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# Perspective:

## Working Together: The Time is Now

By Chad Dorsey

We know a great deal these days about how people learn science, math and engineering and about how good, technology-based curriculum materials can deepen this learning. The National Science Foundation and other agencies have for decades funded inquiry-based programs and approaches that show solid evidence of effectiveness. Yet despite this effort, public awareness about great teaching and learning is still low, and approaches that we know work best have moved barely inches closer to wide adoption. Even with dozens of groups around the nation dedicated to high-quality, technology-enhanced STEM learning, we're seeing minuscule changes in the big picture. It's time to work together.

Long ago, the notion that technology had educational value seemed like no more than a good idea. True application of technology-based tools and learning materials in the classroom felt like a novelty, something futuristic that might only someday be possible. In many ways, this feeling still held as recently as a few years ago.

The concept of inquiry-based learning has proceeded along a similar trajectory. The idea was almost entirely foreign just two decades ago. Of course, many saw its promise and championed the concept, dreaming that inquiry-based learning would someday find its place in the classroom. Since then, uptake has increased and understanding of inquiry's importance for STEM education has matured significantly, yet adoption of good inquiry-based curricula and teaching still remains strikingly low.

### The time is now

Inquiry-based pedagogy and technology-supported teaching and learning are ideas whose time has come. We now understand far more about the nuances of inquiry-based education than ever before, policy and research recommendations are clear about its importance and a wealth of examples and guidebooks exist for its implementation. For technology, times have changed even more radically. In the past few years, we've watched the status of educational technology shift from intriguing novelty to core assumption. Recent developments in consumer technology and investment in educational technology have created a clear expectation that technology should be central in teaching and learning.

We have reached a critical window of opportunity. Interest and new development in educational technology have reached a fever pitch, and conditions are conspiring to create a crucial period for the role of inquiry-based learning. Leading forces such as federal policy documents and the redesigned AP curricula

have paved the road for redesigned curriculum approaches, and the NRC Frameworks and the Next Generation Science Standards stand poised to propel the need for inquiry-based learning to center stage in our country's classrooms. This shift also brings with it important new ideas about how students should understand and participate in the practices of doing science. All of these changes arrive against a backdrop of renewed capacity and expectation for technology-supported curricula.

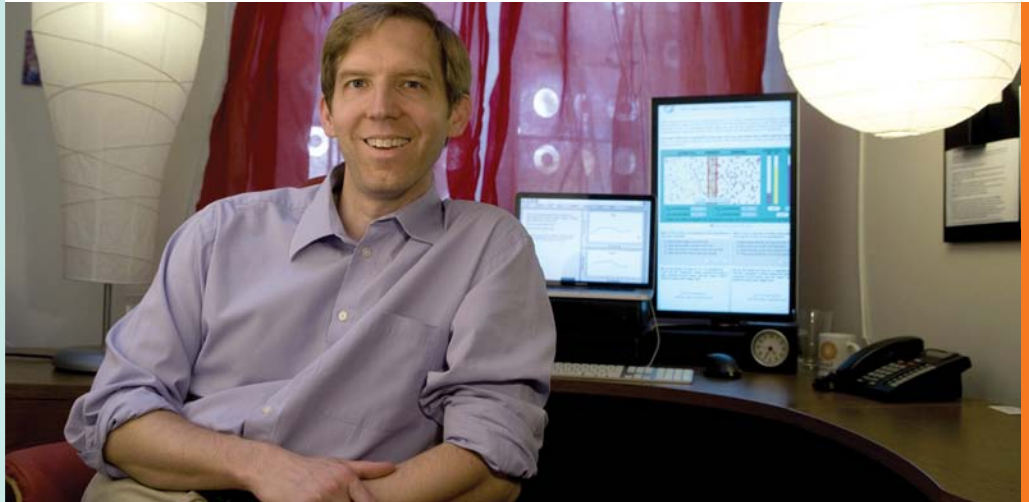
There has never been a more important time to act on a vision of inquiry-based, technology-supported teaching and learning. The conditions are set. The urgency is there. The call for change is clear and present. Yet answering this call is another matter entirely. While technology seems to be surging forward, real, transformative, deeply digital uses—those that tap its true potential for STEM learning—are rare. Understanding of inquiry-based pedagogy is even more inadequate. Perhaps more importantly, both of these concepts have barely any voice in our current public discussions about education, which typically focus on a generalized need for STEM competitiveness or nebulous debates about teacher quality or standardized testing.

But the solutions are more subtle—and more achievable—than the picture these clarion calls and doomsday discussions paint: we must help teachers understand and teach with inquiry-based methods, and we need to provide high-quality solutions for the use of technology in science, math and engineering classrooms.

The problem is fundamental, and the answer is momentous and clear. We and literally dozens of other excellent organizations across the country are working to find solutions. Still, none of our organizations working individually has managed to achieve anywhere near the widespread change we dream about. At this critical juncture, the only solution is to band together.

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There has never been a more important time to act on a vision of inquiry-based, technology-supported teaching and learning.



## Partnering for progress

Promoting these ideas through a partnership, we could stand a chance to meet the opportunity head on. A few obvious goals provide a place to start.

**Raise understanding.** We need to model what high-quality, technology-enhanced STEM teaching and learning looks like. Teachers from elementary to higher education—as well as institutions preparing tomorrow’s teachers—need guidance and clearly demonstrated examples to help them see the value of these approaches. Parents and policymakers also need a similar deep understanding of STEM education to help them ask the right questions at town hall meetings, prepare them for parent conferences or aid them in drafting good legislation.

A national marketing campaign would raise awareness of these ideas and help create a grassroots demand. Such a campaign could tap into growing concern on the part of many that current approaches focused on standardized testing may overlook or de-emphasize important skills and understanding.

**Build a bridge for the best examples.** A partnership could also help ensure that more of the excellent curricula funded by federal dollars survive the transition from concept to classroom. Currently, federally funded programs are among the best—and often the only—examples of curricula and approaches in which in-depth knowledge about teaching and learning are applied to their fullest and results are research-based. Despite this, few of these curriculum materials make their way into wide adoption.

The failure of these curriculum materials or approaches to take off is typically not due to lack of promise on their part. Instead, a complex combination of motivational, societal and

market challenges often stop them well before they reach the runway. While no single solution will remedy this complex problem, dozens of organizations when joined together could provide useful models for this transition, share a knowledge base, generate powerful innovations and create increased presence and bargaining power or even a separate marketplace altogether. This would result in a win for federal agencies, national organizations and classroom teaching and learning while helping increase the value of millions of dollars of federal investment.

### **Create a toolkit for technology-based STEM education.**

The power of such joined forces comes into even sharper relief when considering the possibility technology offers for scaling and accelerating these groups’ efforts. The best thinking of organizations across the country is helping develop ever better examples of how technology can aid STEM education. However, many more ideas out there are squelched before they even begin, simply because of the reality of the infrastructure demands implicit in bringing a solution into classrooms across the country.

A group of organizations working together with common ideas, tools and infrastructure could help reduce this problem significantly. Building and sharing both common tools for STEM learning and more complex environments for delivering deeply digital STEM curricula would radically accelerate the work. Such a partnership wouldn’t need to promote one predominant platform or settle upon only one set of tools; even modest coordination would greatly amplify efforts over time and allow new projects or grants to avoid reinventing the wheel.

With these goals and a common focus, there is a chance to unlock the significant opportunity available to us today. Ready to help us get started? Email us with your ideas and support at [STEM-partnership@concord.org](mailto:STEM-partnership@concord.org).

# Free SmartGraphs activities help students make sense of graphs

by Andy Zucker and Rachel Kay

Graphing calculators are ubiquitous in science, math and engineering courses. But while they have many excellent features—including the fundamental ability to create graphs—these handheld devices don't really know what graphs *mean*. And that's a critical failure; they can't help students make sense of a graph.

Our SmartGraphs open-source software provides scaffolds and hints to students who need help understanding a graph. These visual and textual hints make our SmartGraphs activities *smart*.

Activities run directly in a modern Web browser using HTML5 (JavaScript). There is nothing to download or install. Most SmartGraphs activities also run on tablet computers, like the iPad (although portions of any activity using a motion sensor need to run an invisible Java applet, which isn't feasible on most tablets).

Teachers, curriculum developers or others who want to create a new SmartGraphs activity don't need to know HTML5 or any programming language. Our form-based authoring system makes it easy to customize existing SmartGraphs activities or create new ones simply by filling in online forms. And because the SmartGraphs software is flexible, activities can be used to teach algebra, physical science, biology, psychology or any other subject where it is important for students to make sense of graphs.



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### Physical science activities

Working with several teachers in Pennsylvania, where more than 75,000 students each year take a physical science class in eighth or ninth grade, we developed the first five SmartGraphs activities for a standard curriculum unit on the motion of objects. Graphs are central to the learning goals. Students learn about position-time graphs, slope as a measure of speed or velocity, velocity-time graphs and the acceleration of objects falling under the influence of gravity. Many of these learning goals are similar to those in an algebra class where students often study position-time graphs and learn to interpret the slope of lines as a measure of velocity.

Using SmartGraphs, students draw prediction graphs with a mouse and compare them to data collected by a motion sensor and displayed in the Web browser. They label portions of a graph on the computer screen and calculate the speed of objects based on graphical and tabular representations of data. Students can watch graphs being constructed as the image of a moving car generates position-time and velocity-time graphs. And when students answer embedded questions

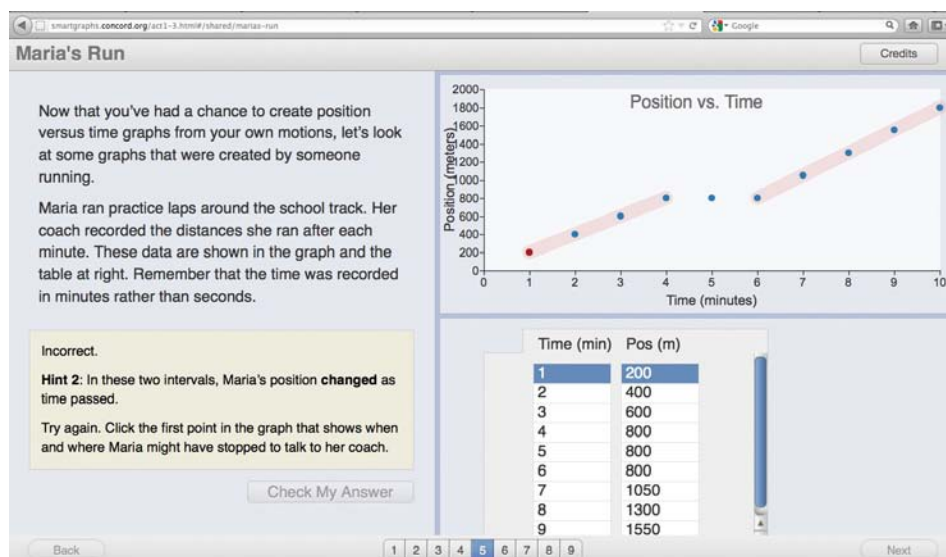


Figure 1. Page 5 of the physical science activity “Maria’s Run.”

incorrectly, SmartGraphs provides visual hints, text hints and arithmetic hints to help them understand the graphs and the underlying concepts (like velocity) represented in the graphs (Figure 1).

For each activity, a lesson plan is provided for teachers. In addition, there is a paper-and-pencil student assessment, which can be assigned as homework or used as a quiz after students complete the activity. Three of the five physical science activities use a motion sensor. Each activity takes less than one class period.

### Research about SmartGraphs

We designed the five activities for physical science classes with multiple criteria in mind. The activities need to be carefully matched to the learning goals of the motion unit. And they need to help students achieve those goals and be perceived by teachers as useful supplements to the course. In order to discover the extent to which these goals were met, we conducted a large-scale randomized experimental trial of the activities in fall 2011 in 29 Pennsylvania schools.

In 14 schools, 17 experimental teachers used SmartGraphs activities with 49 eighth and ninth grade physical science classes studying the motion of objects. In 15 schools, 18 control teachers taught the same topic using the same textbooks with 42 physical science classes.

This study sought to answer two research questions. First, what do teachers using SmartGraphs physical science activities believe about the software, including how well the software matches important learning goals for the motion unit of study? Based on the 203 sessions when experimental teachers used a SmartGraphs activity with a class, teachers agreed or strongly agreed that the SmartGraphs activities address important learning goals and help students meet those goals. Also, in 99% of the sessions teachers reported they would use the activity again, either exactly as is (63%) or with only minor changes (36%).

The second research question was, Do students who use SmartGraphs activities learn more than comparison students studying the same topic from the same textbooks, but who do not use SmartGraphs activities? To answer this question, nearly 1,700 students completed a pre-test and a post-test that included multiple-choice and constructed-response items assessing students' understanding of about a dozen learning goals. The experimental students showed greater gains than the control students on three measures: multiple-choice items, constructed-response items and total score (Table 1). In each case, the results were statistically significant.

Answers to both research questions were encouraging. We will continue to conduct research studies in Pennsylvania in the fall.

### Creating new activities

Thanks to an easy-to-use and continually improving authoring system, SmartGraphs is now customizable and extensible. Teachers who want to make small changes to an activity can do so before they assign it to their students. Or they can create an entirely new activity.

Six algebra teachers recently became the first group outside our project team to create new activities. These activities are aligned with the *Common Core Standards for Mathematics* and peer-reviewed. Several are now available on our website.

	Experimental	Control	Significance (p)
Multiple-Choice	1.16	1.07	.049
Constructed-Response	4.19	3.64	.043
Total	5.07	4.30	.008

**Table 1.** Gain Scores from Pre- to Post-test.

### Next steps

As the physical science and algebra activities demonstrate, learning about graphs in context is critical. Teachers also need to devote time to developing students' "graph literacy," namely the ability to identify the important features of a wide variety of graphs and relate those features to the context of the graphs—in other words, to increase students' understanding of the meaning of graphs. We have begun working with educators in the state of Maine to develop and test free, online graph literacy activities aimed at middle school science classes.

It is easy for teachers to assign SmartGraphs activities to students or to share them with colleagues. All they need is a URL. Our goal is to have tens of thousands of teachers and students using SmartGraphs activities.

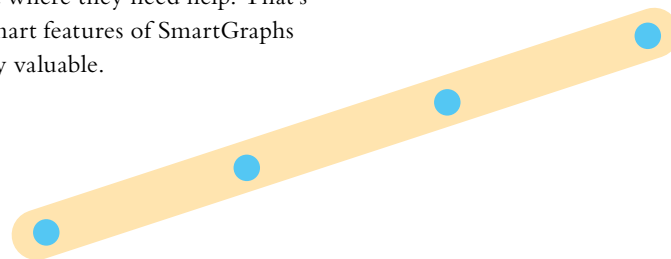
Over the next months and years, we will add new features to SmartGraphs, such as the capability for activity authors to graph any arbitrary function and allow students to interact with it. Another goal is to provide teachers with the option of saving students' data on a server and to generate reports for teachers about student performance while using the activities. These reports can help teachers understand which graph-related concepts students understand and where they need help. That's where the smart features of SmartGraphs are especially valuable.

**Visit the SmartGraphs website to try the activities:**  
<http://concord.org/smartgraphs>

**Click on the curriculum tab for activities or the research tab for information about the results of our research studies.**

**Interested in authoring your own activity? Sign up online at [smartgraphs-authoring.concord.org](http://smartgraphs-authoring.concord.org). An authoring manual walks you through the steps.**

**SmartGraphs software is made available under the GNU Lesser General Public License, which means anyone is free to use and distribute the code.**



### LINKS

SmartGraphs  
<http://concord.org/smartgraphs>



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is a curriculum developer.

# Monday's Lesson:

## Modeling Climate Change with MySystem

By Nathan Kimball

To make sense of science, students must develop their own mental models of the phenomena to glean what is happening. When making mental models—like diagrams of energy flow—it's important to start simply. Refinements and nuances can be added later.

MySystem is an online tool designed to help students diagram their understanding of particular science content. We focus here on energy, a crosscutting theme in middle school science. Students select from a palette of icons (e.g., Earth, sun, greenhouse gas) and drag them onto a canvas. They link these icons together with arrows and label the arrows to indicate what is flowing (e.g., sunlight, IR) as well as the direction of flow.

### Modeling climate change

Try one of the following climate change lessons with your students, then use MySystem diagrams to elicit student ideas, and gauge and build their understanding.

**Modeling Earth's Climate.** <http://concord.org/activities/modeling-earths-climate> This five-day activity explores factors that affect climate, set in the background of Earth's climate history.

**Greenhouse Gases.** <http://concord.org/activities/greenhouse-gases> This one-day activity focuses on the effect of greenhouse gases in the atmosphere.

As students run the activities, stop the class periodically and engage them in discussion. Have them build energy flow diagrams in MySystem and debate which one portrays the system more accurately. If disagreement arises (that's how real science proceeds!), then send students back to the models to gather evidence and formulate arguments.

### Challenges

We authored the icons and links in this MySystem diagram to illustrate the most significant energy flows in climate change. While the models in the above activities

focus on interactions of energy with matter, the MySystem diagrams deal more abstractly with inputs and outputs: energy of sunlight flowing into the system, energy flowing out and the path it takes. These are two different ways of looking at Earth's energy flow and they complement each other. For instance, the activity models show sunlight interacting with the Earth and sky, but don't explicitly show the sun or outer space. MySystem can bring these essential elements to the fore.

After students have a basic understanding of energy, challenge them to create a diagram that illustrates energy flow on any planet—with or without an atmosphere. The MySystem diagram in Figure 1 shows that the planet both absorbs the incoming sunlight and reflects some of it back into space. It radiates absorbed energy as infrared. The net change of energy on the planet is zero. All planets must do this or they would continue heating.

### "What if?" scenarios

Once this basic energy model is established, try "what if" scenarios with your students. For instance, test their understanding of albedo by asking, What if the planet is perfectly reflecting or completely absorbing of sunlight? What if the planet has an atmosphere that contains greenhouse gases?

In Figure 2, the link from Greenhouse Gas to Earth is a double-headed arrow, showing that greenhouse gas circulates energy back to Earth, the cause of greenhouse warming. However, greenhouse gases also radiate energy into space, maintaining a zero energy flux.

What if clouds are added? Continue with "what if" questions to build a more complex diagram—and a more complete understanding of climate change.

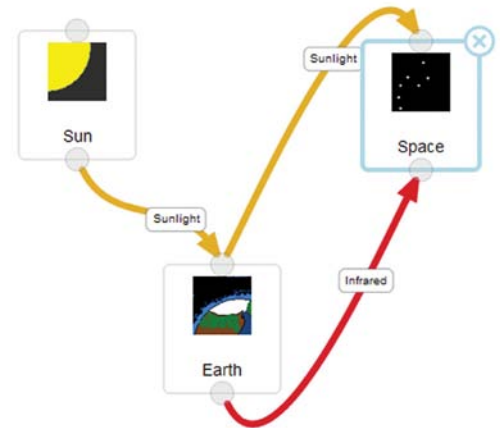


Figure 1. Simple MySystem diagram of energy flow on a planet.

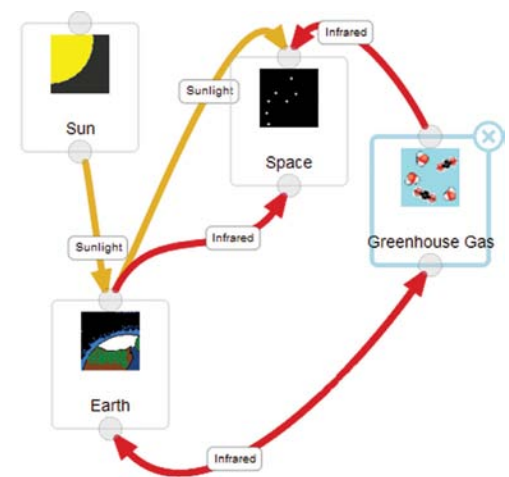


Figure 2. More complex MySystem diagram with the addition of greenhouse gases.

### Try it out

This MySystem diagram allows students to build models showing the flow of energy for several of the major elements involved with the greenhouse effect.

<http://concord.org/mysystem/climate-change>

Save your diagrams by clicking "Save," which places a unique URL in your computer's clipboard. Use this URL to return to or share your diagram.

### LINKS

Activity Finder  
<http://concord.org/activities>

# InquirySpace:

## A Space for Real Science

By Robert Tinker and Ed Hazzard



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***“Before graduating from high school, students working individually or in teams should design and carry out at least one major investigation. They should frame the question, design the approach, estimate the time and costs involved, calibrate the instruments, conduct trial runs, write a report, and finally, respond to criticism.”*** — AAAS Benchmarks

Student research is sometimes called “extended inquiry” to distinguish it from plain inquiry, which has come to mean learning through observing, questioning, thinking, communicating and collaborating. Inquiry is the best way to learn anything, but extended inquiry is in a different dimension because it starts with students defining their own questions and devising their own experiments.

While advocating student research when some kids lack basic science knowledge may seem quixotic, we don’t see it that way. We want students to understand science by *doing* their own research projects. The AAAS Benchmarks, NSES and the new Frameworks concur.

But this is a tall order. Teachers who want to support student research face major practical barriers as they traverse the chasm between standard cookbook labs and open-ended research projects. Their students may lack experimental skills and labs with general-purpose equipment. Teachers may feel unqualified to support student projects that venture into unfamiliar science content. And student research can take time and be difficult to assess.

InquirySpace is designed to provide significant help in bridging this chasm by offering tools and scaffolding that will make it easier for students to carry out their own research investigations. Five high school students recently participated in a daylong “inquiry camp” where we piloted these strategies. We share two encouraging anecdotes here.

### **A variable that didn’t vary**

The first InquirySpace activity used a physical mass-spring system, a motion detector and a computer simulation of oscillating motion (Figure 1). One student team asserted that the mass affected the period of the physical spring-mass system because the heavier mass stretched the spring farther, so it had farther to go up and down and took longer. They investigated their claim by collecting probe data and graphing the period against the starting position of each run. Puzzled to find that the starting position didn’t make much difference, the students proposed that they hadn’t changed the amplitude enough. If there were bigger differences, the change in period would show up.

Next they switched to the computer model in order to try a larger range of starting positions, keeping other things constant. To their surprise, the period was absolutely unchanged, to the thousandths of a second! They concluded that the model was correct and that starting position didn’t matter.

### **Two paths to understanding**

Later in the day, we presented a simple climate change model. The model computes the approximate Earth temperature as a result of changing the sun’s energy, the average albedo (the fraction of sunlight reflected), the amount of clouds and the concentration of CO<sub>2</sub> in the atmosphere. We challenged the students to spend 45

minutes investigating the effects of these variables on the temperature of the Earth.

One team went for wild extremes. They discovered that they could fry the Earth if they increased sunshine, reduced albedo, removed clouds and added CO<sub>2</sub> to the greatest values allowed by the model. The planet temperature soared to 284°C. Then they went the opposite direction. The graphs of their experiments were dramatic (Figure 2). When asked to summarize their results, they could explain the mechanism for each variable that resulted in increased or decreased Earth temperature.

Meanwhile, the other team quietly and systematically explored each variable, one at a time. They made at least four runs of the same duration, changing just one variable each run and summarizing each series with four graphs showing the effect on temperature of sunshine, albedo, CO<sub>2</sub> and clouds. The graph of the impact of clouds on temperature was strikingly non-linear (Figure 3). It was clear from their summary that they understood the graphs and were able to reason about the causes of the trends.

The two teams demonstrated opposite ways to understand a model: test extremes or systematically explore each variable. While the second team uncovered more detail, both teams learned the same ideas and all students experienced *doing* scientific research.



## From camp to classroom

These informal observations indicate that we're on the right track. Students were able to perform and summarize dozens of experiments quickly. They moved comfortably between real and virtual experiments and applied the same inquiry steps to both. And once they mastered the idea of collecting data from multiple runs and summarizing them, they easily went on to do their own investigations.

InquirySpace will provide a package of curricula and technologies with the following features that will allow many more students to experience real science in their classrooms.

### Learning research by example.

Students need to experience examples of doing research. Our inquiry camp showed that after exposure to the tools and methodology, students could go on to investigate their own topics.

### More measurement capacity.

Students need options for taking experimental measurements for their research. InquirySpace will support a wide range of probes and will provide ideas for making more. It will also provide flexible computer models, each of which will support dozens of projects.

**Easy analytical tools.** Having obtained lots of data, it can be overwhelming and time consuming to sift through them. Speeding up this process not only reduces the time required to do a project, it also facilitates learning by closely linking experiment to results. Data collected from probes and models is similar and automatically exported into an easy-to-use data exploration tool specifically designed for students.

### Use graphs, not abstract math.

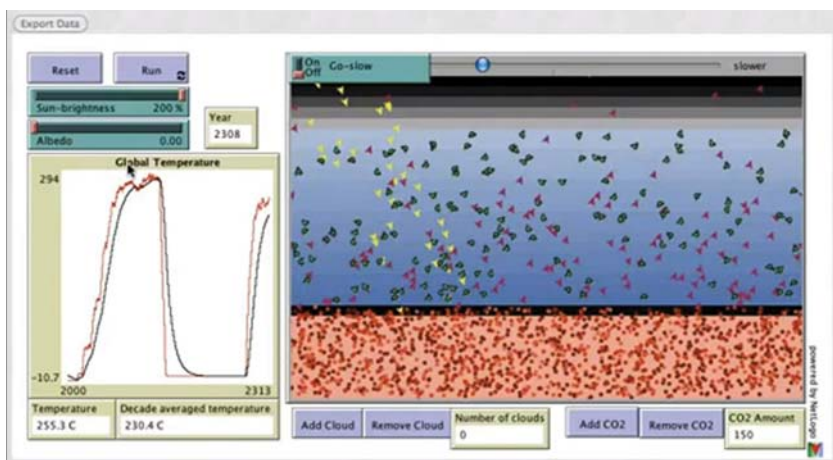
Experimental research often relies on equations and advanced mathematical facility. To democratize research, InquirySpace relies exclusively on graphs. And while graph interpretation is also difficult for students, it is easier to master than more abstract math. (Plus, our Smart-Graphs software can help. See page 4.)



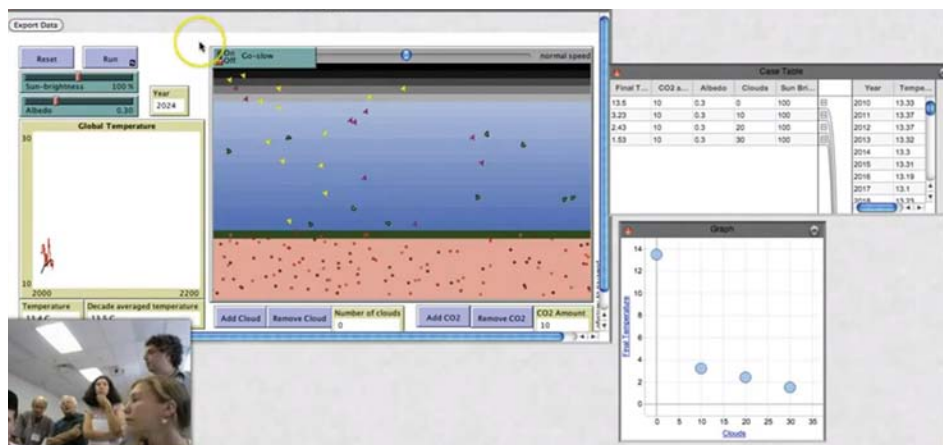
**Figure 1.** A distance sensor measured the up-and-down motion of various masses hung from various springs.

**Practical research ideas.** One of the major problems students face is selecting a practical research question. InquirySpace will provide dozens of feasible and interesting research projects with suggestions and strategies for getting started.

**Research community.** Research is inherently a social act, performed and evaluated by peers. Students must engage an audience to understand this critical part of scientific research. We will provide an online community of student researchers and an online journal where student research reports can be saved or published.



**Figure 2.** Students drove global temperatures to extremes by changing sun brightness, albedo, and CO<sub>2</sub> in the NetLogo Climate Change model.



**Figure 3.** The graph of temperature vs. clouds clearly shows a nonlinear effect. The data was extracted from the NetLogo Climate Change model.

## LINKS

[InquirySpace  
http://concord.org/inquiryspace](http://concord.org/inquiryspace)

# Molecular Workbench

## and the Rise of the MOOC

By Paul Horwitz, Dan Damelin and Chad Dorsey

**MOOCs are all the rage. However, don't worry if you don't recognize the acronym. It popped up only last fall, when Stanford offered—free of charge—a graduate-level course in artificial intelligence. Over 160,000 students from 190 countries signed up, defining what is quickly becoming a new genre in online education: the Massive Open Online Course or MOOC.**

This genre expanded further last spring as MIT attracted over 150,000 students to its “Circuits and Electronics” MOOC. The graduating group made the course’s broad appeal clear—7,157 strong and ranging in age from 14 to 74. The promise of such courses led MIT, Harvard and the University of California, Berkeley to form the nonprofit partnership edX. Now, a collaboration between edX and the Concord Consortium is forging new ground for how MOOCs can be used to teach science.

On October 15, MIT opened a MOOC through edX entitled “Introduction to Solid State Chemistry.” This MOOC, in effect a chemistry approach to materials science, is an online version of one of MIT’s longest-running and highest-enrollment traditional courses. It covers the relationship between such microscopic features as electronic structure, chemical bonding and atomic order and the resulting atomic arrangement and macroscopic properties of various crystalline and amorphous solids, including metals, ceramics, semiconductors, polymers and even proteins.

This course’s strong focus on intermolecular interactions and their importance in giving rise to material properties made integration with the Molecular Workbench

a natural choice. Molecular Workbench’s computational simulation capabilities turn the invisible world of atoms and molecules into an accurate environment for student exploration and experimentation.

Molecular Workbench was one of the first software engines to use research-grade algorithms to simulate atomic motions, forces and interactions for generating real-time visualizations of atomic-level behavior. A grant from Google.org is enabling us to move this molecular dynamics engine to the Web, an advance that permits integrations such as this collaboration with edX.

### Exploring intermolecular forces

The core of this MIT chemistry MOOC is the study of why solids, as opposed to liquids and gases, hang together, a phenomenon that derives directly from the fundamental force between charged particles. Memorizing simple rules such as “like charges repel and unlike charges attract” doesn’t begin to capture the complexity of intermolecular forces in the real world. For the MIT MOOC we used Molecular Workbench to create four interactives that help students experience and understand these nuances:



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### Intermolecular Attractions

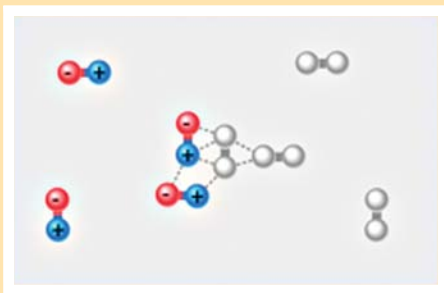
In this introductory activity, students explore patterns of attractive forces between molecules by dragging polar and non-polar molecules around (Figure 1). Dashed lines appear where there are attractions between molecules. Through direct manipulation they explore the surprising notion that neutral atoms attract to everything.

### Differences in Attractive Force

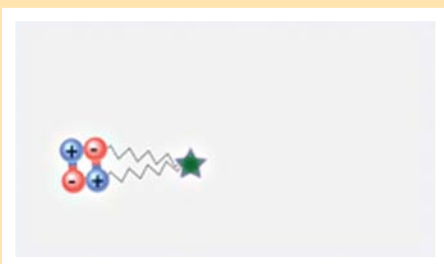
In this activity, students choose between different pairs of molecules—two non-polar molecules, two polar molecules (Figure 2) and a non-polar and polar molecule—and then pull on one of them. Through these experiments, students determine the relative strengths of attraction among combinations of polar and non-polar molecules.

### Phase Change

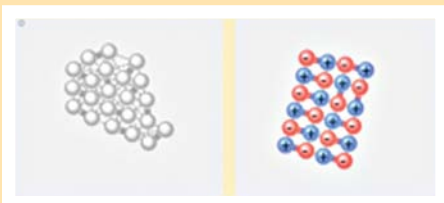
Here, students make the connection between the unseen molecular forces they have just explored and the familiar macroscopic phenomenon of phase change. Using a temperature control, students “boil” two different solids, one composed of non-polar molecules, the other of polar ones (Figure 3).



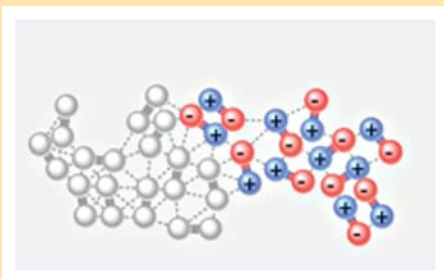
**Figure 1.** Intermolecular Attractions. Oppositely charged atoms (blue and red) attract to each other while neutral atoms (gray) attract to everything. Dashed lines show the attractions.



**Figure 2.** Differences in Attractive Force. Students pull on an imaginary handle (green star attached with springs) to test how strongly pairs of molecules attract to each other.



**Figure 3.** Phase Change. Non-polar (gray) and polar (blue and red) substances can be heated and cooled at the same time to compare melting and boiling points.



**Figure 4.** Solubility. Polar (blue and red) and non-polar (gray) substances separate when mixed together, but are still attracted to each other.

## Solubility

This activity illustrates the point that atomic-level models can connect properties that seem to be entirely unrelated by underscoring the little-understood connection between boiling point and solubility. Students know inherently that oil and water don't mix. However, their investigations have shown that at the atomic level everything attracts to everything else. Students explore this seeming puzzle by mixing a non-polar substance (like oil) with a polar substance (like water). While the two do attract, the stronger attractions between polar water molecules "squeeze" the oil molecules out from between them, causing the two to separate (Figure 4).

## Bringing labs into MOOCs

These interactives serve as initial examples that offer one view into a much larger question: how can MOOCs be used best to teach science content? Most MOOCs today are a fascinating hybrid of the new and the familiar. At their core they are simply a series of videotaped lectures given by the professor. Students "attend" these lectures whenever they want, at their own pace, starting, stopping, repeating or skipping over sections at their discretion. They are given weekly assignments to complete and a discussion forum in which to ask and answer questions. Over time this forum becomes a specialized Wikipedia devoted to the material of the course.

Since they are by definition completely online courses, MOOCs naturally lack in-person laboratory components that students would receive on campus. Many of the first widely popular MOOCs in this quickly rising field were offerings in computer science from groups such as Stanford, Coursera or Udacity. These had the advantage that student programming can act as the "lab," and highly structured computer languages can be adapted to exercises that can be easily auto-scored. Recent MOOCs offered in other domains simply do not attempt to face this challenge,

hewing instead to typical modes of lecture and occasional written homework responses.

However, with the capabilities of models and simulations such as those from the Molecular Workbench, we can provide "lab" experiences in areas beyond what is even possible in physical laboratories. In this case, the exploration occurs at the molecular level, but simulations can permit students to explore multi-scale phenomena such as genetics, long-ranging phenomena such as evolution or large-scale phenomena such as climate change just as easily. MIT has also been a leader in this realm, having created a simulated electronics environment specifically for its initial MOOC offering.

## New frontiers

Using models or simulations for such applications opens the door to much more interesting possibilities such as a reliable means for evaluating student understanding. Researchers at the Concord Consortium are working on logging student interactions with the interactives and providing feedback based on their actions. In the long run, we expect to be able to use students' manipulations of the interactives as a reliable marker for their understanding of the underlying scientific principles and their facility with the practices of science and engineering. By taking advantage of possibilities such as this, MOOCs may indeed become the platform of the future for education, and bring sophisticated learning about science, math and engineering to millions around the world.

## LINKS

Molecular Workbench  
<http://mw.concord.org>

# Visualizing Earth

## and Explaining Seasons

By Jennifer King Chen, Stephen Bannasch and Cynthia McIntyre



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The first person to walk on the surface of the moon, Neil Armstrong viewed our planet as a floating globe in space. He is one of only a dozen who have had the opportunity to view Earth from its orbiting satellite. Photographs from Apollo 11 (Figure 1) give a glimpse of that experience, but what's it really like to see the entire globe from another plane of reference? And how does that perspective change what we know about our planet, our place in the universe and the role of science in discovery?

With our Seasons 3D visualization (Figure 2), students can change the Earth's tilt, rotation, and more—all within a Web browser. A project led by Dr. Marcia Linn and researchers at the University of California, Berkeley, Visualizing to Integrate Science Understanding for All Learners (VISUAL), is creating and researching computer-based visualizations like Seasons to determine how and when they improve science learning. Students use the visualizations to make observations and run simple experiments.

### Curriculum design

The VISUAL team created an inquiry curriculum unit on seasons for secondary Earth science students, using the Web-based Inquiry Science Environment (WISE). WISE is a free, online open-source platform developed at the University of California, Berkeley for delivering science inquiry activities. The seasons unit includes multiple visualizations and hands-on inquiry activities supported by instructional scaffolding.

Throughout the unit, students investigate Earth's seasons through guided inquiry and experimentation. The visualizations were developed both to illustrate key ideas for

understanding seasons and to address common student misconceptions about the topic. One of those misconceptions is that seasonal temperature variations are caused by the Earth's distance from the sun as it travels a highly elliptical orbital path.

The Seasons visualizations, developed at the Concord Consortium, include a number of helpful features to guide students' inquiry:

- 1 Manipulable and linked representations of different perspectives of the Sun-Earth system. Students can switch between preset top and side views for each perspective (Earth from Spaceship and the Sun-Earth System).
- 2 Features that encourage experimentation. Students can adjust variables (such as month and city) to run different experimental trials. Both perspective windows update to reflect the students' choices (e.g., a latitude marker appears on the Earth, indicating the location of the selected city).
- 3 User controls for data collection and analysis. Students can keep track of their experimental trials with various user controls and record-keeping tools such as a

data collection table and a user-controlled temperature graph.

The unit also uses the Idea Manager, a scaffolding tool designed by the VISUAL team to assist students in collecting and managing their ideas for explaining seasons. Using the Idea Manager, students can add ideas during their inquiry investigations, as well as annotate, flag, revise, delete or restore ideas. The Idea Manager also helps students to use evidence collected from their investigations to evaluate their ideas in preparation for writing about seasons.

The Idea Manager and other instructional scaffolds support knowledge integration (KI), or students' ability to make connections among important science concepts by: 1) eliciting prior ideas (e.g., responding to a prediction prompt before each visualization), 2) introducing new ideas (e.g., exploring the visualizations), 3) highlighting distinctions (e.g., comparing experimental trials, as well as collecting and annotating ideas using the Idea Manager), and 4) promoting reflection and refinement of ideas (e.g., evaluating and reflecting upon collected ideas to write an explanation using the Idea Manager).



Figure 1. View from Apollo 11. Photo credit: NASA.

## Results

The seasons unit was tested in high school Earth science classes over a period of 10 hours of instruction.\* Researchers scored students' pre- and post-unit test responses using KI rubrics and found that students significantly improved their understanding of and explanations for seasons. And when they analyzed student use of the

Idea Manager tools, they found that the visualizations appeared to provide key normative ideas for students' learning about seasons.

Specifically, they found that students added more ideas to the Idea Manager when explicitly prompted to do so, demonstrating that it is critical to provide instructional scaffolding and learning

tools that encourage students to track and monitor their developing ideas. In addition, students flagged the ideas they obtained from using the visualizations as important more often than they did ideas from other sources, indicating the potentially valuable role that visualizations can play in contributing to student learning.

## Next steps

The VISUAL team is working on a suite of visualizations for complex scientific phenomena, including chemical bonding, detergents and the energy incident on a solar panel. Our next steps are to connect visualizations with graphs and data tables and to monitor student interactions with them, so we can provide feedback for teachers and researchers (for instance, determining and reporting whether students explore systematically or randomly). We also want to investigate the use of collaborative Idea Manager tools for socially constructing meaning of scientific phenomena.

With each 3D visualization, our research involves exploring the educational effectiveness of different kinds of visualizations as well as student interactions with these visualizations—because, as we know, perspective matters.

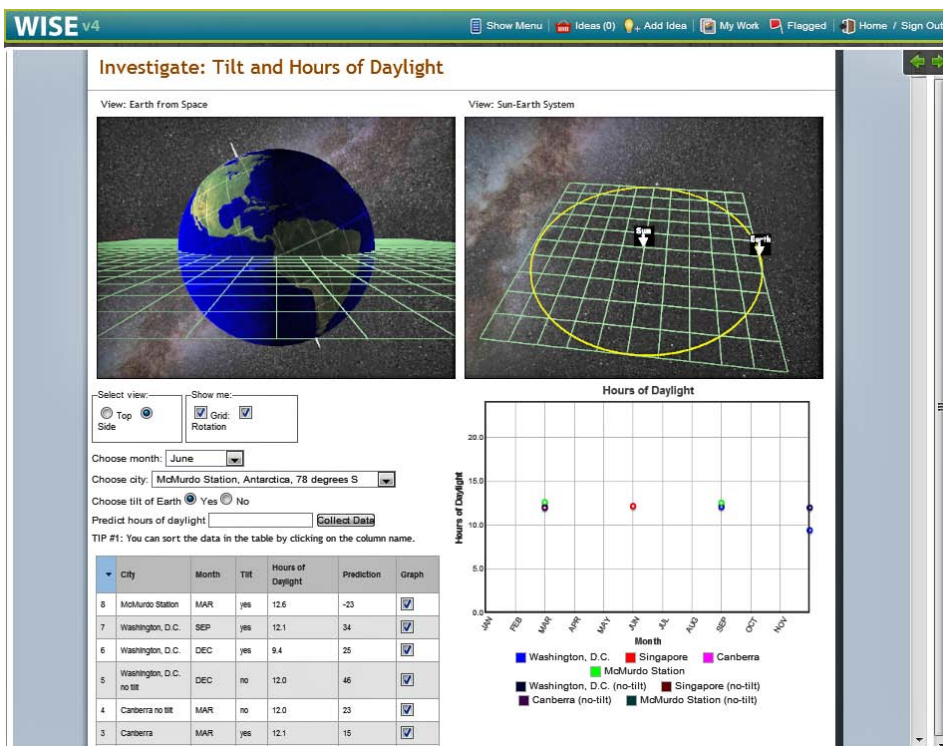


Figure 2. The Seasons software allows students to manipulate perspectives of the Earth.

\* King Chen, J. Y. (2012). *Investigating seasons: Designing for inquiry and learning with dynamic visualizations*. Poster session presented at the International Conference of the Learning Sciences Doctoral Consortium, Sydney, NSW, Australia.

## LINKS

VISUAL  
<http://concord.org/visual>

WISE  
<http://wise.berkeley.edu>

# Under the Hood:

## Using WebGL to Accelerate Advanced Physics Simulations in the Browser

By Piotr Janik



**Piotr Janik**  
(janikpiotrek@gmail.com)  
was a 2012 Google Summer of Code  
student for the Concord Consortium.

Until recently, the idea of running advanced physics simulations in a Web browser was far fetched. While modern Web browsers have 10 times the computational capacity and speed compared with just 18 months ago, pure JavaScript performance isn't enough for advanced physics. Thanks to the rapid advancement of Web technologies—and a bit of ingenuity—we're looking past JavaScript and making use of the power of modern GPUs.

WebGL is a powerful part of the new HTML5 standard, bringing graphics card capabilities directly to the browser. WebGL is an implementation of the OpenGL ES 2.0 API in JavaScript, but rendering 3D graphics isn't the only application of this technology. We're taking advantage of the GPU computational capacity to speed up physics simulations.

We parallelized the computational fluid dynamics algorithms of our Energy2D simulator and implemented these algorithms using WebGL-based resources. The results are promising. A GPU-enabled simulation is 2-15 times faster than the pure JavaScript implementation!

The most important thing to understand is the difference between CPU and GPU workflow. The graphics processor has enormous computational power, but only if it can do a lot of simple tasks in parallel. GPU doesn't like complicated routines, like loops or if-else statements. It works fastest when a large number of threads can perform literally identical instructions.

While native applications have access to technologies like CUDA or OpenCL, which provide a high-level interface for parallel programming, these technologies are not (yet) available in the browser. To get WebGL to perform physics calculations, simply trick your graphics processor by pretending that you're rendering graphics.

First, keep the simulation data in the graphics card memory. WebGL defines 2D texture type. Think of it as an image (or a matrix) with four color channels:

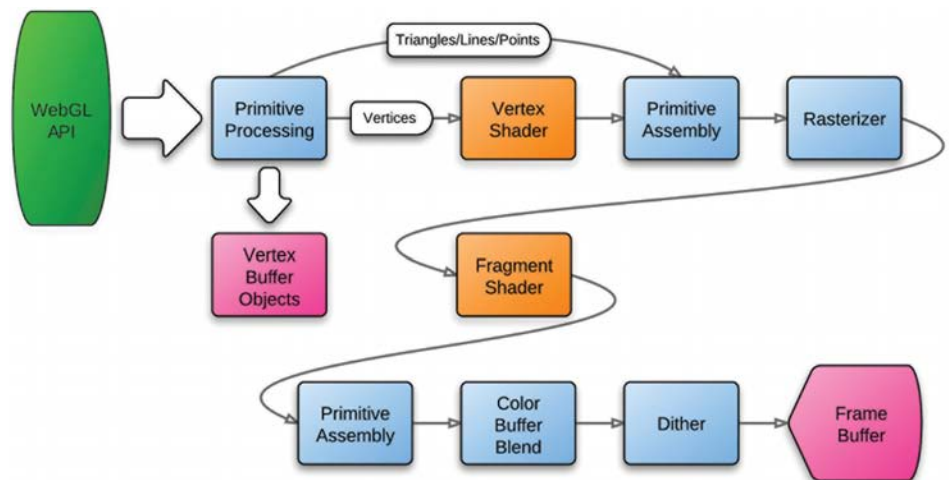


Figure 1. A typical WebGL rendering pipeline.

R, G, B, A. Each can hold your data and each is encoded using one unsigned byte (accepted values are from 0 to 255). Since this isn't enough for advanced physics, use *OES\_texture\_float* extension, which changes encoding of channels from byte to a 32-bit floating point number.

Next, change the rendering output. By default, what is rendered by the graphics card is displayed on the screen. Fortunately, WebGL allows us to change the render target to the given texture, so we can render directly to our "simulation grid."

Finally, program the graphics processor with simulation routines and begin rendering. It's common to render a full-screen quad object to enforce coverage of the whole output texture.

In a typical rendering pipeline, two areas (orange in Figure 1) can be customized using the GLSL language, which has very similar syntax to C.

The Vertex Shader is responsible for transformations of geometry vertices. It's great when dealing with the perspective and movement or rotation of objects, but it's often useless for GPGPU calculations.

The Fragment Shader does all the work. GPU executes it for every pixel of output image after geometry rasterization to calculate resulting colors, which can be used for amazing visual effects during graphics rendering. When you're doing GPGPU calculations, put your routines here. Don't think about colors, just calculate a new value of a simulation cell represented by a texture pixel. You've successfully tricked the GPU!

### LINKS

[HTML5 Energy2D  
http://lab.concord.org/energy2d.html](http://lab.concord.org/energy2d.html)

# Innovator Interview:

Pendred Noyce

**Dr. Pendred “Penny” Noyce served on Concord Consortium’s Board of Directors from 1997 to 2012. She was instrumental in launching the Virtual High School as an independent nonprofit and became chair of our board in 2008 to lead the presidential search committee. Penny is co-editor of *New Frontiers in Formative Assessment* (Harvard Education Press), which includes two chapters by Concord Consortium staff, and author of two children’s books, *Lost in Lexicon: An Adventure in Words and Numbers* and *The Ice Castle: An Adventure in Music*.**

**Q. How did you go from being a medical doctor to becoming involved in supporting education?**

**A.** My father [Intel co-founder Robert Noyce] had decided to work on K-12 education at the time of his sudden death. When I lost him, I realized I wanted to take a new direction in my life. My stepmother, Ann Bowers, my uncle and I were the first trustees of the Noyce Foundation, created to honor his memory.

**Q. What were the overarching problems to be addressed?**

**A.** My father believed in upward mobility through education as a foundation of our democracy. He wanted to increase opportunities for kids by making science and math exciting and effective. The foundation currently focuses on out-of-school science because we believe that kids with potential are not getting the inspiration to pursue technical fields. We’re also trying to figure out a more strategic solution for math education.

**Q. What are you most proud of in your foundation work?**

**A.** I’m very proud of the systemic approach we’re taking to building a world of informal and afterschool science. We helped fund an NRC study to look at growth in interest and engagement over time. We’re also funding Click 2 Science, which will offer short, just-in-time online video learning experiences for afterschool personnel in delivering inquiry science instruction. We’re trying to strengthen afterschool networks with a science focus, while also addressing funding and policy.

**Q. What were the influences of your father?**

**A.** You’d think it was all about technology, but it wasn’t! He always believed and taught us to believe we could do and accomplish anything we wanted and that he would be behind us all the way. He had an essential optimism about people. He also loved adventure. He gave me gliding lessons for my 14<sup>th</sup> birthday and took me helicopter skiing in the Canadian Rockies when I was in residency. He was my ski buddy.

**Q. Why did you decide to write children’s books a few years ago?**

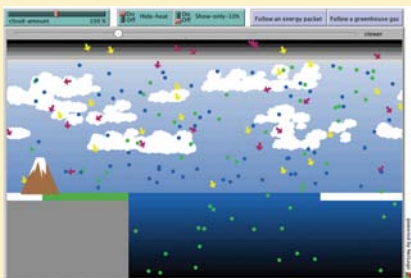
**A.** When I was six, I wanted to be a writer, mommy and candy store owner. I went back to writing when my older kids went off to college. I wrote *Lost in Lexicon* for my youngest, Damian. People said it was too old-fashioned and didactic (they meant it had too much math), so I initially published it myself. Scarletta Press is publishing the Lexicon series now. The second book [*The Ice Castle: An Adventure in Music*] came out in August.

**Q. What’s next?**

**A.** I’m working with a playwright and a math teacher who is also a composer to develop a Lexicon middle school musical. And I have launched a new company combining science activities with science mystery books!



## NEWS FROM THE CONCORD CONSORTIUM



### Earth's Systems and Sustainability

Students significantly improved their scientific argumentation ability and understanding of Earth and space science using High-Adventure Science curriculum units. A new project—High-Adventure Science: Earth's Systems and Sustainability—builds on these promising findings, thanks to the National Science Foundation.

We are partnering with the University of California, Santa Cruz and the National Geographic Society to develop units for middle and high school students on climate change, fresh water availability, fossil fuel utilization, resource sustainability and land use management. We will test the hypothesis that students who use computational models, analyze real-world data and engage in scientific reasoning will be better able to understand how humans affect Earth's systems.

#### Read more about High-Adventure Science.

- "Modeling Climate Change,"  
*The Science Teacher*, October 2012
- "Exploring the Unknown,"  
*The Science Teacher*, March 2012

### Geniverse and Whyville Combine Forces

Can the intersection of school and social media transform STEM learning? With funding from the National Science Foundation, our Geniverse software and the Whyville virtual world are teaming up to explore this question.

Geniverse games have demonstrated that interactive technology is effective for teaching genetics in the classroom. Whyville has more than 7 million registered users from around the world, most between 8 and 15 years old, two-thirds of them girls. Their "learning by doing" approach to STEM education encourages children to engage in authentic scientific inquiry in an informal, collaborative setting. We'll introduce Whyville users to our genetics games and research the effect of combining technologies intended for formal and informal learning.

### Graph Literacy for Middle School Students

For success in math and science courses students should be able to identify the important features of a wide variety of graphs and relate those features to the context of the graphs. Thanks to the National Science Foundation, we are using our powerful SmartGraphs software to develop and pilot test activities and assessments to improve student graph comprehension. We are focused on scatter and line graphs and will test these activities with students in grades 7 and 8 in Maine, which has a 1:1 middle school laptop program.

### K-2 Students Are Sensing Science




Heat and temperature are both abstract and invisible, but real-time visualizations linked to probes and sensors have shown great promise in aiding students as young as third grade in understanding these ideas. A new project, funded by the National Science Foundation, is developing innovative remote sensing technology and curriculum units for K-2 students. Activities focus on children's physical and tactile experiences of heat and temperature in the everyday world. Research will focus on student preconceptions and the role of well-designed curriculum and software in improving science teaching and learning in K-2 classrooms.

### Back to School Webcast with Chad Dorsey

In a live webcast on November 14, 2012, from 7:30 – 8:30 p.m. (EDT), Chad Dorsey will introduce scientific and engineering practices from the Next Generation Science Standards and describe how free, technology-based activities can support students. Please put this event on your calendar now and register at <http://concord.org/webcasts>. We'll send a reminder before the webcast.

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