www.concord.org vol. 14, no. 1 Spring 2010

@Concord.org

REALIZING THE EDUCATIONAL PROMISE OF TECHNOLOGY

Practice SPARKS Perfection in Students

Formative assessments in electronics transform novices into experts.

BY TRUDI LORD AND PAUL HORWITZ

"It's really cool! It tells you exactly what you did wrong."

– MINUTEMAN CAREER AND TECHNICAL HIGH SCHOOL STUDENT

Students working toward a technical degree need to master certain routine skills before they can manipulate more complex systems. In electronics, for example, the ability to read a resistor color code and to use a multimeter must become second nature. Unfortunately, instructors do not have time to stand behind every student, mentoring them during the many hours that it takes for novices to become experts at operating lab equipment.

The SPARKS project in electronics not only logs student errors, but also provides students with useful feedback on how to improve their performance and hone their skills.

SPARKS, which stands for *Simulations for Performance Assessments that Report on Knowledge and Skills*, builds upon the successful logging functionality of our recently completed *Computer-Assisted Performance Assessment* (CAPA) project. Supported by the Advanced Technological Education Program at the National Science Foundation, and working closely with research partners at CORD in Waco, TX, and Tidewater Community College in Virginia Beach, VA, SPARKS is creating interactive assessments that monitor student performance and offer insightful critiques and helpful hints.

continued on page 4

Inside

Are We There Yet? Contemplating Two Generations of Technology Vision

BY CHAD DORSEY

Everything comes full circle. That was the thought on the minds of some when Apple recently released its newest product. As its creator famously remarked, using the iPad seems very much "like holding the Internet in your hands." But as futuristic as it feels, the iPad owes a great deal to ideas of the past. It provides a number of useful lessons about the gradual progress of educational technology. It can also teach us about the conditions that support technology adoption.

> The iPad provides a number of useful lessons about the **gradual progress** of educational technology. It can also teach us about the conditions that **support technology adoption.**

As many people noted when the iPad was introduced, its time had first come over 40 years ago. In 1968, computer scientist Alan Kay at Xerox's revolutionary PARC think tank began to outline his vision of a portable computer. He called it the Dynabook, and the vision he described is still fresh today. Kay wrote that the size should be no larger than a notebook and weigh less than four pounds. He includes a picture that could have been a sketch of the iPad. He even nails the merits and use of touch-sensitive screens, 40 years before their time: "Suppose the display covers the full extent of the notebook surface. Any keyboard arrangement one might wish can then be displayed anywhere on the surface."

But more impressive, and still inspiring today, is the educational vision Kay held up for this technology. He describes students using powerful simulations to discover principles of physics through inquiry. He depicts them collaborating via the same technology. He also forecasts the existence, use, and distribution of digital textbooks. Kay notes in his seminal paper that enacting his vision was within reach in 1972. It took a bit longer than expected.

With the recent unveiling of the iPad—and with many similar devices coming hot on its heels—one might argue that the technology platforms to deliver the Dynabook vision have finally arrived. But the widespread use of quality educational technology is still disappointingly far off.

What does the iPad have to teach educational technology about how a phenomenon becomes popular and adopted? Quite a bit. First, acceptance is high, with a half-million units sold in the first week of release. Six weeks later, Apple was selling twice as many iPads per week as Mac computers. Given some recent history, this should be surprising—the idea of a tablet device has been around for at least a decade or two, but most such devices have not experienced anything close to wide adoption. However, some specific factors have paved the way for the iPad's adoption. And these factors harbor advice that educational technology would do well to heed.

Prime the technology pump. The iPhone, direct predecessor to the iPad, came onto the market amid a wave of technology that permitted small packages to deliver powerful computing. This hardware, including GPS location sensors, fast and efficient microprocessors, and the evolution of touch screen technology was a necessary condition for the emergence and success of both the iPhone and the iPad generation of devices.

Define (and answer) the problem. The hugely popular mobile smartphones had an equally huge problem. People hated their interfaces. A decade of frustration with labyrinthian voicemail menus and inscrutable settings had created an army of frustrated mobile phone users with enough pent-up rage to fuel a revolution. By providing a device that was easy to use, the iPhone had identified a core problem and set a new bar for its solution, one that was quickly taken up by many others.

Whet undiscovered appetites. The explosion of mobile devices also created for millions the idea of constant, away-from-home connectivity. The iPhone upped the ante significantly by providing a full browsing and even computing experience, giving consumers the expectation that they should be only inches away from powerful, networked computing at all times.

Provide the practice. The iPhone defined a new set of touch-based interactions. While using the iPhone was intuitive and easy for almost everyone, it also demanded some important practice. The public had to adapt to a new way of using a computer, and software developers had to think in a very new way about designing applications. Establishing both of these takes time, and the three releases of the iPhone provided just this back-and-forth. In a realm as dynamic as the mobile phone market, both users and developers are accustomed to learning and accounting for new and shifting interfaces. This patience and flexibility allowed ideas about interaction to flourish that would have failed if they had been shoehorned into people's concepts of a desktop or laptop computer.

It took all of these factors, combined with a generation of new applications, to pave the way for the iPad. Educational technology should be well past all four of these factors and thriving in the hands of students worldwide. Sadly, that is not the case. Computer access has improved, but is hardly universal even in many places in this country. Educational software has increased in complexity, but it is often barely more sophisticated than the drill-and-kill options that masqueraded as educational 30 years ago. Digital textbooks now loom on the horizon, but they could easily squander their computing platforms' educational possibilities if not designed thoughtfully.

Can we learn from these four conditions and bring education forward in a similar manner? A couple of factors are in place already. Plunging technology costs have primed the pump. Lower costs could enable increasing numbers of schools to begin widespread hardware adoption. And the problem seems increasingly obvious, as people acknowledge that existing educational resources frequently fail to convey important concepts in a compelling fashion.

However, the last two factors have certainly not yet been addressed. First, people's appetite must be whetted for the right revolutionary idea. To create an atmosphere that encourages substantial change, we must introduce concepts for the classroom that are as compelling as the iPhone's "everywhere browser" was for consumers. Teachers must experience how real-time feedback about student performance can revolutionize their instructional possibilities. They must see how powerful and customizable simulations can aid understanding of abstract concepts. They must gain a taste for rich, instantaneous performance assessments for complex tasks. Most importantly, the contexts for these must be more than simply superficial. Technology-based texts, courses, and experiences must be deeply digital to help teachers understand what technology can truly offer. Such examples properly raise students' and teachers' expectations for what educational technology should do.

As we saw with the iPhone experience, we must also provide sufficient practice. As with the touch interface example, this practice must occur on the part of both the users—in our case, teachers and students—and those who develop the technology. Teachers must learn the difficult and new art of teaching with technology. Good educational technology is neither a substitute teacher nor a crutch for sub-par pedagogy. Using technology well demands a teaching style that rests technical fluency upon pedagogical agility. Facilitating students in digital inquiry is a learned skill. Developers of educational technology must also demonstrate excellent pedagogical facility and understand how to apply technology in powerful but appropriate ways. They must provide engaging, flexible curricula that anticipate classroom demands and provide useful data for teachers.

Technology-based texts, courses, and experiences must be **deeply digital** to help teachers understand what technology can truly offer.

To enable the revolution we desire, a great deal of work still lies ahead. Even as we are heartened by recent signs—mounting discussion about digital texts, increasing enrollment in virtual schools, recent federal interest in finding and applying the best ideas available—we must be ready to seize the moment as these elements converge. Efforts to push educational technology forward must not shy away from launching bold initiatives for creating whole courses and curricula on a national scale or creating digital texts that take full advantage of the interactive capabilities of models and simulations and the power of real-time data collection.

At the Concord Consortium, we continue to try and hold out the finest of these examples to the world. The articles in this issue showcase some of our current efforts to get educational technology into the hands of teachers and students in a deeply digital fashion. Forty years after Alan Kay's vision, we are committed to bringing forth the best of educational technology in new and exciting ways.

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

SPARKS—*continued from page 1*

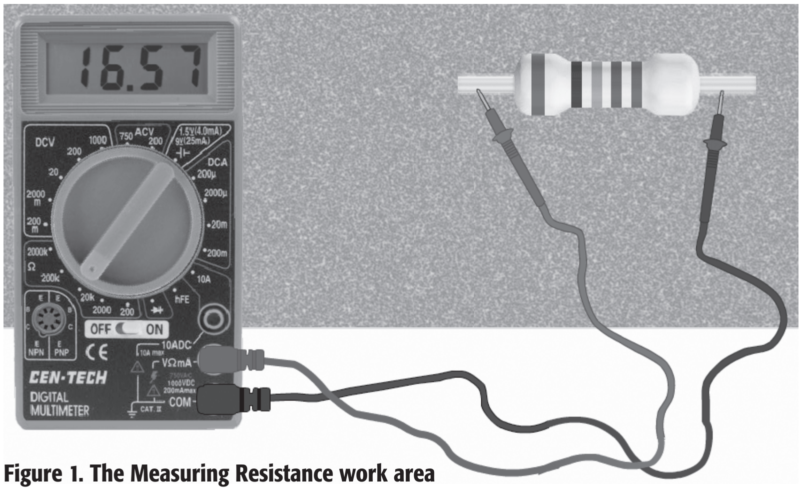


Figure 1. The Measuring Resistance work area includes a digital multimeter, probes, and a randomly assigned 4- or 5-band resistor.

In pilot tests we have found that this kind of scaffolded practice appeals to motivated students. Our personalized guidance can help these students build proficiency.

While CAPA focused on summative assessment for certification in electronics, SPARKS, which covers 14 topics in the basic electronics curriculum, is creating formative assessments that enable students to practice their skills and improve their performance in a safe, supportive environment. The assessments are aligned with a college-level introductory course in electronics and constitute a sequence of realistic tasks of increasing complexity. The software runs in a browser and does not require special software.

In the first module, Measuring Resistance, students are presented with a random resistor and asked to complete three tasks. First, they must interpret the color bands to provide the rated resistance and tolerance of the resistor. Next, they are asked to measure the resistance directly, using a digital multimeter. Finally, they must calculate the tolerance range and decide whether the resistor is within tolerance. These tasks are relatively complex and there are many ways in which beginning students can go astray. Accordingly, we have developed a comprehensive rubric for scoring the students' performance and giving them the detailed feedback they need to improve. Students are encouraged to run the assessment multiple times. They can see their progress because the computer keeps track of their scores.

Reporting rubrics

After students complete the steps in an assessment, they receive a report that explains exactly what they did, including the proverbial good, bad, and ugly. Did the student get a correct value *(good)*, but with an incorrect unit *(bad)*? Did they cause a virtual fire *(ugly)*?

Students not only see the correct answers, but also suggestions on how to improve the process for using the tools and calculating measurements. In some cases they are directed to specific tutorials aimed at refining deficient skills so they will do better the next time.

SPARKS gives students as many "do-overs" as necessary to master the skills in the module. You might not think students want to hear about the error of their ways but they do! In our preliminary research, we have observed students working to perfect their scores one step at a time.

We score student performance on 12 different measures. While we care about whether or not they give the correct answers and how long it takes to complete the assessment, our rubric

	Task	Correct value	Your Answer	Points	Feedback
Step 1 tutorial	Resistor value	240 Ω	240 V	0/20	Incorrect units (not resistance units)
	Tolerance value	5%	1%	0/5	Incorrect tolerance value
				0/25	
Step 2 tutorial	Measuring resistance	241 Ω	0.24 kΩ	5/10	Did not record comoplete value from DMM display
	Connections to DMM		Correct	5/5	Correct connections to the DMM
	Connections to Resistor		Correct	2/2	Correct connections to the resistor
	DMM knob setting	Ω - 2000	Ω - 20k	10/20	DMM knob set to incorrect resistance scale.
	DMM power switch		Correct	2/2	DMM turned ON
	order of tasks		Correct	6/6	Order of tasks is acceptable
				30/45	
Step 3	Tolerance range	[228 Ω, 252 Ω]	[242.4 Ω, 237.6 Ω]	10/15	Correct calculation based on wrong resistance/tolerance
	Within tolerance	yes	yes	0/5	Previous question(s) incorrect
				10/20	
Time	Interpreting color bands		24 seconds	2/5	Can you speed it up?
	Measuring R with the DMM		36 seconds	2/5	Efficient
				4/10	
Total				**44/100**	

SPARKS feedback ×

The correct tolerance of this resistor is 5% and you reported 1%, which was incorrect. However, you did calculate the tolerance using the correct formula, so you received partial credit.

Click the tutorial button to see the resistor color code.

close tutorial

Figure 2. Student report. In Step 1, the student reported a tolerance value of 1%, which was incorrect. He later reported (Step 3) the tolerance range based on this incorrect value. While the answer was wrong, he received two points because he calculated the range correctly. When a student clicks on the feedback, a window pops up with additional details and a link to a tutorial that explains how to improve performance.

also awards some points for partially correct answers. It takes off points if a student fails to report the right number of significant digits. The reports go beyond merely looking at a student's answers. We also analyze student actions and point out process errors, such as incorrect or unsafe settings of test equipment. And we take into account the fact that an incorrect answer in an early step of a process may affect a student's later answers. Our rubric gives partial credit, for example, to the student who gets the rated resistance wrong but then correctly calculates the tolerance range, even though it was based on the initial incorrect value.

When "failure" means success

We recently piloted the Measuring Resistance module with students in introductory electronics classes at a high school and a two-year college. Our purpose went beyond identifying software bugs and problems in the user interface (though, thanks to perceptive students, we found both). We gathered student feedback on the overall experience. Did the activity teach students anything? Were they able to improve their scores over multiple trials? Would they want to use SPARKS assessments again?

The answer to all three questions is yes. Yes, students learned; yes, they improved their scores with repeated attempts; and, yes, they would use the assessments again. In fact, one student asked if he could use the software at home to practice on his own—exactly the response we had hoped for!

During pilot software testing at Tidewater Community College, students vied with each other to see who would be the first to get a perfect score. Students ran the activity multiple times in the hope of improving their performance with each new resistor. The table in Figure 4 shows one student's dramatic improvement over multiple trials with four different resistors.

At Minuteman Career and Technical High School in Lexington, Massachusetts, we observed a class of electronics students as they worked through the resistor measurement module, interacting with them at key points in the process. We gave them the types and depth of feedback they needed in order to understand the mistakes they had made. We also provided hints so they could do better the next time. With the right feedback students were able to improve their performance in subsequent trials. And their feedback to us has led to significant improvements in the reports. Students not only want to know where they went wrong, they have good ideas about what they need to know to get better.

	Time (secs)	Step 1	Step 2	Step 3	Time (Pts)	Total Score
Trial 1	276	0	25	8	0	33
Trial 2	177	↑ 25	↑ 40	↑ 15	↑ 2	↑ 82
Trial 3	45	25	↑ 45	↓ 5	↑ 10	↑ 85
Trial 4	58	25	45	↑ 20	↓ 7	↑ 97

Figure 4. Tidewater Community College student report with arrows pointing up showing improvement over previous trial.

Virtual monitoring and mentoring

Without guidance and support, learning new skills can be a frustrating experience. Designed to be used with or without human mentoring, the SPARKS software guides students by giving them instant responses and comprehensive feedback. Circuits and oscilloscopes cannot tell a student why he got the wrong answer or how to avoid shorting out the power supply. The SPARKS simulations do that and more. Our students, in turn, are showing that given constructive feedback they are willing to practice a procedure over and over. With SPARKS, doing it wrong is just the first step toward learning how to do it right.

Trudi Lord *(tlord@concord.org) is the SPARKS project manager.*
Paul Horwitz *(phorwitz@concord.org) directs the project.*

LINKS *SPARKS*

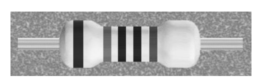
SPARKS *http://sparks.concord.org*

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

Tutorial assistance

For each step in a module, students can view a tutorial that explains how to complete the task correctly. Instructional text, diagrams, and video help students review the topic. In Figure 2, on the previous page, the student is shown how to calculate the tolerance of an example resistor. Because students struggle with calculating percentages, we provide additional support for that step.

How to calculate the tolerance of a resistor



Step 1
Determine the rated value of the resistor. The resistor above is a 680 ohm resistor.

Step 2
Determine the tolerance of the resistor. The last band is red, which indicates that this resistor has a 2% tolerance. This means that the resistor should have a measured value that falls into the range between +/-2% of 680 ohms.

Step 3
Determine the value of 2% of 680 ohms. To do this, use a calculator and multiply 680 by .02 to get 13.6 ohms. Another way to calculate the percentage is to find 1% of the resistance. One percent of 680 ohms is 6.8. To find one percent of a number, simply move the decimal two places to the left, as shown below.

6.80

Multiply 6.8 ohms by 2 to get 13.6 ohms.

Step 4
Find the range by calculating the maximum and minimum values.
To calculate the min: **680 ohms – 13.6 ohms = 666.4 ohms**
To calculate the max: **680 ohms + 13.6 ohms = 693.6 ohms**

Figure 3. This tutorial gives step-by-step instructions on how to calculate tolerance on a resistor.

Modeling the Unknown is High Adventure Science

BY AMY PALLANT

"Very few see science as the high adventure it really is, the wildest of all explorations ever taken by human beings, the chance to catch close views of things never seen before, the shrewdest maneuver for discovering how the world works. Instead, they become baffled early on, and they are misled into thinking that bafflement is simply the result of not having learned all the facts."

— LEWIS THOMAS[1]

How did life begin? What is the universe made of? What is at Earth's core?

To celebrate its 125th year, *Science* published a special issue entitled "What Don't We Know." The issue features articles on the 25 top unanswered questions in science as identified by a panel of scientists and lists 100 additional questions. What scientists don't know is no small matter. These are big questions and there are a lot of them!

Just browsing the list is exciting for anyone with a scientific bent. But we wondered—is it possible to generate similar excitement and motivation in middle and high school students? Teens seem to value facts and certainty over doubt and curiosity. And while there are no guaranteed answers, the unknown offers opportunities to explore the wildest possibilities.

In the *High Adventure Science* project, funded by the National Science Foundation, our goal is to engage students in current research in the unanswered questions of science and to shift the teaching and learning process from textbook facts to the ongoing process of science. We are exploring a practical approach to motivating students and teaching science that is widely recognized but rarely implemented because of the lack of appropriate student activities and the pressure of tests. (Ironically, those tests are based on standards that emphasize the process of science as much as the content.) We are building curriculum units that show students how science truly proceeds as they learn about unsolved science topics.

Many attempts have been made to interest students in "real" science by putting them in contact with scientists or engaging them in research, but these approaches are not practical for wide scale or long-term adoption. There are too few scientists who can offer the time needed to sustain these efforts. The High Adventure Science project is bringing current research on relevant topics into the classroom in a way that is true to the spirit of science—doing authentic inquiry, experimenting with models, and exploring aspects of actual unanswered questions in science. Using modern technology and proven methods of cyberlearning, it could be easily scaled up to have a measurable impact on science teaching.

We identified 13 unanswered areas of research in earth and space sciences (see sidebar) that connect to the science curriculum and standards. We then surveyed students and teachers, explored potential modeling ideas, and narrowed our focus to three: "Climate Change: Is Earth's past a good climate model for the future?" "Space: Is there life on other planets?" and "Natural Resources: Will there be enough fresh water?" These units will simulate a current key experiment by researchers, though simplified for educational purposes. We will also include several short videos of scientists presenting their own research and how the data they are collecting is related to solving aspects of these unanswered questions. Finally, the units will include real-world data for analysis. What makes these units unique will be the way in which students are able to gather data from the models, and through the perspective of the researchers in the videos, compare their results to real-world data.

Our research will investigate the following questions: Does the curriculum increase student understanding of and interest in science? How do these materials affect student understanding about the nature of science and science research?

Is Earth's past a good climate model for the future?

Though scientists agree that global warming is occurring, there are still many unknowns about what exactly will happen to Earth and the environment as a result of global warming. Daniel Schrag, a leading researcher on climate change, states in the video *Freeze, Freeze, Fry: Climate Past, Present, and Future,* "When you hear debates about climate change it is all about whether scientists know enough, whether scientists are sure, and I kind of laugh about it. We are doing something to the Earth that hasn't been done in 35 million years. The idea that scientists like me are supposed to predict exactly what is going to happen, when no human has ever seen this ever before, is kind of crazy. The Earth is a very complicated system, and no one can make perfect predictions of the future. You can't trust your weather forecaster out more than five days. So why do they think we should be able to predict what climate is going to be more than 100 years from now? Especially when nobody has ever seen such

REFERENCES

1. Kennedy, D., & Norman, C. (2005). 125 Questions: What don't we know? *Science*, 1 July 2005, http://www.sciencemag.org/sciext/125th/
2. Schrag, D.P. (Producer). (2007). *Freeze, freeze, fry: Climate past, present, and future* [DVD]. Available from http://www.classroomencounters.org/

high levels of CO_2 on the Earth. It's an experiment. It is a terrifying experiment, but it is an experiment."[2]

Students will study some of the many variables scientists are exploring, such as changes in CO_2 and other greenhouse gases, albedo, ocean temperature, and cloud cover. The models will enable students to alter the levels of each of these variables and observe the shift in the model's climate temperatures. In addition to the modeling interactivity, the unit will set the context for exploring climate variation by looking at Earth's climate history and in particular comparing today's changing climate with the climate of the Eocene, when atmospheric CO_2 was high and the last thermal maximum occurred. Students will explore light-matter interactions, in other words, what happens when sunlight enters Earth's atmosphere and encounters clouds, greenhouse gases, and land.

Additionally, students will learn about the distribution of Earth's continents over time, and how changes in ocean currents are closely related to global climate over time. Finally, students will discuss how scientists recreate models of past climates and why this work is important in predicting future climates. By addressing earth science content, these explorations will fit into existing secondary science classes and meet both content and inquiry standards.

Student scientists and the power of models

Of course, scientists spend entire careers researching one question, so we do not expect that students will solve the big questions. However, students will be able to explore aspects of the research by using interactive models; their data will come from manipulating model parameters and studying the emergent behavior. Just as discoveries are made at local and national science fairs every year by young scientists doing original research, our students will have the opportunity to explore their own questions about the unknown.

By combining the motivation of unanswered science questions with the pedagogical potential of robust inquiry supporting models in geosciences, we hope to provide students with compelling views of how science is done while engaging them in today's most vital science content. There is no doubt that there will be a new set of questions for *Science's* next list, but with the help of modeling simulations some of the current questions may be closer to being answered.

LINKS *High Adventure Science*

High Adventure Science
http://has.concord.org

Amy Pallant *(apallant@concord.org) directs the High Adventure Science project.*

Questions for Exploration

What causes mass extinction? In geologic history there have been at least five times when more than half of the world's species died. What caused these events?

Is there life on other planets? Scientists have found over 400 planets around other stars. Could life exist somewhere out there?

How hot will Earth get? Global warming will affect our world in profound ways. What predictions can be made about future trends that account for natural cycles and anthropogenic factors?

How are solar systems formed? The conventional theory of solar system formation examines only our own solar system as a test case, but our solar system is not typical. How were others created?

How does Earth's interior work? The convection of Earth's core produces a magnetic field, which may influence surface conditions. Mantle convection is related to volcanoes, seafloor spreading, and mountain creation. How do these motions in Earth's interior really work and in what ways do they affect Earth's surface?

What is dark matter? Most scientists believe that there must be "something" to account for missing mass in order to obey the theory of gravity. Dark matter has mass, but is invisible, so what exactly is it?

What causes lightning? New research has discovered that lightning emits large bursts of x-rays. Could cosmic rays from outer space be involved?

Will there be enough water? The green revolution has brought many lands into self-sufficiency, but essential water pumped from the ground is not being replenished by precipitation. Can countries feed future populations when they are running out of water?

What if the ocean's conveyor belt changed? Deep ocean currents distribute heat around the planet, affecting climate. Could global warming shut down the ocean's conveyor belt with devastating effects on weather patterns, collapse of plankton stocks, and a depletion of oxygen?

What causes ice ages? Changes in solar radiation absorbed by Earth due to periodic orbital fluctuations are one factor in the creation of an ice age. What are other factors?

Is human space travel likely? How can humans be protected from the harsh radiation, cold, and vacuum of space? Is space travel about science or human exploration?

When will an earthquake hit? Earthquake forecasts of the locations and magnitudes of future large earthquakes could save lives. Yet, making a precise prediction has eluded scientists. Is it possible?

Will hurricanes become stronger? Hurricanes Katrina and Rita in 2005 were the worst in many years; their strength was attributed to warmer sea surface temperatures caused by global warming. Can we predict hurricane seasons of the future?

Teaching and Learning Heat Transfer with Energy2D

BY CHARLES XIE AND EDMUND HAZZARD

Everyone experiences heat transfer. Indeed, we constantly seek thermal comfort. Because heat transfer is so common in everyday life, one would think that the science and engineering of heat transfer should be easy to teach and learn.

According to the *Massachusetts Science and Technology/Engineering Curriculum Framework,* published in October 2006, high school students are required to learn thermodynamics and heat transfer in a physics or engineering course. Students are expected to understand that thermal energy is transferred by three different mechanisms: conduction, convection, and radiation. In an engineering course, they are further expected to apply these concepts to analyze and solve problems in real-world thermal systems.

The idea that heat flows from hot to cold may not be difficult to grasp for modern people who live in a thermally controlled environment. Indeed, the fundamental principles of heat transfer and fluid flow were discovered in the 19th century. The hard part is to deepen the conceptual understanding and translate it into problem-solving skills. Most textbooks teach heat transfer as the three separate processes of conduction, convection, and radiation, but in the real world, these processes are often concurrent and intertwined. Reasoning about a thermal phenomenon requires calculations based on a synthesis of knowledge from all three. A hand calculator alone won't do the trick, however, as the geometric complexity of a thermal system such as an internal combustion engine or a building makes the analysis far too complicated.

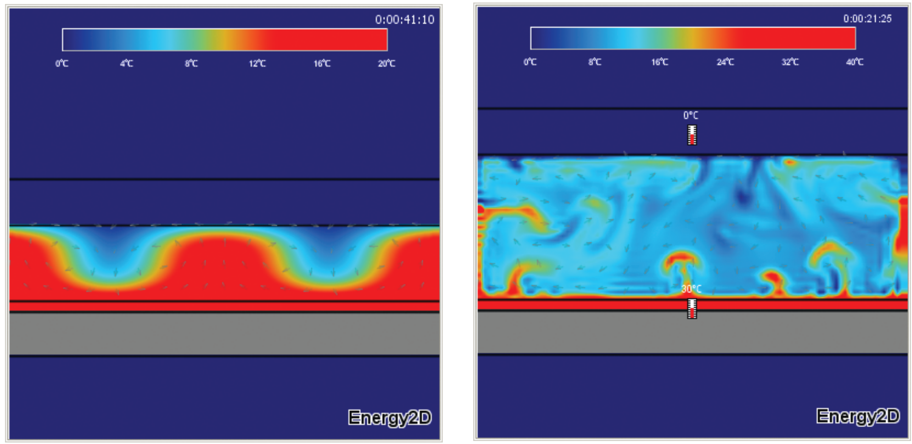


Figure 2. Energy2D simulations show convection between a hot plate at the top and a cold plate at the bottom. With a low Reynolds number, Bénard convection cells are formed (left). The turbulent pattern of rising hot plumes and sinking cold plumes is the result of a high Reynolds number (right). The small arrows represent the velocity vectors of the fluid. Red represents warm and blue cold.

Engineering education for the 21st century

Engineering design skills are emphasized in the Massachusetts framework as well. To diagnose a problem and find an optimal solution, students must learn to consider various factors and constraints, make assumptions, design prototypes, conduct experiments, and analyze results. Through this iterative process, the products get better and better. These skills are at the core of the craftsmanship that has propelled our society since the Industrial Revolution.

In the past decades, however, the context of engineering education has changed dramatically. According to the *Moving Forward to Improve Engineering Education* report, published by the National Science Board in 2007, "Conventional engineering work from conceptual design through manufacturing is increasingly outsourced to countries where the engineering costs are lower. The speed of change means that any set

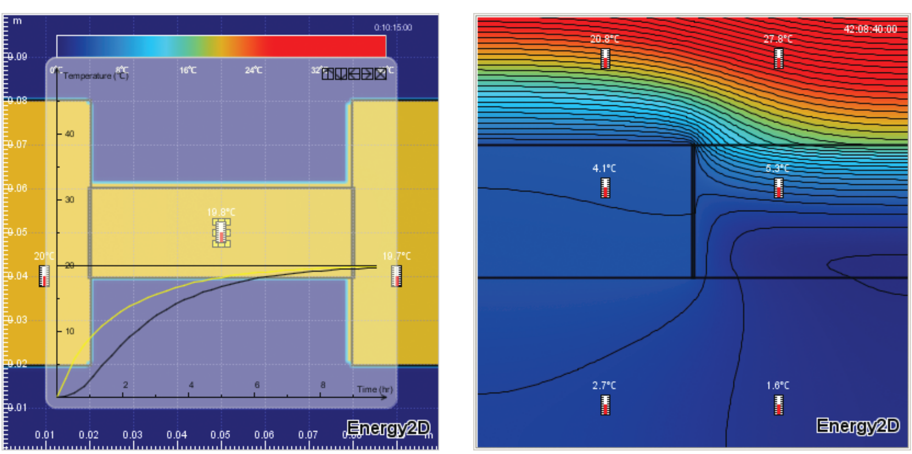


Figure 1. Energy2D simulations of heat conduction. A thermal bridge connects a hot area with a cold area (left). The curves show the temperature measured at three locations. The comparison of heat conduction through two materials of different thermal conductivities (right). Isotherm lines are shown. Red represents warm and blue cold.

of technical skills may quickly become obsolete. To prosper, U.S. engineers need to provide high value and excel at high-level design, systems integration, innovation, and leadership."

To help U.S. students compete in a flat world, American schools must reform their curricula and pedagogies to ensure students acquire higher-level skills than their counterparts in lower-cost countries. Cutting-edge educational technologies must be developed and used to modernize classroom experience.

Supported by the National Science Foundation, we are developing a software tool for simulating heat transfer in two dimensions called Energy2D. The software—the result of technology transfer from computational fluid dynamics research to education—is based on fast algorithms for solving the Heat Equation and the Navier-Stokes Equation. Energy2D can simulate conduction and convection for complex 2D structures in real time. This is an important feature that—unlike many simulation tools not explicitly designed for education—allows users to interact with the simulation while it is running and see the results immediately.

Deep roots in science

Since the software is based on fundamental principles in heat and mass transfer, it is able to simulate a large variety of phenomena. Students thus have at their fingertips a powerful computational laboratory for experimentation.

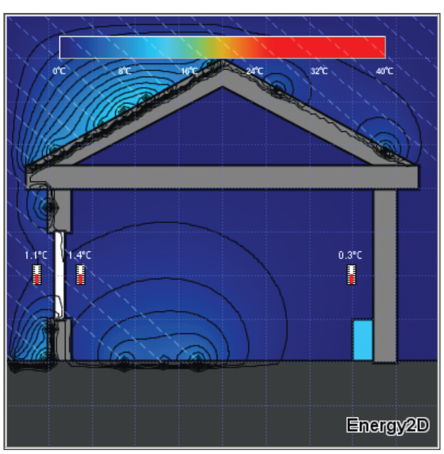


Figure 3. Energy2D simulations of solar heating in a house with different angles of sunlight. The images show the effect of heating through a window.

LINKS *Heat Transfer*

Engineering Energy Efficiency
http://energy.concord.org

Figure 1 shows two simulations of heat conduction. The first simulation illustrates the concept of thermal bridging. A thermal bridge is created when a conductive piece connects two otherwise insulated pieces, allowing heat to flow through the pathway created. The second simulation shows a comparison of heat conduction through materials with different conductivities. In this setup, heat flows from the top. Two materials are placed in the middle. The left one is 100 times more conductive than the right one. This side-by-side comparison clearly illustrates the effect of insulation using less conductive materials.

Figure 2 shows two simulations of convection between a hot plate at the bottom and a cold plate at the top. Science teachers often use a physical experiment like this to demonstrate thermal convection. Energy2D now presents online simulations that can be used to complement the experiment.

Modeling solar energy

Students in our *Engineering Energy Efficiency* project will be challenged to design energy-efficient scale model houses that exploit solar power. Hence, it is important to model insolation and radiation. In Energy2D, light particles can be emitted into the simulation box and a ray-tracing method is used to calculate their positions and interactions with other objects. Figure 3 shows a simulation of the solar heating of a simple house.

Virtual sensors

Users can add any number of virtual sensors to a model to record properties at different locations. A virtual thermometer collects temperature data like a data logger. Results from this virtual thermometer can be used to compare with experimental results measured using real temperature sensors. Figure 4 shows the heating and cooling curves produced by two virtual thermometers placed inside two balls with different thermal masses. The results show that the ball with the smaller thermal mass heats up and cools down faster than the one with the greater thermal mass.

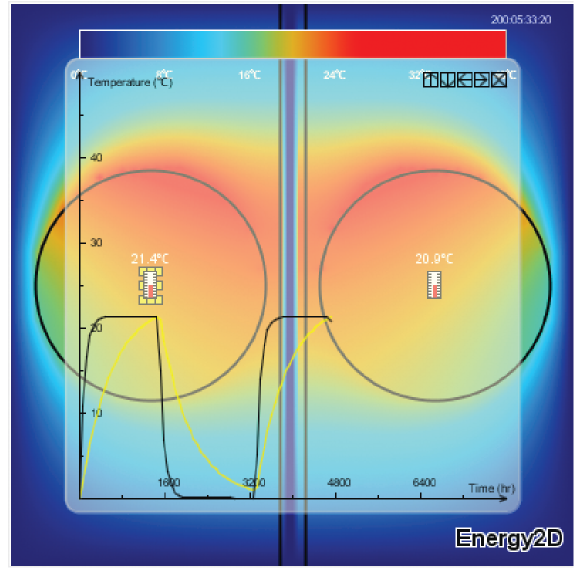


Figure 4. Temperature graphs recorded by virtual thermometers placed in materials with different thermal masses, showing the effect of thermal mass on heating and cooling rates.

Conclusion

Visual learning is crucial in science education, perhaps especially so for today's students who have grown up with the Internet culture. In the real world, however, heat is invisible to the human eye. Energy2D presents a compelling visualization of temperature distribution and heat flow.

The Energy2D prototype simulations have demonstrated its power in modeling very complex thermal systems. With future enhancements to the computational engine and the user interface, students will have a tool far better than a worksheet for crunching numbers to calculate heat transfer. Just as simulation-based computer-aided design tools are now part of the toolkit for engineers, educational tools such as Energy2D are needed to bring this modern engineering methodology to the classroom.

Charles Xie *(qxie@concord.org) is the creator of Energy2D and the director of the Engineering Energy Efficiency project.* ***Edmund Hazzard*** *(ehazzard@concord.org) is a senior curriculum developer and a green building architect.*

Satellites in Orbit

BY ROBERT TINKER

Satellites can stay in orbit almost forever, but only if they are high enough. Because it is so massive, the International Space Station (ISS) has to stay in low orbit, about 350 km above the Earth. At this altitude, air friction causes the ISS to lose over 30 km in altitude every year. So thrusters have to give it a boost every few months to keep it in orbit. Otherwise it would enter the atmosphere, burn up, and rain more than 300 tons of flaming debris onto some unlucky location on the Earth.

However, in a few years the ISS will be obsolete and too expensive to keep in orbit. Would you send it into deep space or arrange for a controlled crash in an uninhabited spot on Earth?

With a series of simulations, your students can explore these questions. Use the Newton's Cannon simulation to get a feel for orbits. Then use the ISS simulation to investigate whether the fate of the ISS should be the Pacific Ocean or deep space.

Newton's Cannon

In 1728 Isaac Newton imagined a cannonball fired from a cannon on top of a tall mountain. He reasoned that gravity could bend the path of the cannonball. Under the right conditions, he hypothesized, the cannonball could orbit the Earth much the way the moon does. It might even go around the Earth and hit the back of the cannon!

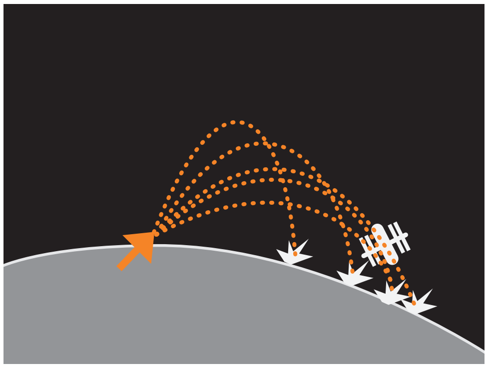


Figure 2. Different launch angles for a starting speed of 5 km/s. Note that the scale is very different from Figure 1. Mount Everest is too small to be seen and the atmosphere is just a thin line.

With the help of a *NetLogo* model, we can test Newton's ideas. Go to: http://www.concord.org/spring2010/netlogo/index.html

To run Newton's Cannon (see Figure 1), click the Turn On button and leave it on (the button turns black).

Press Launch and watch as the ISS crashes. You'll see an explosion and some debris that marks the landing spot.

Experiment with different launch angle and speed settings.

If you increase the launch speed, the ISS zooms off the screen. Change the Main Scale slider to zoom out and watch this happen.

Guided inquiry

After free exploration, encourage students to be systematic with their research. Have them answer the question: What launch speed and angle will make the ISS orbit?

Assign a different launch speed to each group of students. Depending on the number of groups, assign steps of 1.0 km/s or

LINKS *Monday's Lesson*

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

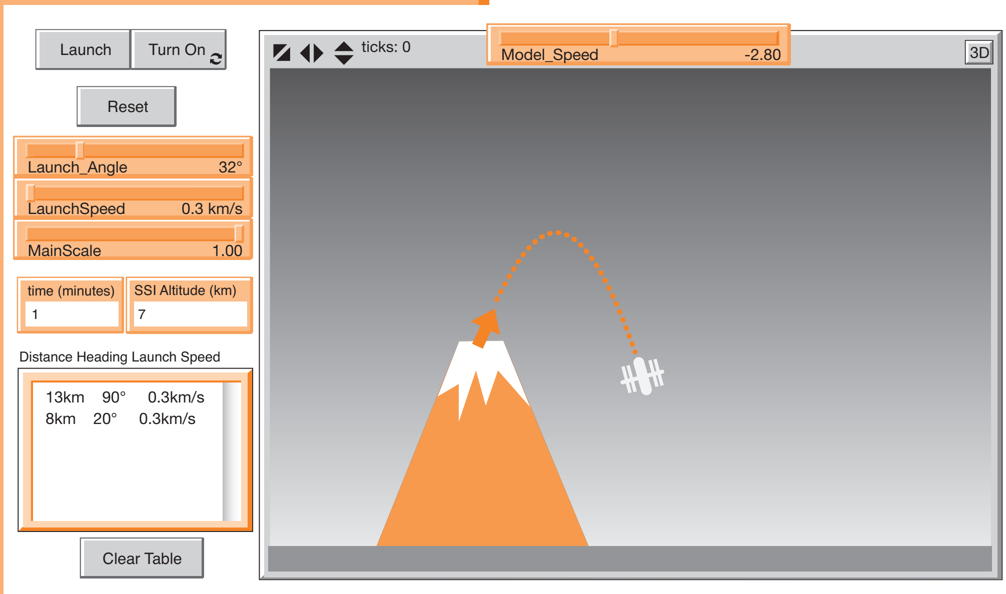


Figure 1. Newton's Cannon. The arrow represents the cannon placed on a mountain the height of Mount Everest. A space station has been launched with insufficient starting speed and is about to crash.

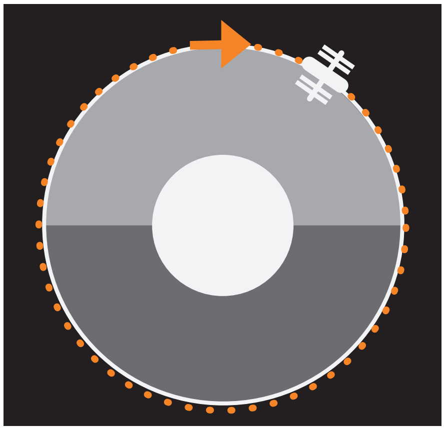


Figure 3. The ISS orbits! In this picture, the ISS has completed one orbit and has started another. Note how near the Earth it is.

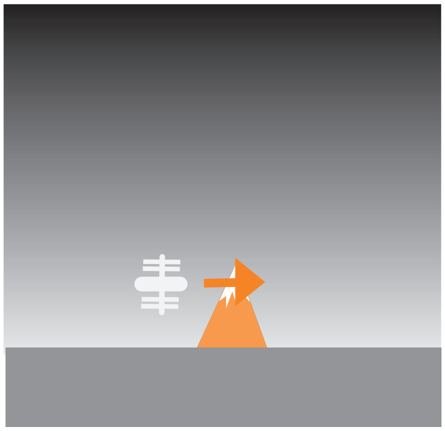


Figure 4. The ISS was launched to the right and is about to hit the back of the launcher after completing one orbit.

0.5 km/s. (Be sure one groups gets 8.0 km/s.) Ask each group to find the launch angle that gives the greatest range. For instance, Figure 2 shows a series of launch angles for a starting speed of 5 km/s. As they experiment with various settings, students can keep track of their results with the table on the lower left of the model.

Collect the results from each group. You should find that the maximum range starts out around 45° or 50° for low launch speeds and slowly increases to 90° at 8 km/s at which time the ISS orbits, as shown in Figure 3.

Challenge 1

Challenge students to reproduce Figure 4, which shows the International Space Station just before completing one full orbit.

(To do this, students need to change the scale to get a close-up view. They also need to use the Model Speed slider to slow down the ISS as it gets close to the launcher. To take a screenshot, stop the model using the Turn On button.)

The ISS simulation

The ISS simulation is similar to Newton's Cannon, but modified to start with the ISS in orbit. It also has a small thruster that can be used to lift the ISS into a higher orbit or to bring it to Earth.

Go to: http://www.concord.org/spring2010/netlogo/index.html

1. Click Run, then click Launch to see the ISS in orbit 350 km above the Earth.
2. Use ISS-Direction to turn the ISS to face left or right of its forward direction, or backward.
3. Each time you fire, you give the ISS a tiny impulse forward. Impulse is measured in thousands of Newton-seconds or kNs. You can adjust the impulse delivered each time you fire.

The thrust is tiny and you may have to fire many times to have a noticeable effect.

Figure 5 shows one strategy that has not yet resulted in escape after 400 kNs were expended. Have your students try to get the ISS far out into space so it never returns.

Next, try to get the ISS to "de-orbit" as the space jockeys say. Find a strategy that uses the least amount of fuel, since fuel is so expensive. It should be possible to bring it down with less than 20 kNs. This shows why NASA prefers the de-orbit strategy to sending it into deep space. The real ISS does not have thrusters capable of delivering 20 kNs. So, to de-orbit the ISS, a new thruster and its fuel will have to be sent up to the ISS to bring it down safely.

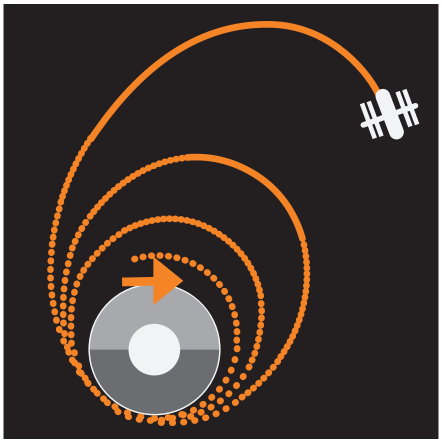


Figure 5. The result of expending 400 kNs of fuel. Ten shots of 10 kNs were given each time the ISS was at the bottom of the screen.

Challenge 2

Have your students try to get the ISS to crash at a predetermined spot. A good choice for a crash site is the mountain just under the launcher. A successful effort will require coordination of the model speed and scale.

The VISUAL project

One of the most unusual visual aspects of these simulations is the treatment of scale. Science requires students to be fluent with ideas of scale, but they rarely experience the tremendous ranges of scale that occur frequently in science. The scale slider in these models covers almost five orders of magnitude. The 8.8 km mountain, the blue atmosphere at 50 km, the ISS launcher at 350 km, and the 6,378 km radius of Earth help establish visual references.

These simulations are being developed in collaboration with researchers at the University of California, Berkeley, as part of the National Science Foundation-funded project called VISUAL, Visualizing to Integrate Science Understanding for All Learners. We are studying how eighth grade students learn from interactive visualizations. In addition to helping students consider the fate of the International Space Station, we hope these simulations help them visualize the range of scale from one mountain to the whole Earth—and everything in between.

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

Collaboratories for Genetics Learning

BY FRIEDA REICHSMAN AND CHAD DORSEY

Genetics data stores have grown explosively in size and complexity over the past two decades. The amount of public DNA sequence data available has doubled every 14 months for 20 years.[1] A technique announced in January 2009 promises to make DNA sequencing 30,000 times faster, sequencing an entire human genome in less than 30 minutes for under $1,000.[2] This technique will be available for doctors and patients within two years.[3] These rapid developments in genetics will radically affect individual health decisions, national political debates, and human ethical concerns.

Open any textbook, however, and you'll read a different story entirely. In current classroom materials, genetics looks far too much like a dusty science of the nineteenth century. Students first encounter this modern science by reading about a monk studying wrinkled peas a century and a half ago. Historical perspectives are important in understanding modern biology, but current curricula rarely do justice to biology's recent transformations. Entire new fields within genetics and DNA science have appeared in the period since existing national science curriculum standards were published, and Mendel's rules from the 1800s have been exposed as very narrow exceptions to the true, complex process of inheritance.

LINKS *Collaboratories*

- **Maine Mathematics and Science Alliance**
  http://www.mmsa.org/
- **Jackson Laboratory**
  http://www.jax.org/
- **BSCS (Biological Sciences Curriculum Study)**
  http://www.bscs.org/

Biology isn't the only thing in flux. Technology, connectivity, and the need to tackle complex problems have made science more collaborative than ever. Scientists work in global "collaboratories"—collaborative laboratories—to combine expertise across disciplines. For many, the computer has replaced the lab bench as the main experimental tool for the new discipline of bioinformatics, the application of statistics and computer science to the study of molecular biology. Modern techniques and analyses rely on databases that are populated with the findings of thousands of researchers across the globe.

Current classroom approaches fail to expose students to current content and techniques, but even more importantly, they do not capture the dynamic, collaborative nature of science. Tomorrow's scientists will enter future professions armed with an obsolete education.

This problem calls for more than a simple fix. Every year, textbook publishers tuck a few new pages into existing thousand-page tomes or create sidebars describing new scientific discoveries, but this treatment does little more than pay lip service to the emerging sciences and fields of study. The knowledge is also different enough that traditional teaching approaches simply do not work. In order to help students understand the complex world of genetics and genomics and appreciate their intricate details, curricula must reach much deeper and engage students in a new manner. The Geniverse project, funded by the National Science Foundation, is building such a curriculum.

Enter the world of dragons

Geniverse extends an existing partnership among the Concord Consortium, the Maine Mathematics and Science Alliance, and the Jackson Laboratory, and adds education researchers from BSCS. Building on an exploratory project that brought cutting-edge genomics experimental techniques to high school students, Geniverse is creating a collaborative web-based environment in which students study core genetics and heredity concepts, collect evidence and study a problem, and work together as scientists to solve relevant scientific puzzles and challenges.

Geniverse shares a pedigree with past Concord Consortium projects reaching back to the pioneering GenScope software and is built upon the same compelling premise—students explore relevant aspects of heredity and genetics by breeding and studying virtual dragons.

These dragons have made it possible to link genotype and phenotype visually, bringing vital biological connections to life for students. Using this software, students can quickly grasp the connection between genes and traits and easily understand the way Mendelian inheritance works. (For example, the genotypes Hh

REFERENCES

1. National Research Council Committee on Metagenomics: Challenges and Functional Applications. (2007). *The new science of metagenomics: Revealing the secrets of our microbial planet.* Washington, DC: National Academies Press.
2. Eid, J., Fehr, A., Gray, J., Luong, K., Lyle, J., Otto, G., … Turner, S. (2009). Real-time DNA sequencing from single polymerase molecules. *Science,* 323, 133-138.
3. http://www.aaas.org/news/releases/2010/0407pers_medicine.shtml

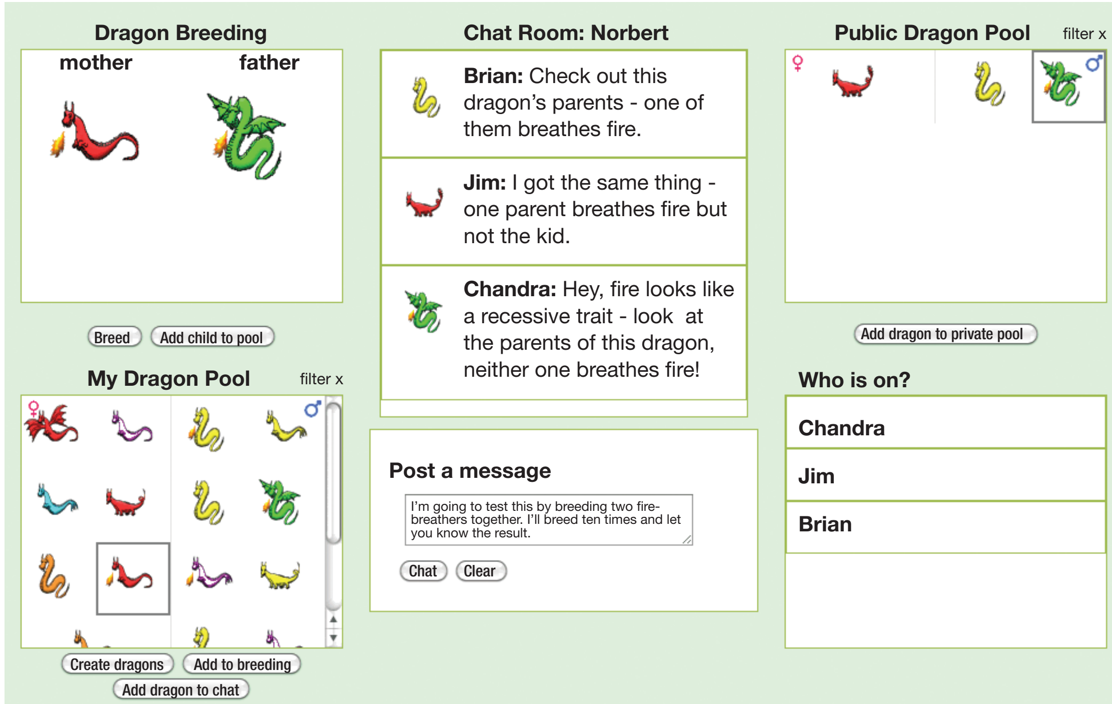


Figure 1. Students have access to individual and shared "dragon pools" for breeding experiments. They can share their results by chatting with one another.

and HH both express the phenotype graphically as a dragon with horns while a dragon with the recessive hh does not display horns.) The Geniverse project is extending these capabilities; dragons' traits are now linked to the molecular nature of genes. Further, students are able to collaborate to ask and answer important questions.

The tools allow students to move quickly and easily among three critical levels of biological investigation and understanding: the nano-level (nucleotides), micro-level (chromosomes), and macro-level (traits). As they do so, students make important conceptual connections among these integral stages. Narrative scenarios woven through the curriculum engage students and ensure that the connections between these levels are relevant and compelling. For example, in one scenario, while breeding dragons a student may uncover a disease and learn that it is spreading through the population unchecked.

The student encountering this disease is able to analyze the affected dragon's DNA and compare it with known sequences in an online database, identifying a specific mutation as the cause of the disease. Instructional sequences such as this require students to apply analytical skills to this multi-level model and perform virtual laboratory procedures in attempts to pinpoint the difficulties causing the disease and to treat it.

Moving to a more complex understanding

A student who completes a Geniverse curriculum module may have correctly identified a recessive mutation as a cause of the disease in the dragon population. Upon concluding this, she can share her result with the rest of the class as a "publication." As part of her publication, she also shares the line of dragons she has isolated as evidence supporting her discovery. Other students in the class test her research by breeding their own dragons with her isolated strain and verifying her result.

Soon after this, however, the same student might learn of a publication by another student that clearly contradicts her findings. This student has bred the isolated strain with a disease-bearing strain of his own. When the two diseased strains are bred together, the offspring are mysteriously disease-free. What can be causing this strange result?

To further understand the problem, students must work together, share findings and evidence, cite other results, and share database searches, dragons, and DNA snippets. Through their collaboration, it gradually becomes clear that two separate mutations in entirely different genes can cause the same disease. In fact, the students discover, the two genes both act in a single pathway—a sequence of enzyme-powered, biochemical reactions that is essential for health; if any gene in the pathway is faulty, the pathway fails, resulting in the same disease.

While solving a mystery, students uncover for themselves the underlying nature of gene expression: by virtue of the molecules they encode, genes act in concert, and not simply as individual entities. Students move beyond "dominant" and "recessive" and enter a more complex, multilayered understanding of genetics.

In other modules, students work both as individual learners and collaborating scientists to solve additional challenges, revealing and addressing various quandaries in the dragon population while building and reinforcing their understanding of core genetics concepts. By layering such puzzles and compelling narratives within standard curriculum, the Geniverse project exposes students to the techniques of modern genetics and helps students develop an understanding of biology as an active, experiment-driven science. With a solid foundation of core genetics concepts, students will be better prepared for a future in which these concepts are increasingly important.

Frieda Reichsman *(freichsman@concord.org) directs the Geniverse project.* ***Chad Dorsey*** *(cdorsey@concord.org) is President of the Concord Consortium.*

Teaching Future Nanoscientists in Today's Classrooms

BY CHARLES XIE

The new field of nanoscience promises to solve many critical problems in medicine, electronics, and energy production. Advancements in nanoscience and nanotechnology will require creativity from scientists and technologists for many generations, which puts nanoscience education at a pivotal point in the field of science education.

Nanoscience is the science of controlling and manufacturing matter at the atomic and molecular scale. There has been considerable investment in nanoscience education in K-12 classrooms since the inception of the National Nanotechnology Initiative in 2001. However, it is still unclear how nanoscience should be taught at the secondary level. One unanswered question is: Should nanoscience be treated as a new discipline or should it be spread across existing disciplines?

Purists vs. pragmatists

The purists propose an independent course. And there are good reasons for such a recommendation. Nanoscience can be considered a foundational science from which large portions of physical and biological sciences are derived. The reason that we put different parts of nanoscience into different branches of science is mostly artificial. All natural and synthesized nanoscale systems are made of electrons, atoms, and molecules that obey the same set of rules. They differ only in structures and functions that can be explained by applying those rules. Occam's razor, which assumes the simplest solution is usually correct, seems to suggest that students might be better off if nanoscience were a prerequisite for physical and biological sciences.

The pragmatists plead for a conservative treatment that views nanoscience as an applied science rather than as a basic science. Arguably, many breakthroughs in nanoscience can be proclaimed triumphs of applying physics, chemistry, biology, or some combination of the three to problems at the nanoscale. For this reason, it appears natural to break up nanoscience into a collection of supplementary modules that can be readily plugged into the current curricular frameworks. In this way, students are exposed to cutting-edge nanoscience concepts without compromising the integrity of the current science curricula and the continuity of the teaching tradition.

Both sides are paradoxical. Advocating for an independent course suffers from the reality that young students typically lack the abstract thinking skills needed to reason from fundamental principles. Ironically, these skills are usually acquired only after learning the more factual physical and biological sciences. Without an understanding of scientific concepts at the macroscopic level that connect to their everyday lives, students may not be able to make the theoretical leap to the nano scale.

The argument for integrating nanoscience into the current science curricula has a fundamental flaw as it raises the very barriers between disciplines that scientists and engineers working in the nano field strive to eliminate. By describing nanoscience as an exten-

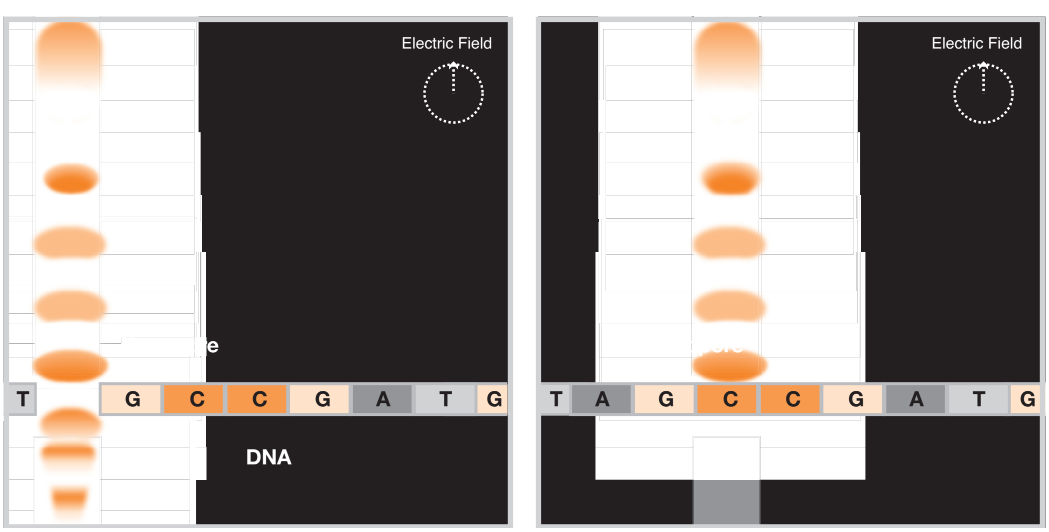


Figure 1. A schematic quantum dynamics simulation that explains the principle of nanopore DNA sequencing based on quantum tunneling.

sion or an application of a discipline, educators risk failing to deliver an important message from the frontier researchers—that the nature of nanoscience is multidisciplinary, the artificial barriers between sciences need to be broken down, and students should have this updated mindset as early as possible.

Since there is no perfect solution, these two divergent approaches to nanoscience education will coexist for a long time. On the one hand, there are college-level courses dedicated to teaching nanoscience systematically, which will gradually influence secondary level practice. On the other hand, as the current science curricula incorporate more and more nanoscience content, we may reach a point where the mission of nanoscience education has been quietly accomplished under the guise of other disciplines.

In any case, it is time to roll up our sleeves and get to work on creating ways to make nanoscience education more effective, regardless of which path it takes.

Teaching quantum mechanics

One of the hardest challenges in nanoscience education is the teaching of quantum mechanics. Since quantum mechanics rules the nanoscale world, its importance cannot be overestimated. But the quantum world is totally counterintuitive and sometimes even downright spooky. Yet, it is undeniably real and ubiquitous. IBM Fellow Donald M. Eigler, Ph.D., has said of his work with colleagues who discovered a way to transport information based on the wave nature of electrons, "We have become quantum mechanics—engineering and exploring the properties of quantum states. We're paving the way for the future nanotechnicians." Indeed, many technological advances would not have been possible without a solid understanding of quantum mechanics.

The *Electron Technologies* project, funded by the National Science Foundation, has developed a quantum dynamics engine for simulating the quantum behavior of the nanoscale world. Based on numerically solving the time-dependent Schrödinger equation, this engine is capable of simulating a wide variety of dynamic quantum processes: bound state, excited state, quantum transition, the formation of a covalent bond, chemical polarity, field-induced polarization, ionization, diffraction, interference, tunneling, quantum transport, and more. It is fascinating to see that these seemingly disparate concepts in physics and chemistry emerge from quantum dynamics simulations that are based on a few basic assumptions—that electrons are represented by moving waves and that waves interact with each other and nuclei through electrostatic interactions. In fact, the quantum explanation of chemistry is among the greatest scientific discoveries in the 20th century, as evidenced by several Nobel Prizes awarded to computational chemists.

The quantum dynamics engine is part of the NSF-funded *Molecular Workbench* software and has been used to produce simulations for several interactive modules for the Electron Technologies project. These modules cover nanoscience lessons that teach concepts such as scanning tunneling microscopy and nanoelectronics. For example, Figure 1 shows how quantum dynamics simulations can be used to explain the principle of rapid DNA sequencing using a solid-state nanopore. Developed by the Harvard Nanopore Group, this innovative technology works like a scanning tunneling microscope. A denatured DNA strand steps through an electrically biased nanopore electrophoretically. The passing base alters the tunneling current across the nanopore, generating a signal that tells its type. Thus, the DNA code can be cracked while the strand translocates through the pore.

LINKS *Nanoscientists*

Electron Technologies
http://et.concord.org

Molecular Workbench
http://mw.concord.org

By making **counterintuitive and mysterious phenomena** more understandable and approachable, we are paving the way for future nanoscientists and nanotechnicians.

Of course, quantum dynamics simulations and molecular dynamics simulations provided by the Molecular Workbench software cannot solve the paradox of nanoscience education. But they do provide visible and tangible solutions that lower learning barriers. By making counterintuitive and mysterious phenomena more understandable and approachable, the Concord Consortium is paving the way for future nanoscientists and nanotechnicians. Purists and pragmatists alike will celebrate as nanoscience education makes leaps and bounds—at the nano scale, of course.

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

The Concord Consortium
25 Love Lane
Concord, MA 01742

NONPROFIT ORG
US POSTAGE
PAID
PERMIT NO 54601
BOSTON, MA

NEWS at Concord Consortium

What CC projects are reading

The following projects share their summer reading lists. Enjoy!

Evolution Readiness
Why Evolution is True by Jerry A. Coyne

Geniverse
Rules of Play: Game Design Fundamentals by Katie Salen and Eric Zimmerman

High Adventure Science
Last Oasis: Facing Water Scarcity by Sandra Postel; *Water Follies: Groundwater Pumping and the Fate of America's Fresh Waters* by Robert Glennon

SmartGraphs
Human Inference: Strategies and Shortcomings of Social Judgment by Richard Nisbett and Lee Ross; *Mrs. Perkins's Electric Quilt and Other Intriguing Stories of Mathematical Physics* by Paul J. Nahin

VISUAL (Visualizing to Integrate Science Understanding for All Learners)
Modeling Theory in Science Education by Ibrahim A. Halloun; *Making Learning Whole: How Seven Principles of Teaching Can Transform Education* by David Perkins

Engineering Energy Efficiency
Engineering Education: Research and Development in Curriculum and Instruction by John Heywood

LOOPS (Logging Opportunities in Online Programs for Science)
Automated Scoring of Complex Tasks in Computer-Based Testing, (eds.) David M. Williamson, Robert J. Mislevy, and Isaac I. Bejar

The Concord Consortium staff.

Evolution Readiness is evolving

The Evolution Readiness project is adding animals to its model, introducing a food chain and highlighting the importance of competition between species. (er.concord.org)

The LOOPS "Classroom in a Box"

The Logging Opportunities in Online Programs for Science project is designing ways for teachers to receive student work in real time in order to adapt their teaching and increase student learning. In a pilot test in a middle school in Arlington, MA, we used a set of computers, including one that acts as a server, plus a local wireless network. While this "Classroom in a Box" is not scalable, the setup enables teachers and students to focus only on teaching and learning, not the technology. (loops.concord.org)

@Concord

Editor: Chad Dorsey
Managing Editor: Cynthia McIntyre
Design: Susan W. Gilday
www.concord.org

The Concord Consortium
25 Love Lane
Concord, MA 01742
978-405-3200 | fax: 978-405-2076

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

This material is based upon work supported by the National Science Foundation under several grants (DUE-090324, DUE-080253, DRL-0918743, DRL-0918449, DRL-0918642, DRL-0929774). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.