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REALIZING THE EDUCATIONAL PROMISE OF TECHNOLOGY

Combining Science and Technology

One district shares secrets to success for their students.

BY CAROL WILLIAMSON, JULIE MILLER, AND KEVIN BOSWORTH

In Olathe (KS) District Schools, we share a vision: students prepared for their futures. So, when the Concord Consortium invited our district to participate in *ITSI* (Information Technology in Science Instruction), a project funded by the *National Science Foundation*, we jumped at the opportunity to help us realize our vision. The ITSI project aims to increase the number and diversity of students entering careers in the information technologies (IT) by engaging them in designing exciting inquiry-based science activities that use computational models and real-time data acquisition and analysis. And while we don't know what specific IT careers many of our students will eventually choose, we know they'll need certain IT skills for any vocation in the 21st century. ITSI has helped us help our students.

Implementing ITSI

Two of our staff attended training in Concord, MA, with other staff developers from Boston, MA, and Desert Sands, CA, that are also part of this project. Then in summer 2007, we hosted an ITSI institute in Olathe. With project funding for two Concord Consortium staff members to attend, plus stipends for our teachers, we hosted our first summer institute. Twenty-six grade 7-12 Olathe district science teachers—including teachers of biology, earth science, and physical science—plus four math

continued on page 4

Inside

The Concord Consortium Vision

BY ROBERT TINKER

The mission of the Concord Consortium is to foster equity and self-realization through improved education. The greatest and most underexploited opportunity for advancing this mission is through educational technologies. We know that students at all ages are capable of learning more, earlier, and at a far deeper level than is currently achieved and we have seen this kind of learning in well-designed schools that have creative teachers and use excellent, computer-based materials. Our goal is to make this the norm.

The Concord Consortium focuses on the challenges created by STEM education (science, technology, engineering, and mathematics) because it is so critical to society and many schools are baffled about how to improve it.

The single most valuable and underused strategy in STEM education (science, technology, engineering, and mathematics) is student inquiry-based learning.

The single most valuable and underused strategy in STEM education is student inquiry-based learning. Every educational standards effort and a large body of research all support the central role of inquiry in improving STEM education. In spite of this overwhelming support for inquiry, it is seldom used in STEM teaching, which continues to be dominated by text and lecture.

The central finding of 25 years of research on educational technology is that students can learn important concepts earlier and more deeply through guided inquiry using computer-based models and tools. The impact of these uses of information technologies can even be seen in national tests. The 2000 National Assessment of Educational Progress found "Eighth-graders whose teachers had students use computers for simulations and models or for data analysis scored higher, on average, than eighth-graders whose teachers did not." Similar results were seen in grade 12.

Technology can improve teaching and learning as measured against current educational standards. We do this by using technology to help students learn concepts through exploration while delaying formal and abstract treatments of the material. Core concepts like energy, plate tectonics, and evolution are accessible to young learners who can use these concepts to understand large parts of STEM that previously had to be memorized. In the long run, however, the standards must change, because technology alters what can be taught and the order in which STEM concepts should be introduced. For instance, current standards are based on research that purports to prove that students cannot understand atoms and molecules until high school, but research based on using our interactive models demonstrates that kids as early as grade five can achieve a level of "molecular literacy" that goes far beyond current practice.

It is sometimes asserted that inquiry-based instruction is not appropriate in urban and under-performing schools. A number of research studies have come to the opposite conclusion. It is no surprise that research has demonstrated that well-designed inquiry is just as valuable in an under-resourced urban classroom as anywhere else, even in ELL classrooms. Similarly, it is also often assumed that technology is a barrier and a luxury in urban schools that need to concentrate on basics. Again, research contradicts this. With support, technology can make significant contributions to student learning in urban settings. It has long been recognized that the "digital gap" in education is much less about the availability of technology than about how the technology is being used. High-quality materials supported with professional development are the best way to address these inequities.

A New Medium

The Concord Consortium has a vision for totally new ways of developing, sharing, and supporting STEM learning materials that have inquiry at their core. In collaboration with colleagues at the University of California, Berkeley, and the University of Toronto, we have pioneered an innovative software architecture called SAIL, the Scalable Architecture for Interactive Learning. SAIL is a revolutionary framework for generating, delivering, and modifying inquiry-based learning activities that have built-in guidance and real-time assessment. We have also developed OTrunk, a software interface standard for applications that simplifies incorporating new functionality into the SAIL framework. Together, these technologies can support a broad range of learning materials that support inquiry.

We are developing materials with these technologies that redefine STEM curriculum, how teaching is done, and what educational research can be undertaken. The materials created using this system will have the following features:

Learning through guided inquiry. The primary learning strategy used in the materials will engage students in investigating real or simulated systems that require and invite student investigation. Proven instructional patterns such as predict-observe-explain (POE) will be used to structure student inquiry.

Support for inquiry tools. Probeware is used extensively to increase the responsiveness, range, and number of lab investigations. For systems that cannot be studied directly, powerful computational models with dynamic graphics are used. Other materials engage students in explorations of online scientific data, such as found in both earthquake and protein databases.

Collaborative development. The materials are fluid and easy to adapt to new developments, resources, and needs. Unlike texts and most software that is cast in stone and handed down to teachers as received wisdom, these materials are in a constant state of flux; using the expertise of a community, the materials are updated continually and improved based on inputs from scientists, teachers, data from student learning, new software from programmers, and new approaches from educational developers.

Free and available online. The materials are available online at no cost for any educational use. This ensures that students, teachers, parents, informal educators, and volunteers can easily access, utilize, and improve the materials.

Teacher feedback. The materials will soon include automatic detection of student actions and responses. When used by individuals or small groups, this provides students, teachers, and researchers with detailed data of where students are in an activity, their path through the material, help requested, time required for each task, and inquiry skills. Teachers will be able to use these data to modify instruction to increase learning.

Universal Design for Learning. The materials will incorporate principles of UDL so that they are effective with the largest possible range of students. This requires providing alternative communication channels, incorporating different kinds of scaffolds, and giving the learner cognitive prompts and tools. One important Concord Consortium innovation in this area is smart tools that can communicate with learners about patterns of data and models.

> The Concord Consortium has a vision for **totally new ways** of developing, sharing, and supporting STEM learning materials that have **inquiry at their core.**

Our developments in computational models exemplify the kinds of innovations that the SAIL/OTrunk system will enable. BioLogica, the Molecular Workbench, and NetLogo are powerful modeling environments that need the underlying SAIL/OTrunk technology and demonstrate its importance. But educators want solutions to their educational problems, not models, tools, or architectures. The emerging Concord Consortium technology framework facilitates our work in solving current problems using our growing set of tools. As our technologies mature, we are increasingly able to produce materials economically that are innovative, educationally effective, and easily implemented.

We are developing another class of technologies that provide access to student data generated by the technology. Teacher portals will give teachers unprecedented insights into how students are progressing and what problems they may be encountering. The portal will also give teachers controls that can be used to improve learning. Teachers will be able to create collaborative groups, make assignments, probe student understanding, and share student models, data, and reports. Researchers will have portals for fine-grained analysis of student actions and teacher use of the resources. This will permit a new kind of research based on detailed analysis of very large numbers of students.

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

> **"If real inquiry is happening,** then I observe the students trying out their own ideas and testing to see if their predictions come true. **We saw that big time** when they used the laptop microphone with the Sound Grapher."

Combining—*continued from page 1*

teachers participated. Twenty students also attended for four days and were paid for their time.

During the 2007-08 academic year, we held a half-day workshop to gear up for the school year and to ensure that ITSI online resources were accessible at all schools. In fall 2007, ITSI teachers participated in a five-week online course on inquiry with probes and models. And in spring 2008, teachers took part in a self-paced online course focusing on VideoPaper Builder, a tool to create a video case study so teachers can reflect on their teaching with ITSI activities.

We have been so excited about the ITSI model that we offered an "ITSI for All" professional development session in January, attended by all 120 secondary science teachers and seven secondary math teachers in the district. Current ITSI teachers shared the lessons they'd developed while recruiting new teachers to join, and with so many success stories to share, it was easy to recruit.

ITSI empowers students as effective inquiry learners of science and technology

"I found that the use of probes brings out the inquiry in everyone regardless of age or grade level, not just the adults!" – Marsha

In a ninth grade physical science class, students engaged in an ITSI activity adapted by a teacher, "You've Got the Music in You." Students used a microphone with the Sound Grapher to compare waves and frequencies. They began by making a lot of noises, and it isn't very often that students are assigned to make loud noise! Students made motorboat and animal sounds, dropped books, changed the pitch of their voices, and sang in order to observe the variables of the waves shown in the Sound Grapher. Students kept asking, "What if I…?," and then they tested their questions.

After watching the video of his lesson, this teacher posted to the online course, "I couldn't stop watching

Students prepared for their future will likely…	How ITSI meets this need in Olathe, Kansas…
Work and problem solve as part of a dynamic team, building strong relationships with colleagues.	• Student-teacher teams collaborated to develop lessons in the summer institute. • Students work in teams in the science lab to learn through probe and modeling lessons.
Think creatively in their work.	• ITSI teachers provide inquiry experiences for their students, not "cookbook labs." Using probes and models allows students to generate and answer their own questions in the course of an investigation, with a rich data set to analyze.
Need strong communication skills.	• Online journaling is a component of ITSI lessons, providing a "writing to learn" format to help students record their observations and analysis. Teachers can review student online journals (including graphs), and students can refine their online entries. Communication skills are also developed in student teams and class discussions.
Need scientific and technological literacy.	• Students learn and apply technology skills in the context of science learning with probes and models. • Students learn about particular STEM careers (science, technology, engineering, and mathematics) by ITSI teachers.
Change careers during their work life. Need to be skillful, self-directed learners, ready for ongoing post-secondary learning opportunities.	• In the future, our students will likely learn in an online format in college and/or at work. Most secondary teachers have never taken an online course. ITSI online courses provide a well-developed course model for our science teachers. Our teachers can better prepare their students for online learning because they have taken online courses themselves.

LINKS *Science and Technology*

ITSI *http://itsi.concord.org*

National Science Foundation *http://www.nsf.gov*

it and laughing at myself. It looks like the kids were even more engaged and on task than I perceived them to be." He went on to say, "If real inquiry is happening, then I observe the students trying out their own ideas and testing to see if their predictions come true. We saw that big time when they used the laptop microphone with the Sound Grapher."

ITSI empowers teachers as creative practitioners

"I had to work on editing each activity to make the directions very clear for my students. I would make changes sometimes to the activity during one class so the next hour would not have the problem. I also added some worksheets that went along with the lessons to make sure my students were accountable. This allowed me to pass back their grade so they could keep it as their record of the activity." – Dana

Teachers are encouraged to modify ITSI activities to make them most relevant for their local students, a hallmark of giving teachers professional freedom and trust. Teachers change titles, add images, modify directions, and add links to local standards.

Students are learning with probes and interface hardware that were available, but previously unused

"For years I have complained about the probes and how they were of little use to us in the classroom. Now I feel that they can be used and the benefits for the students are great." – Robin

Some ITSI teachers who had never used the probes that were available at their schools have revamped their teaching and their students' learning through their ITSI participation. "I drank the Kool-Aid and I am a complete believer," commented one. He found that his students were fully engaged and kept working the entire class period when doing ITSI activities. Another said she didn't realize she would have as much fun building the probes as she did, and that her students loved it.

In one school, teachers searched their storeroom for probes, and discovered an unopened box of new probes; they immediately began playing. The following day, a physical science teacher and his students were using the motion sensors. ITSI has opened up a world to many teachers that they did not know existed.

ITSI is infectious

The energy at the "ITSI for All" workshop was infectious. Teachers walked away with ideas on using probes, building probes, implementing models, and using an incredibly powerful model for viewing events at the atomic level called the Molecular Workbench. Soon after the event, at a junior high school that does not currently have any ITSI teachers, the science teachers began brainstorming how they, too, could use models and probes in their classrooms. After one life science teacher engaged his students with ITSI's "How Genes Determine Appearance" activity, another life science teacher tried it, too.

Next steps

In our summer 2008 ITSI institute, the 30 veteran ITSI teachers will be joined by 30 additional teachers from Olathe and surrounding districts to build on the success of ITSI. The veteran teachers will be "trainers of trainers," facilitating new teachers as they prepare to use ITSI activities with their students in 2008-09. The summer institute will feature an "ITSI Showcase" to highlight ITSI learning activities for community members, including school district business partners with an interest in information technology, such as Garmin Industries, whose world headquarters is in Olathe. The expected outcome of the summer institute? Same thing we've come to expect from ITSI: more students will be learning in a style that will prepare them for their futures.

__Carol Williamson__ is the Science Coordinator at Olathe (KS) District Schools. __Julie Miller__ and __Kevin Bosworth__ are ITSI facilitators in Olathe, KS.

Understanding Heat and Temperature: Can Atoms Help?

BY ROBERT TINKER AND AMY PALLANT

A fundamental tenet of our work is that a deeper conceptual understanding can simplify learning. If students understand deep, unifying ideas, they don't have to memorize apparently disconnected effects. This fits with the recent recommendation from the National Academy of Sciences for "revising standards to focus on core ideas."[1]

Our *Science of Atoms and Molecules* (SAM) project is developing activities for a Physics First curriculum, which permits high school freshmen to apply the concepts they learn in physics in later courses in chemistry and biology; their understanding of all sciences is improved because they can go deeper and make connections. Using the *Molecular Workbench* (MW) modeling environment, students gain an understanding of what is happening at the atomic scale, which helps to explain multiple macroscopic phenomena across the sciences.

The idea of reaching for fundamentals sounds great in theory, but how does it work in practice? The concepts involved with heat and temperature challenged our theory of teaching deeper concepts to simplify a collection of phenomena. We believed that if students understood the atomic nature of heat and temperature, they would have a profound foundation for building an understanding of phenomena related to phase change, gas laws, van der Waals attractions, and chemical reactions, plus protein folding, diffusion, and osmosis. While agreeing on the concepts, we were challenged to articulate what could be taught at this level and how to approach the topic conceptually.

Challenge 1: Temperature and kinetic energy

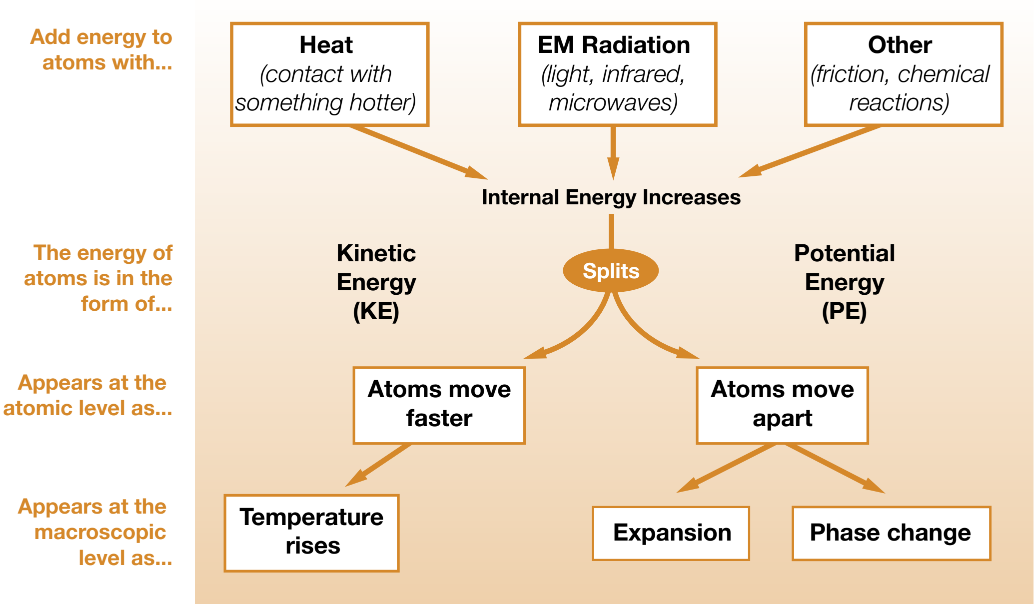
We defined the following learning goals for our *Heat and Temperature activity* in the SAM project:

- Heat flows from hot to cold through collisions of atoms and molecules.
- A temperature scale is a measure of the average kinetic energy of atoms and molecules.
- At equilibrium all particles have the same average kinetic energy over time regardless of size, shape, or mass.

One of the most documented areas in science educational research is students' understanding and misconceptions about heat and temperature. So it came as a great surprise that when we began to develop our models and curriculum on this topic, we uncovered nuances to teaching and learning we had not expected.

The definition of temperature is usually not addressed in science curricula until the ideal gas laws are encountered. Then, at some point the kinetic-molecular theory is introduced, often as a set of assumptions without any explanation of how these relate to the gas laws. We wanted to know whether it is helpful to define temperature as the average kinetic energy of atoms. But as you look closely at this, questions arise. Are we using the average kinetic energy over time? Or the average per atom? Is temperature the average kinetic energy of the atoms or the molecules? Why exactly is temperature related to kinetic energy and not the average speed or mass times speed or some other quantity? Will students confuse macroscopic kinetic energy—like that of a falling rock, for example—with temperature?

Molecular Workbench is a wonderful tool for correlating random thermal motion to changes in temperature. Students can think about the properties of temperature and look for something at the atomic scale with the same properties. The simplest property of temperature can be seen by observing how changes in random kinetic energy of



Atoms and Energy Can Help. Thinking atomically helps connect added energy (top row) to observed changes (bottom row). All the ways of adding energy shown increase the internal energy. This increase is split between increases in kinetic and potential energy. The former is seen at the atomic level as faster atoms and at the macroscopic level as increased temperature. Increases in potential energy involve moving atoms farther apart, which can cause expansion and phase change.

1. Science education that makes sense. (2007). *Research Points: Essential Information for Education Policy,* 5(1). American Educational Research Association.

molecules are related to changes in the temperature. Some experimentation should convince students that atoms speed up when the temperature rises.

Another experiment has students isolate objects at different temperatures. Students put these objects in contact while they remain isolated from anything else and observe how they come to a single temperature between the starting temperatures. They can experiment with molecules of varying mass, phase, or composition while observing different properties, such as average speed and kinetic energy. In this dynamic and robust environment in which students have control of variables, they quickly grasp the relationship between temperature and the average kinetic energy due to random motion.

Challenge 2: What about heat?

Heat and temperature are easily confused. A lot of confusion is in the terminology. Textbooks that introduce heat offer different definitions: "heat is energy," says one; "heat is a form of energy," reports another; and "heat is internal energy." The term "heat energy" sounds a lot like temperature, which we are emphasizing is a form of energy, namely kinetic energy.

What is heat? At the atomic scale, heat is the total energy of atoms, that is, the kinetic energy plus the potential energy. That still sounds a lot like temperature, but with this new idea of potential energy. The potential of what? Where does potential energy come from?

How do we use an atomic view of heat as seen in MW in a way that might help clarify some of these confusions? Some of the issues we faced were:

1. **What do we call it?** Many authors use "heat energy," but that can be confused with "kinetic energy," which is temperature. "Thermal energy" is used, too, but doesn't seem any better. A strong case was made for "internal energy" because it is accurate and it isn't loaded with meaning or common terminology. But we did not want to introduce a new term that teachers and students might find intimidating. In the end, we decided the simple word "heat" was best.
2. **How exactly do you convey the difference between heat and temperature?** At the atomic scale, heat is the total internal energy—kinetic energy (KE) plus potential energy (PE)—and temperature is average KE. While this is simple and elegant, potential energy at the atomic scale takes some getting used to.
3. **Do we want to talk about heat per atom?** Temperature is KE per atom, an intensive quantity. Heat is the total KE plus PE for all atoms, an extensive quantity. To bring out the differences between heat and temperature, it is tempting to introduce the average heat per atom. Students have problems with intensive quantities, however, so it may be good to not talk about the heat per atom.

From classical mechanics students should learn that whenever there is a force, there is a potential energy (at least if it depends only on distance). The problem is that a full understanding of the relationship between force and potential energy involves calculus and few ninth graders have had calculus. We decided to make a qualitative case that energy is needed to tear atoms apart and this energy is called potential energy.

Potential energy at the atomic scale helped explain several common observations. An increase in PE for atoms means they get farther apart. And if students understand this, then they can observe models of evaporation, change of state, and even thermal expansion. At last, we began to see some payoffs from thinking atomically (see figure).

Challenge 3: How do we make it simple?

In the end, through simple steps in our Heat and Temperature activity, students are able to investigate the way the atomic scale uses energy concepts from physics to relate heat, heat flow, temperature, light, mechanical motion, phase change, evaporation, and thermal expansion.

By starting with a foundational atomic-scale understanding of heat and temperature, subsequent activities in the SAM project can build on this. For instance, the phase change activity relies on student understanding that energy is required to change states of matter, and to overcome attractive forces of atoms and molecules. In the chemical reaction activity, students are asked to explain the connection between temperature, collisions, and reaction rates. A biological application in SAM's protein folding activity relates how changes in temperatures might cause an increase in random thermal motion and denaturation of a protein.

Developing this unit revealed a problem with our approach of teaching fundamental concepts that can relate many particular observations: you don't get fundamentals for free, even when a tool like MW appears to make them transparent. Teaching the fundamentals requires new concepts, vocabulary, and approaches. *Internal energy, heat per atom,* and *potential energy at the atomic scale* help unify many parts of science, but they also are part of a new and unfamiliar perspective.

We know that introducing atomic-scale concepts works, confirming what the American Educational Research Association reported: "students gain insights when they use visualizations to link situations, rather than using only text or static drawings. Such tools can help learners connect salient information to their existing ideas." Molecular Workbench allows students to go deeper and simplify many phenomena, including what might seem as basic as heat and temperature.

LINKS *Heat and Temperature*

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

The Molecular Workbench
http://mw.concord.org/modeler

Heat and Temperature
http://mw2.concord.org/tmp.jnlp?address=http://mw2.concord.org/public/part2/heat/index.cml

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An Atomic Look at Why Thing

BY CHARLES XIE

Most children learn early that things break, whether it's a stick, a favorite toy, or Humpty Dumpty himself. Although the nursery rhyme may be culturally specific, the phenomenon is universal. But it turns out that what is so common in our daily experience contains a lot of profound science that even scientists do not fully understand today.

Molecular literacy

The question about why things break has to be answered from a microscopic perspective. Ultimately, things break because atoms and molecules are pulled apart. Such a bottom-up approach of explaining things based on an atomic-scale picture is called *molecular literacy*. Like language literacy, students need experience and opportunities for learning in order to acquire molecular literacy. The Molecular Workbench (MW) software developed by the Concord Consortium is a powerful tool that can greatly help students develop their molecular literacy.

In this Monday's Lesson, your students can use MW simulations to answer the questions about why and how things break.

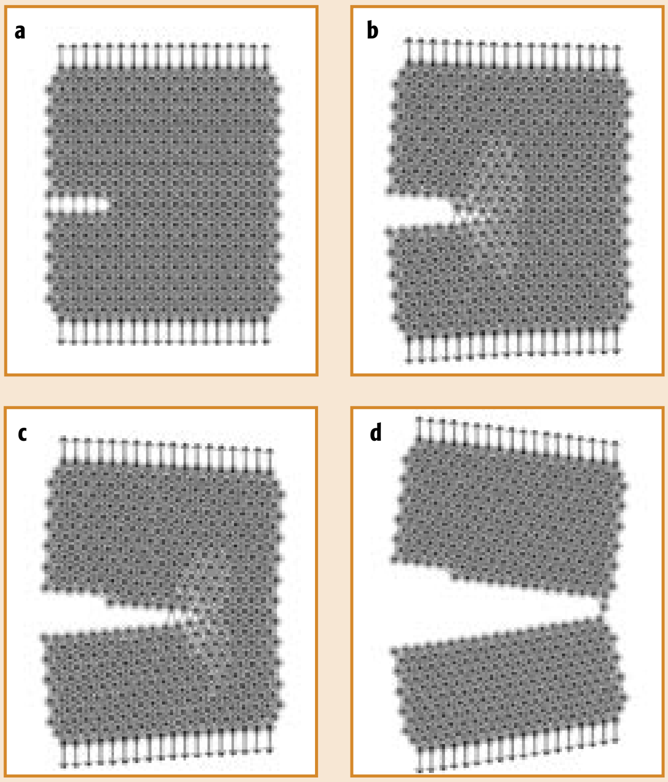


Figure 1 **An MW model showing crack propagation, initiated from a cut in a perfect crystal.**

System requirements

You must have Java Version 5 or higher in order to run MW. Go to *http://java.com* to get the latest Java software.

Crack propagation

A break often starts from a microscopic crack, which may be an imperfection in the material when it was made, or created by an impact or repeated flexing "fatigue." A crack can grow longer and larger when a force is applied. Think of cracking an egg on the side of a frying pan. This is called crack propagation, and it's useful to understand for physics, engineering, and geosciences, not to mention making breakfast.

A crack is a wonderful example of a micro-macro connection, that is, where events at the molecular level affect phenomenon at the macroscopic or visible realm. Regardless of its size, a crack has a tip where the atoms are just coming unzipped. What happens at the tip is the most important thing during the growth of a crack and, therefore, the entire process of breaking.

Go to: *http://mw.concord.org/modeler1.3/mirror/materials/fracture.html*

Click "Launch the models." Then "Trust" the certificate.

The model depicts a lattice of atoms, representing a crystal. External forces are applied to the top and bottom layers of atoms, represented by the arrows. The yellow bar serves as a marker to create an initial cut.

1. Click the "Cut" button to cut the lattice, and then run the simulation. Observe what happens.

2. Reset the model, then "Shift cut area to the right," cut, and run the model again.
3. Reset, shift the cut area two units, cut, and run a third time. What do you notice?

An astute student will observe during the simulation that the bonds at the tip break one at a time as the crack grows. Without that small fissure, the crystal would not have broken under the same stress. Students can run the simulation of the same crystal without a crack to verify this. Simply move the yellow bar to the left (off the crystal entirely) and run the model. The atoms wiggle in place due to the external forces, but nothing breaks!

Students discover that crack propagation is the key that causes things to break. It provides a mechanism for conveying a large force to the atoms at the tip and ripping apart bonds between them one at a time as the crack travels.

Testing "what if?" conditions

If a crack is not deep enough, it cannot propagate (figure 3a). But if there are microcavities nearby, it can "hop" to them and the material breaks apart along a path that connects these defects, as illustrated by figure 2.

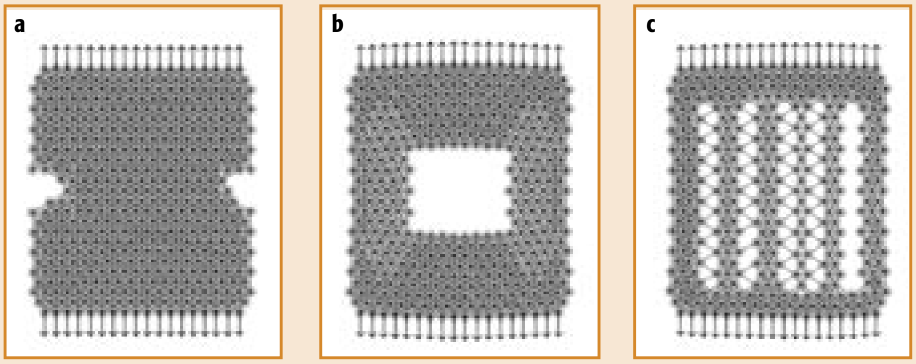


Figure 3 Some structures that do not break under the same stress.

LINKS *Monday's Lesson*

The Molecular Workbench
http://mw.concord.org/modeler

A fascinating aspect of a computational model is that it allows students to test many different "what if?" conditions quickly.

For example, have your students use the scissors tool on the tool bar above the model to cut out a big cavity in the middle of the material (figure 3b), or create a structure that looks like a bundle of fibers (figure 3c). They will soon discover that these structures can withstand a surprising amount of tension. Such experimentation may help them dispel the idea that heavy pieces are stronger than lighter ones.

Finally, you can assign a challenge to your students and have them document their success. For example, what's the smallest initial crack that will cause a crack propagation? Or, what's the largest design of microcavities that will not break?

Have students take and annotate snapshots and print or submit a report.

Conclusion

Fracture is one of the most important factors that affects our safety. We rely on each piece in the backbone structures of the buildings we live in, the planes we travel on, and the bridges we cross not to break. Preventing fracture is a hot research topic; fracture in real materials under real conditions is still not well understood.

Nevertheless, as we can see, a better understanding of fracture can be built upon the very simple essence of the atomic-scale mechanics without formal treatment or complicated mathematics. By applying the basic ideas that a material is composed of interacting atoms and the interactions among them govern the material's behavior under different conditions, students can develop concepts and intuitions through a pathway that may be less difficult. The innovative Molecular Workbench software provides many technical capabilities that have made such a new treatment much easier to implement.

Unfortunately, not even MW can put Humpty Dumpty—or that favorite toy—together again!

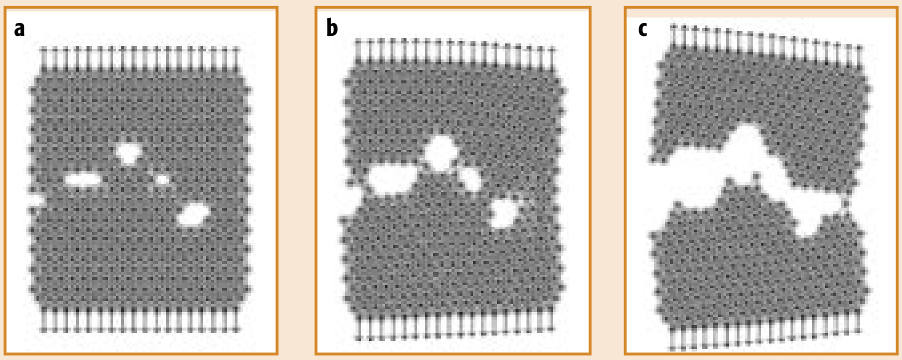


Figure 2 Crack propagation in the presence of microcavities.

Charles Xie *(qxie@concord.org) is a Senior Scientist, responsible for creating the Molecular Workbench.*

The Center for Technology Enhanced Learning of Science

BY ROBERT TINKER AND KEN BELL

Five years ago we created the *Center for Technology Enhanced Learning* (TELS). The TELS Center has created a unique vision of the effective use of information technologies in science learning. The basic idea is that students integrate their growing understanding with prior knowledge through guided exploration of highly interactive software, thoughtful questioning, and dramatic visualizations.

TELS combines the development of new teaching materials and research on classroom use of these materials with graduate training. TELS has been extraordinarily productive. We have:

- Developed 18 curriculum modules that address challenging topics in secondary science.
- Engaged 104 teachers in over 42 schools nationwide.
- Tested modules in 330 classes with over 14,000 students.
- Trained more than 40 Fellows and nine post-doctoral scholars who have received fellowships, tenure, and other awards.
- Administered over 20,000 annual benchmark assessments and over 24,000 pre-tests and post-tests.
- Published 106 academic papers, with 32 more in press.
- Presented at over 200 conferences.

The TELS Center is a huge enterprise that, in addition to the Concord Consortium, includes the University of California, Berkeley; Arizona State University; Mills College; Christopher Newport University; North Carolina Central University; Pennsylvania State University; the University of Toronto; the Technion Institute of Technology; and public schools in Acton (MA), Berkeley (CA), Mount Diablo (CA), Norfolk (VA), Durham (NC), and Tempe (AZ).

Middle school and high school science modules

Try out the *modules*—they are free and available online. There are at least two for each of the six common middle and high school science courses. Go to *http://wise.berkeley.edu/*, join, sign in, go to Projects, and then to the TELS Project Family.

These modules demonstrate the value of the collaboration supported by the TELS Center. The authors are primarily graduate students at Berkeley and Arizona State. Many of the modules take advantage of Concord Consortium models based on BioLogica and the Molecular Workbench. The technology to deliver the modules online was developed at Berkeley, Toronto, and the Concord Consortium. The modules were tested at schools near TELS partners in Arizona, California, Massachusetts, North Carolina, and Virginia. An impressive network of people and partners worked to make each part a success.

TELS instructional materials have a wide audience, including more than 25 research groups internationally. Curriculum materials have been translated into six languages. For example, graduate students in Korea presented research findings using Korean versions of the Global Warming and Rock Cycle modules at the East-Asian Association for Science Education meetings in 2007.

In support of its work, TELS has developed new resources for researchers, an improved approach to the design of materials based on design principles and patterns, a platform for developing, deploying, and studying the modules, a targeted professional development program, a national testbed of diverse schools and teachers, and new assessments.

Sailing with TELS Technology

We call TELS the "Educational Accelerator" because we wanted to use our tools to help accelerate the work of others with similar interests. We have developed technologies that are helpful to anyone developing applications of information technologies to STEM education. Borrowing the concept of a particle accelerator, but on a far more modest scale, we make it possible for others to: increase the sophistication of the software studied; create high-quality learning activities; customize tested activities to new curricular standards; test instructional patterns and principles that have succeeded in other research; design embedded assessments to test ideas about how students learn; expand the number of students in studies; and increase the amount and detail of data collected.

These advantages result from open source software developed for TELS called the Scalable Architecture for Interactive Learning (SAIL). SAIL features the ability to author and deliver sophisticated, highly interactive applications to student computers in educational contexts. SAIL was developed to support applications that must run locally, such as probeware and computationally intense models like the Molecular Workbench. Such applications are of fundamental importance to STEM education because they support learning through inquiry of real and virtual worlds. While not restricted to this class of applications, SAIL is uniquely able to integrate them into complete, interactive learning activities. If you want to become involved in SAIL software development, contact us.

TELS research has driven the development of SAIL, but other projects are using and expanding it. Several projects at the Concord Consortium have already made important contributions to SAIL. It is in use at Northwestern University; the University of Hawaii, Manoa; Michigan State University; UCLA; Maximilians University, Munich; the University of Twente; and other European Union universities.

TELS research

TELS has gathered compelling evidence for the impact of technology-enhanced instruction on student acquisition of important science concepts and their integration to create robust knowledge. The TELS partners have created, tested, and refined materials that cover middle and high school science content that teachers have identified as particularly difficult to learn. At the TELS schools, we have explored the contribution of instructional materials, principal leadership, professional development, assessment strategies, and improved supports for students.

In a study of 9,000 students in the first year of implementation, TELS modules showed improved outcomes compared to the typical curriculum, a result we published in *Science*.[1] We attribute these gains to the features of the TELS design, which include: guided inquiry based on interactive visualizations, models, and probeware; relevant contexts that interest students; ample time for reflection; a focus on integrating prior experiences with new observations, student collaboration, comprehensive activities, and easy implementation. We have developed new assessment strategies that give us unprecedented detail about the degree of student knowledge integration that results from only a few weeks of exposure to TELS materials in an entire year.[2]

We have begun to disentangle the effects of technology on student and teacher success with science. We used evidence from the first year classroom trials and teacher responses to improve the materials. Using these proven materials, reliable outcome measures, powerful logging capabilities, and experienced teachers allows TELS to detail specific benefits in design studies, comparison studies, and case-based analyses. One interesting study showed that students who systematically explored models learned more.

LINKS *Technology Enhanced Learning*

- **Center for Technology Enhanced Learning** *http://www.telscenter.org*
- **TELS modules** *http://www.telscenter.org/curricula/modules.html*
- **WISE (Web-based Inquiry Science Environment)** *http://wise.berkeley.edu*

Robert Tinker *(bob@concord.org) is President of the Concord Consortium.* ***Ken Bell*** *(kbell@concord.org) is the Project Manager for TELS.*

NOTES

1. Linn, M., Lee, H.-S., Tinker, R., Husic, R. & Chiu, J. (2006, August 25). Teaching and assessing knowledge integration in science. *Science*, 313, 1049-1050.

2. Linn, M. & Eylon, B.-S. (2006). Science education: Integrating views of learning and instruction. In Alexander, P. A. & Winne, P. H. (Eds.), *Handbook of educational psychology,* 2nd ed. (pp. 511-544). Mahwah, NJ: Lawrence Erlbaum Associates.

Concord Consortium Hosts TELS Teachers on Leap Day

On February 29, 2008, twenty teachers, administrators, and researchers from TELS participating schools and partner institutions gathered in Concord, MA, for a workshop hosted by the Concord Consortium.

Attendees included teachers from Portsmouth, VA; the Governors School in Hampton, VA; Catawba County and Durham, NC, schools; the O'Bryant School of Math and Science in Boston, MA; and Acton-Boxborough High School and R.J. Gray Junior High School in Acton, MA. TELS faculty/researchers Dr. Shiladitya Chaudhury of Christopher Newport University and Dr. Gail P. Hallowell from North Carolina Central University also attended the workshop.

Teachers shared their experiences with TELS activities and experimented with ways to integrate other technology, including probeware, into their classroom curriculum. They designed their own experiments and generated data with temperature, humidity, motion, force, and voltage probes. They also took a hands-on tour of the new *WISE* 3 portal, the first version of WISE to use SAIL.

Do **Actions** Really Speak Louder than **Words** or Just **Differently?**

BY PAUL HORWITZ

Say you're interviewing an applicant for a job as an electronics technician and you want to know whether she knows how to use a multimeter—a common piece of test equipment that can measure voltages, currents, and resistances—but you don't happen to have a multimeter on hand to test her. What do you do?

You could ask the person to explain to you how to use a multimeter to make some specific measurement. If you wanted a permanent record for your files, you could ask her to explain it in writing. But either method might discriminate against someone who knows perfectly well how to do the job, but is not very good at communicating how to do it to someone else. To get around that problem, you could show your applicant a few different setups and ask her which one she would use to make the measurement—in effect, a multiple-choice test for circuit measurement.

Figure 1. Simulated circuit and multimeter set up to measure the current through the resistor.

Would that work? Can you get the same information by asking multiple-choice questions that you get from observing someone do something?

To find out, we did an experiment. In February 2008, Tidewater Community College, located in Virginia Beach, VA, and one of our partner schools on the CAPA (Computer-Assisted Performance Assessment) project, was host to hundreds of students from local technical high schools as part of a nationwide observance of Engineering Week. We took advantage of the opportunity to work with 89 of these students. Using software developed on the CAPA project, we presented 46 of the students with the simulated circuit and multimeter shown in figure 1 and challenged them to measure the voltage across the resistor, the current through the resistor, and the resistance itself. The other 43 students were given a multiple-choice test that dealt with how to use a multimeter to make measurements. One of the items from that test is presented in figure 2. It deals with measuring the current through the resistor—which turned out to be the hardest of the three measurements, as we shall see.

How do you measure current?

A multimeter can measure voltage, current, or resistance[1] so one of the requirements for this task is that it be set to measure current—that is, function as an ammeter. The multiple-choice item presupposed that the meter would be set appropriately, but the performance assessment gave no guidance as to how to do this. Still, most of the students, it turned out, did accomplish this sub-task correctly. What they found more difficult was the correct placement of the probes in the circuit when the multimeter was serving as an ammeter. To see why, we must briefly delve into the electronics.

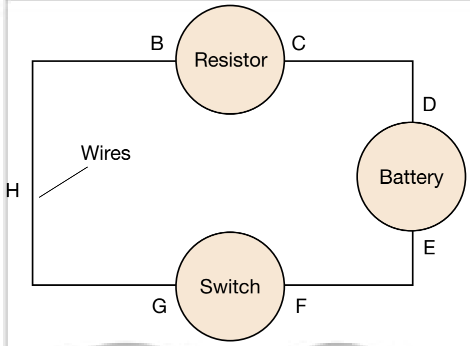
To measure the current through the resistor the multimeter must be placed in series so that the current passes through it. This means that it must become an integral part of the circuit that supplies the current. Normally, to measure current one "opens" the circuit somehow in order to place the multimeter directly in the flow. For our test, the students couldn't do this (the simulation wouldn't let them), but to make the measurement all they had to do to was *open* the switch and then *bypass* it with the multimeter (as shown in figure 1). And this setup is answer "C" on the multiple-choice question.

The current measurement is counter-intuitive because the leads of the multimeter have to be placed across the switch, rather than (as with the voltage and resistance measurements) across the resistor. Also, the switch must be open in order to force the current to pass through the ammeter. For both these reasons, we predicted from the start that the current measurement would be the hardest of the three, both for the multiple-choice test and for the performance assessment.

And we were right, but with a twist…

A surprise in the data

Of the 43 students who took our multiple-choice test, only 28% correctly answered the question about measuring current (the question depicted in figure 2). This is a score only slightly better than chance: if the students had just thrown darts at the test to determine their choices, they would have received a score of 25% since there were only four possible answers.



7. To find the current through the resistor, set the selector for measuring current,
   a. Close the switch, and place the DMM probes at B and C.
   b. Open the switch, and place the DMM probes at D and E.
   c. Open the switch, and place the DMM probes at G and F.
   d. Close the switch, and place the DMM probes at B and G.

Figure 2. One item on multiple-choice test asking students how to use a multimeter to make measurements.

But they didn't throw darts and they didn't just guess randomly. How can we tell? Because their answers were by no means evenly distributed among the four possibilities. On the contrary, two of the four answers received 86% of the students' "votes" and of these the most popular—chosen by more than half the students—was the one in which the multimeter's leads were placed on either side of the resistance and the switch was closed—the appropriate setting for measuring voltage, but not current. This incorrect choice can confidently be attributed to a widely held misconception, not a guess.

So, what about the performance assessment? Before I let the cat out of the bag, what would you predict? Were the students who took the performance assessment, and actually measured the current (albeit using a simulation), more or less likely to succeed than were the students who answered that multiple-choice question? You may argue that the comparison isn't a fair one, because the measurement calls for more initiative than the question. After all, in order to measure the current the student has to (a) set the multimeter to measure current, (b) open the switch, (c) place the leads on either side of the switch, (d) read off the measurement and write it in the answer box provided, and (e) pick the appropriate units from a pulldown menu. This certainly sounds harder than simply picking the correct answer out of a set of four.

But wait a minute! What if we were to score the performance assessment solely in terms of lead placement and switch position, the two steps called out in the multiple-choice item? Wouldn't that "tilt" the contest toward the performance assessment? Remember, the student gets immediate feedback from the simulation, so if something doesn't "feel right" about a measurement, he is free to repeat it until he thinks he's got it right.[2] And what about the students who aren't very verbal, but are "good with their hands"? Shouldn't they do better on a hands-on assignment than one that involves reading words and parsing static diagrams?

When we put it to the test, here's what happened: of the 46 students who took the performance assessment, only 4, or 9%, got both the leads and the switch position correct! Most of the rest set the circuit up for a voltage measurement—exactly the same mistake made by the students who answered the question on the multiple-choice test.

LINKS *Actions and Words*

CAPA *http://capa.concord.org*

What does this all mean?

First of all, clearly these students weren't very good at using a multimeter to measure current. If they had been applying for a "multimeter technician" job, most of them probably wouldn't have been hired. And we see the same pattern whether they're measuring the current with a simulation or merely answering a question about it. But it's striking that only one-third as many students performed correctly on the simulation as were able to answer the question correctly. Since the two groups were chosen at random from all the students who were visiting the college that day, it's reasonable to assume that if the conditions had been reversed, the results would have been the same.

If this finding is replicated in future trials, it could have important implications for the way we certify technicians. The majority of certification tests, used both as criteria for graduation and by employers evaluating new hires, are in multiple-choice format. Our research indicates that many students who receive a passing score on a multiple-choice test may not be able to do the job for which they're being tested. Assuming that simulated assessments are a reasonable substitute for the "real thing," we may be greatly overestimating the skills of the people we are graduating from technical schools. The data is still preliminary and we plan to repeat this "micro-experiment" soon, using more students and more complex assessment tasks. In the meantime, though, if someone tells you he knows how to use a multimeter, maybe you'd better have one handy. Or at least a computer.

Paul Horwitz *(phorwitz@concord.org) directs the Computer-Assisted Performance Assessment project.*

NOTES

1. Some multimeters can measure other things as well, but the one we simulated for the students could only do those three.

2. Although we only count the measurement that the student actually reports, the software keeps track of how many measurements he made and gives the teacher the option to start taking off points if he makes "too many." For the purposes of this experiment, however, we ignored all but the reported measurement.

Alternative Assessments with Snapshots

BY CAROLYN STAUDT

Over twenty years ago an administrator walked into my physics classroom while students were working on computer simulations during class. Although the students were highly engaged, his question still resonates: "How do you know what the student is learning while using technology?"

Allowing students to use technology during class introduces a new set of challenges and demands new assessment methods. In order to analyze students' level of understanding while using models, graphs, and sensors as they investigate scientific content, the technology must have a rich set of assessment tools to track and archive student findings. Having a real-time pulse on student progress is fundamental to determining student learning and can help the teacher modify instruction. Our Snapshot tool is embedded in probe and model-based science activities to allow students to record their findings throughout an activity. This tool provides a powerful way to assess student understanding.

First developed in *Molecular Workbench*, the Snapshot tool permits students to capture their progress while manipulating a computational model of molecular phenomena (figure 1). Students can also annotate their snapshots by labeling and identifying significant features of the model (figure 2). By taking and annotating these pictures, students focus on the key features of a sequence of events, looking at cause-and-effect and effectively slowing down a simulation into discrete steps. Student snapshots are automatically added to a Snapshot Gallery, which can be uploaded and sent to the teacher (figure 3).

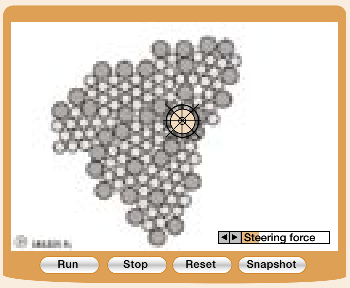


Figure 1. A Molecular Workbench model of a molecule and a "steering" atom that will diffuse through the molecule.

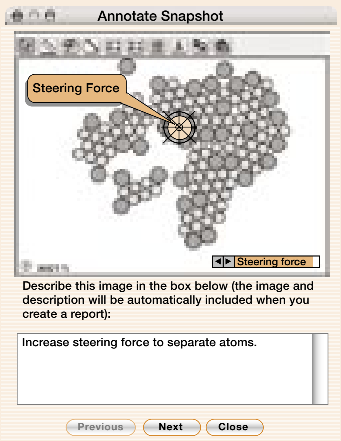


Figure 2. A student annotates her screenshot by describing what she did or what she sees.

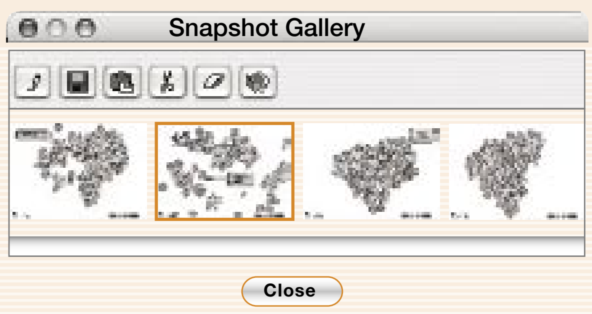


Figure 3. Snapshot Gallery showing thumbnails of each snapshot taken by the student.

Taking snapshots of probe data

Snapshots are not only powerful in mapping student learning with models, but also for determining how students interpret graphs during real-time data collection. In our *Information Technology in Science Instruction* (ITSI) activities, students use snapshots to capture their work with probeware.

Having students document their work provides a chance for students to begin the process of defending and refining their work to present to their peers and teacher. While collecting data with a probe, the student should retest and refine her experimental procedure by performing a series of collections. This continuing process of review and modification is important and minimizes the influence of individual bias by requiring that experimental results be reproducible. In other words, students do science as real scientists.

In one ITSI activity, "Heating by Hitting," students study how energy is conserved during a collision. Students embed a fast-response temperature sensor into a lump of clay and use a weight to smash into the clay (figure 4).

Theoretically, if the weight stopped moving when it hit the clay, all of the energy of the weight would end up as

LINKS *Alternative Assessments*

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

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

UDL Science *http://udl.concord.org*

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

Figure 4. In "Heating by Hitting," students measure the energy (as heat) after a weight collides with a lump of clay.

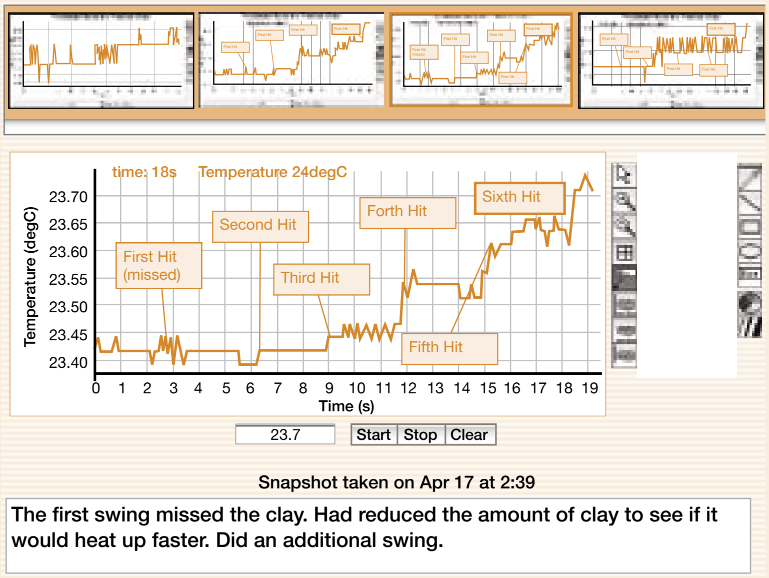


Figure 5. Multiple graphs are saved as snapshots with individual annotations as students change conditions and run the experiment several times.

heat in the clay. Students are asked to calculate the gravitational potential energy of the weight. After hitting the clay with the weight five times, students calculate the amount of heat energy gained by the clay per hit by using the temperature change registered on the graph. Students are asked how these two amounts of energy compare. They are encouraged to repeat their procedure and aim to have the energy transfer happen with as little energy loss as possible. Students use the Snapshot tool to document their various attempts, which might include attaching the clay to a different surface, perfecting the swing of the weight, or changing the amount of clay (figure 5).

Drawing tool helps young students

Often, students in grades 3-6 can better describe an event by drawing than by explaining in essay responses. Providing alternative ways to communicate understanding is one of the defining features of Universal Design for Learning (UDL). (Providing multiple means of engagement and multiple means of representation are the two other defining features.) In our *UDL Science* project, Snapshot and Draw tools are both available to students.

Students are encouraged to select and label important changes that occur during a probe or model-based activity. The Snapshot tool allows students to demonstrate their knowledge in an efficient and novel method. An album of student snapshots also lets teachers have a glimpse into student understanding.

In one unit, fifth and sixth graders collect artifacts of their investigations around the question "What is electricity?" Using a Draw tool (with key elements like batteries and bulbs available as premade stamps), students predict how to light a bulb with wire and a battery. Students then try it out with an embedded *Physics Education Technology* model and take a snapshot when they successfully light a bulb. During a summative "wrap up" activity, students select specific evidence gathered in their album that helped answer the driving question (figure 6).

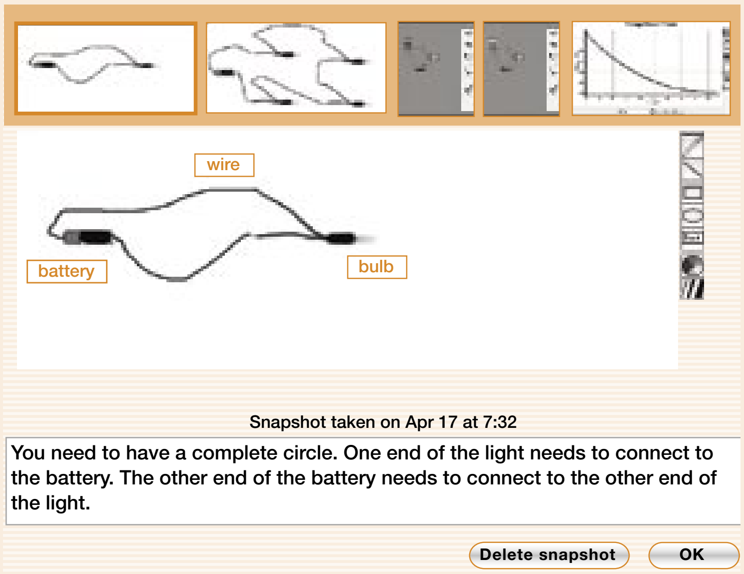


Figure 6. Students select from an album of their saved images when they complete a summative activity used to assess their understanding.

Technology can provide a window into student progress as well as student thinking. Our graphics tools allow students to explain their understanding of complex relationships through their choice of the graphic and the annotations that they attach. Students with weak language skills can still communicate and be assessed without worrying about grammar and spelling.

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NEWS at Concord Consortium

New Book – Transforming Schools with Technology

Harvard Education Press has published a new book by the Concord Consortium's Andy Zucker, *Transforming Schools with Technology: How Smart Use of Digital Tools Helps Achieve Six Key Education Goals.* The book states that the value of technology rests on whether computers and other digital tools help meet six key goals: increasing student achievement; making schools more engaging and relevant (thereby reducing drop-out rates); providing a high-quality education for *all* students (including English language learners and students with disabilities); attracting, preparing, and retaining high-quality teachers; increasing parental and community support for children outside of school; and requiring accountability for results. Andy argues that digital technology has begun to transform schools into the more modern, effective, responsive institutions that our society needs and he provides many examples.

Electron Models

Electrons and their interactions with materials are central to a wide range of phenomena, techniques, and apparatus. An understanding of the basic concepts of electrical conduction and semiconductors can explain important phenomena related to light spectra, electronics, material science, photonics, and chemistry. This atomic-scale perspective is seldom included in introductory science because it is considered "advanced" and is usually obscured by difficult math. We are convinced that allowing students to explore interactive computer models of electron interactions will make all this much more accessible.

The National Science Foundation recently awarded the Concord Consortium a grant called "Electron Technologies: Modeling Pico Worlds for New Careers" to test our conviction by measuring student progress when they use interactive models of electron interactions. Partners include Parkland College and three NSF Centers.

Project research will look at whether learning with these models is more accessible, transferable, and more accurately recalled later. Although this approach could be used at any introductory level, the project focuses on students pursuing technical careers at the high school and college levels.

Collaborations

The Concord Consortium has recently collaborated with many different groups to apply our "new medium" (see "Perspective" on p.2), including:

- The Maine Math Science Alliance and the Jackson Laboratory are collaborating with us to apply our technology to bioinformatics.
- We helped one state write a proposal that would use our technology in secondary science statewide.
- We are working with faculty at Winston-Salem State University to customize our materials for their introductory science courses.
- We are working with three companies to adapt our technology to their products.
- We work closely with all the probeware vendors to ensure that their hardware works with our technology.
- We are working with the NSF and their Presidential Awardees to create an ITSI-like site (see p.1) that will contain the awardees' own online activities.

We can help your organization with proposal development, professional development, curriculum, or products. Our new medium will enhance your work. Send inquiries to info@concord.org.

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