the publicly shared data set from the Jackson Laboratories with powerful analysis tools and innovative approaches in science instruction, developers will build a biology computing environment to support student investigation and inquiry. Pilot studies will be conducted in Maine, which is geographically large and rural, and possesses high-quality classroom access to technology.

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