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The Concord Consortium™

Perspective:
Defining a Deeply Digital Education

By Chad Dorsey

This issue of *@Concord* marks some significant occurrences at the Concord Consortium. This summer our Molecular Workbench software received the *Science* Prize for Online Resources in Education, a prestigious award given to the top science education efforts across the country. This summer also marked the 30-year anniversary of the invention of educational probeware by Bob Tinker and Stephen Bannasch, technology that has ignited a revolution in science education by bringing real-time data collection to schools. These innovations represent two of the many important ways in which technology can transform learning.

In our workplaces and homes, we currently benefit from immense technological innovation, much of it having arrived only in the past few years. But true change comes more slowly to the practice and materials of education. Computers and connectivity have come to most schools and classrooms, but curricula—and often teaching—remain oddly stranded in a former age. Students sit around shiny new computers, only to build PowerPoint presentations. Miles of high-bandwidth cabling snake to and from the nation's schools, but pulse far too often with simple WebQuests or Wikipedia searches. Valid but superficial uses of technology stop far short of the possibilities technology can offer. Settling for such uses brings society's full-speed technological revolution to a screeching halt at the schoolhouse doors.

Of course, if few compelling alternatives exist it is hardly surprising to see the technological wave changing life and work, but barely seeping in at the margins of teaching and learning. Today's curricula do not apply new approaches to delivering core content, and teachers lack powerful tools for timely understanding of student learning.

Whispers of a technology revolution in teaching and learning are becoming audible, however. Digital textbooks provide some of the loudest of these rumbles, and the benefits seem clear. Heavy backpacks would be banished forever. Content would be annotated, highlighted, and shared. Interactive aspects would accentuate the text. But these are far from enough. At the Concord Consortium, we are excited about bringing technology to the core of the classroom. But too often we see examples heralded as the education of tomorrow that are simply surface-level implementations that fail to deliver technology's true potential.

The Concord Consortium raised these concerns two years ago when we identified the possibility that shallow examples of digital textbooks might end up *feeling* like important change while providing little more than digitized PDFs of their paper counterparts. We feared that integration of simple video clips or loose ties to social media sites might go down as the biggest technological contributions to learning. In response, the Concord Consortium introduced the Deeply Digital Texts initiative, devoted to developing the essential elements necessary for the curriculum of the future. We're pleased to note that the term we coined has caught some attention—for one, the PCAST (President's Council of Advisors on Science and Technology) report to President Obama featured it prominently. In the meantime, we've been hard at work developing and further defining the critical facets of this *deeply digital* education.

Deeply digital texts should be much more than texts. We all need placeholders. Scaffolds. Steps we can stand on to peer over the wall into the future. For teaching and learning, textbooks are precisely that. The single most important thing about these central objects that we often hold as critical to learning is actually their role as a placeholder.

A decade from now, it is highly unlikely that these central objects will still be made of paper. We also hope they are no longer thought of as textbooks, with all their associated notions of static ideas waiting to be passively absorbed, but that we instead graduate to the concept of deeply digital *curricula*. In our vision, such curricula take full advantage of all the possibilities digital technology offers to improve teaching and learning. Though they will naturally come in all shapes and sizes, these deeply digital curricula should possess several common elements.

Embedded models, simulations, and data collection enable digital inquiry. Videos, animations, and 3D depictions enhance plain text content, but fall far short of activating the practice of scientific inquiry. Deeply digital materials take students far beyond these high-tech reference items and enable students to *do* science within their everyday learning. Simulations allow students to design and conduct investigations and learn through experimentation—by manipulating molecules, directing the division of DNA, or capturing the complexities of climate change for themselves. With probeware, students can explore the invisible world around them, collect and share data, and test new ideas. These experiences shouldn't be relegated to stand-alone activities or labs. Instead, they must be

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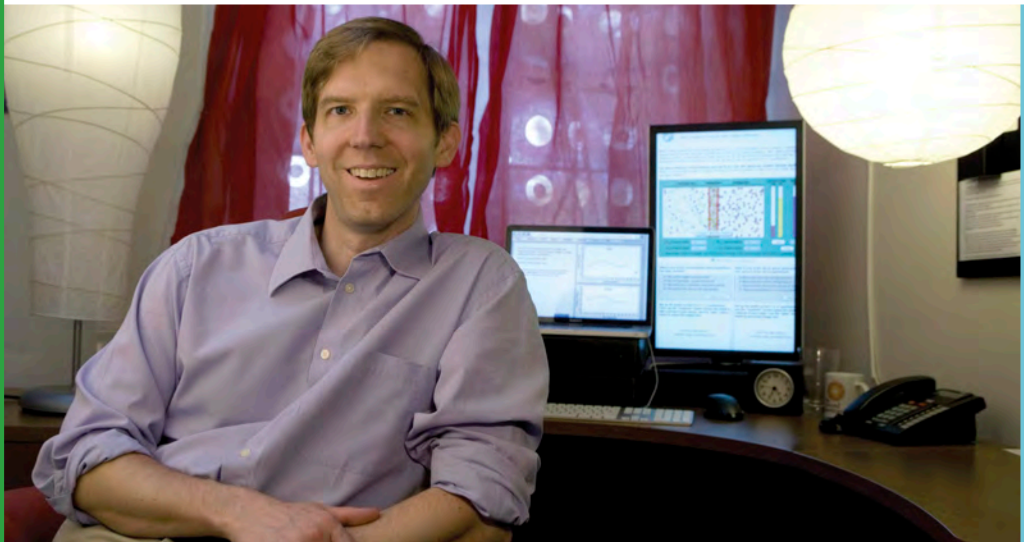

fully embedded within curricular text, assessments, multimedia, and more.

Seamless data sharing facilitates fluid scientific discourse. Students' work in typical classrooms is confined to a very small universe. Laboratory experiments fall to a single student or lab pair to analyze, and students experience interactive models and simulations at a singular point in time. The information—and often the learning—typically vanishes or is discarded, along with myriad opportunities for collaboration and learning. Deeply digital curricula should retain, collate, aggregate, and share data with other students, the teacher, and other classes worldwide, opening up broad possibilities for debating and learning science from data.

Student progress data permit efficient assessment and adjustment of teaching. In deeply digital curricula, teachers should have access to real-time data about student progress at all times. This detailed, ever-evolving picture of student learning will permit unprecedented tailoring of teaching responses, bring to the surface student misconceptions as they occur, and allow teachers to treat vital ideas precisely as they become important for future learning. Data from student interactions with models and simulations will also form sophisticated performance assessments of science process skills.

Monitoring and feedback support and individualize learning. The importance of feedback is clear to any teacher and well established in education research. Deeply digital materials should provide nuanced and individual feedback, from leveled hints to smart scaffolding. Additionally, the rich environments of serious games are working to raise this concept to even more sophisticated levels.

Flexible and adaptive presentation of curricula enhances teacher support. Teachers can occasionally cater to students' many unique needs and strengths, but the task becomes rapidly overwhelming even for experts. Adaptive curricula have already made notable strides in some well-constrained subjects. Deeply digital curricula should enable students to construct their own paths toward flexible, coherent, and organized sets of learning goals.

Curricula can be customized and can be refined based on extensive data. Deeply digital curricula should permit teachers to add, subtract, or rearrange elements or to create new examples if they wish. And teachers should be able to easily share their creations with others. Combined with the impending revolution of student data from thousands of online classrooms, this will open wide new possibilities for classifying and optimizing curricula as patterns of student learning can be linked to individual curricular sequences.

Curricula provide in-depth experience with crosscutting concepts. Most importantly, deeply digital curricula should supply the possibility for deeper *learning* overall. By enabling students to investigate fundamental science concepts such as molecular motion, energy, evolution, genetics, and many others firsthand, these curricula will transcend manipulation and memorization of facts. Instead, students will see and experiment directly with the core principles of scientific phenomena and gain an appreciation for the unifying concepts of science. Students will hone fundamental abilities of analysis, prediction, and comprehension of new ideas that they will encounter in the laboratory, the office, or the latest news report.


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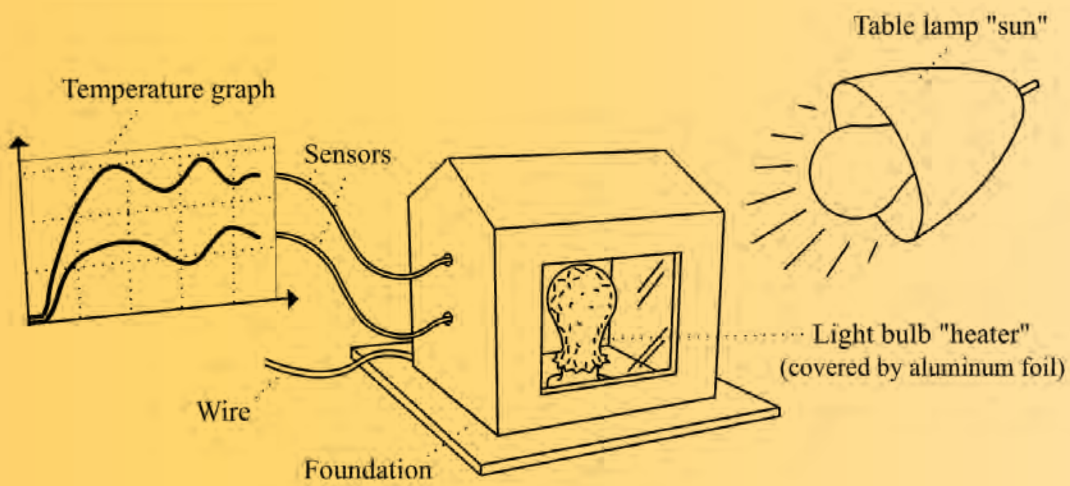
Engineering Energy Efficiency with a Green Building Model Kit

By Charles Xie, Edmund Hazzard, and Saeid Nourian

Precollege engineering education is increasingly recognized as an indispensable part of STEM education. The National Research Council's conceptual framework for new science education standards has concluded that engineering should be incorporated into American science education.* When the new standards are finally made, thousands of science teachers will be charged with teaching engineering—a subject that may be new to many.

At the center of engineering education is the question of how to teach engineering design. Engineering without design is like science without inquiry. It is through the cycle of designing, testing, and modifying that students engage in authentic engineering practices and learn proven engineering principles. A classroom engineering project without a design challenge for students to make a product is incomplete at best. But the variety of engineering systems precollege students can realistically design, build, and test in classrooms is limited by time, resources, and student preparedness.

Robotics and computer programming are perhaps the most frequently adopted student projects. To cover a wider spectrum of science and allow for broader and deeper infusion of engineering, more options are needed. Situated in the context of sustainability and centered on the concept of energy, our *Green Building Model Kit* adds to the family of engineering design projects.



An engineering kit

The *Green Building Model Kit* was developed to support our Engineering Energy Efficiency curriculum for high school engineering. The curriculum bridges science and engineering by combining scientific inquiry with engineering design. Through laboratory experiments and computer simulations, students are guided to learn the science behind energy flow and energy usage in houses. Having acquired the basic knowledge and skills necessary to undertake more sophisticated tasks, they then team up to design, construct, test, and improve a model house step-by-step using the kit, with the goal of maximizing the house's energy efficiency. The curriculum has been improved through several rounds of field tests involving more than 300 high school students in Massachusetts. The majority of students surveyed have indicated that creating a model house and measuring its energy performance using the kit was easy.

The *Green Building Model Kit* uses inexpensive tools and materials, so it can be easily implemented in precollege classrooms. For example, a 40 W light bulb is used to simulate a furnace—it has low heat capacity and can reach a high temperature rapidly, which allows it to warm up a model house in a short time. Wrapped with aluminum foil that has low emissivity, the light energy it radiates heats the foil and the air around it, mimicking the heat transfer through air circulation from a furnace. A 300 W light bulb in a gooseneck fixture simulates the sun at different angles in different seasons. The kit includes fast-response temperature sensors for testing each design and modification, and students are able to repeatedly assess whether their designs improve energy efficiency.

We have also developed two free software tools that enhance the kit. Energy3D is an educational computer-aided design (CAD) tool that can be easily used to sketch up buildings and print them out for scale-up and assembly using cardstock or foam core. Energy2D is an educational computational fluid dynamics (CFD) tool that provides interactive simulations for studying basic concepts in thermodynamics and heat transfer, such as heat capacity, conduction, convection, and radiation.

Engineering design

The richness of design is the key to successful engineering projects as the vast success of robotics and programming projects has demonstrated. The *Green Building Model Kit* allows for two design phases. In the first phase, students design and build their own model houses. In the second phase, they design and add energy-efficiency measures to their houses. The kit is flexible enough for different classroom implementations. Students can design their own house, and then add green features to reduce energy usage. Or, to save time, teachers may choose to have students make a model house made from a cardstock template more efficient. Improving the energy efficiency of a standard model house provides the same starting point and constraints for every team.

To make their houses more energy efficient, students might add insulation, sealing, or passive solar units. Each of these features is an application of one or more concepts in power, energy, and heat transfer. For example, insulation reduces energy loss through heat conduction while air sealing prevents infiltration through thermal convection. Both insulation and air sealing achieve energy efficiency by cutting heat loss. Passive solar units, on the other hand, conserve energy by harnessing energy from the sun. Using our kit, students can design different ways to harvest solar energy for supplemental heating.

Designing a solar hot air collector

Passive solar architecture studies the interactions between a building and solar radiation, with the goal of finding an optimal way to collect as much solar energy as possible for heating the building in winter. These interactions can be modeled using our kit. The design of a hot air collector (HAC) demonstrates this.

A hot air collector consists of a light-absorbing dark surface, an air space enclosed by glass, and two vents (Figure 2a). Sunlight shines through the glass and heats up the dark surface. A collector transfers the absorbed heat to the house in two ways. First, the heat conducts into the wall behind the surface and is then radiated into the house. Second, the heat warms the air near the surface. The hot air rises and enters the house through the upper vent, which creates an updraft force that draws the cooler air at the bottom

> "I would have to say the part of the Engineering Energy Efficiency project I enjoyed the most was seeing the drastic change in energy usage after minor modifications were made."
> – *Student, Arlington (MA) High School*

Figure 1. The *Green Building Model Kit* at work: A simple model house can be heated by a light bulb inside and an adjustable table lamp outside, simulating a furnace and the sun, respectively. Temperature sensors are used to monitor and investigate the temperature distribution inside the house and heat flow across the building envelope.

Figure 2. (a) A side-by-side layout of an HAC and a window. (b) An alternative layout of two HACs and a window, with the window in the middle. In both designs, the idea is to maximize the use of the sun-facing wall for collecting solar energy.

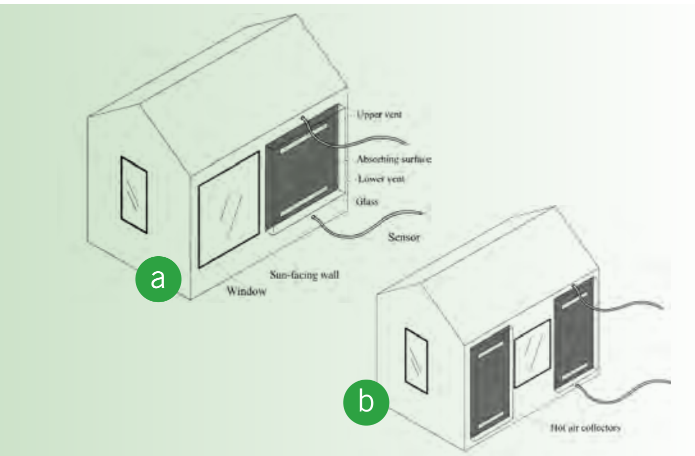
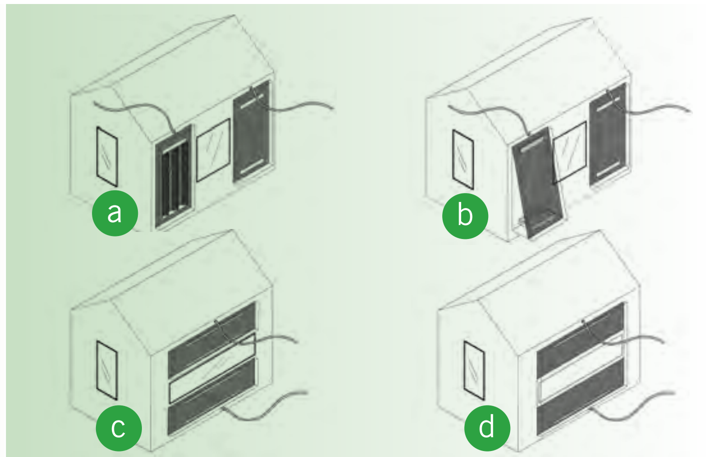


Figure 3. Four design variations of HAC units. (a) A corrugated absorbing surface. (b) A slanted surface to receive more sunlight. (c) Two HACs aligned with a window in the middle. (d) A large HAC unit with a window.



of the house into the air space through the lower vent. The air in the house can, therefore, circulate through the HAC and get heated. This circulation effect is sometimes called thermosiphon.

Hot air collector units are usually mounted to the sun-facing wall, which also has windows to let light in. If you think of this design challenge as a task to capture as much energy from the sun as possible, it is really a problem about the optimal use of the sun-facing wall surface. What's the best way to use this precious house surface area?

This example is fascinating because it involves the synthesis of knowledge about all three mechanisms of heat transfer. Students can easily make a hot air collector and add it to a model house. The variety of designs they can invent and test is limited only by their imagination. Figure 2 shows two possible layouts of hot air collectors and windows. For the design shown in Figure 2a, students can compare the energy gains and losses through a window and a hot air collector. Figure 2b shows an alternative design with two HAC units when, for other design constraints (for example, aesthetics), the window must be located in the middle of the wall.

Figure 3 shows four additional variations. Figure 3a illustrates the idea of corrugating the absorbing surface to enlarge the interface for heat exchange between the air and the surface. Although an interesting idea, the design does not increase solar input. Figure 3b shows a design in which the absorbing surface slants to receive more sunlight, similar to a solar hot water collector. Figure 3c aligns two HACs and a window vertically while Figure 3d improves the energy efficiency by combining the benefits of windows and HACs. With a large HAC unit with the middle part replaced by a window, sunlight can still shine into the house through the window. As the HAC unit is tall, the convective heat flow into the house is more significant.

The hot air collector examples demonstrate the ability of the *Green Building Model Kit* to support creative engineering design. Students can also design many variations of sunspaces, such as sunrooms, solariums, and greenhouses. Some of these capabilities will be added to our Energy3D design software to enable the exploration and evaluation of various designs before making real products. All these design capacities are critically important to engineering education as they hold the promise of reducing the tendency of "cookbook" design in the classroom. By empowering students to think and design in many different ways, precollege engineering education will blossom.

* National Research Council. (2011). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: The National Academies.

Tools and materials

- Computer
- Logger Lite
- Vernier temperature sensors
- Ruler and protractor
- Pencils
- Scissors
- Utility cutter
- Cardstock
- Transparency film
- Foamcore board
- Clear tape
- Aluminum foil
- 40 W light bulb in a socket with an inline switch as the "heater"
- 300 W light bulb in a gooseneck fixture as the "sun"
- Electric fan to create wind
- Energy3D (CAD tool)
- Energy2D (CFD tool)

LINKS

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

Monday's Lesson:

Asking Big Questions about Our Solar System

By Carolyn Staudt and Edmund Hazzard

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"The diversity of the phenomena of nature is so great, and the treasures hidden in the heavens so rich, precisely in order that the human mind shall never be lacking in fresh nourishment."
— Johannes Kepler, 17th century astronomer

Middle school students are fascinated by the solar system. It evokes big questions about the sky, the planets, and the earth's place in it. Help your students uncover the link between the math and the science with "Our Solar System," which uses NetLogo models to explore the orbital periods of the six inner planets.

Students collect experimental data with the models and formulate a relationship between the radius of a planet's orbit and its period. The goal of the activity is not only to have students verify Kepler's Third Law, but also to engage them in scientific discussion.

But when students are glued to their computer screens watching virtual orbits zip around a model sun, how can you promote deep discussion? Whether they're working alone, in a group, or as a whole class, it is important to provide discussion questions before, during, and after they use the activity.

Questions are embedded throughout the Solar System online activity. Use the following classroom questions to spark additional discussion and make the activities more meaningful to students.

Set the stage. Prepare students for undertaking the scientific process with interactive, digital models. They should have an open mind and be ready to engage the model with their own questions and to take measurements. Before students run the activity, ask: Do all planets in our solar system take the same amount of time to orbit the sun? (Answer: No. Each planet has a different path and distance from the sun.)

How does size and distance from the sun influence the path of a planet? (Answer: Size doesn't matter, but distance from the sun does, which may be intriguing to students. Surprisingly, a baseball placed in the earth's orbit and given the same velocity as the earth would follow the same path around the sun.)

Ask questions that require evidence. Students should be making predictions and collecting data as they work with models. While they're using the activity, ask: How do "earth years" compare to other "planet years"? (Answer: They vary by the distance a planet is away from the sun.)

Is it possible to determine the speed at which each planet is moving? If so, how? (Answer: Yes. Calculate the circumference of the orbit, find the radius in astronomical units, and then determine the speed in astronomical units per earth year. Students may be surprised to learn that outer planets are traveling slower and they are much, much further away from the sun.)

Wrap up. At the conclusion of the activity, students should review their data and explain trends. Ask: Why do you think it takes longer to rotate around the sun the further away the planet is? (Answer: The distance travelled is much greater and, surprisingly perhaps, the outer planets have slower speeds than the inner ones. Mercury is the fastest. The model is based on gravitational forces and Newton's Laws of Motion, but Kepler was not aware of these.)

Do you think that other astronomical objects outside the solar system exhibit orbital motion? Do you think that Kepler's Laws could be applied to these objects? (The answer to both questions is yes. As long as the attractive force is gravitational toward a single central body, the object will follow an elliptical path and Kepler's Laws apply.)

Point out that the simulation is not just a movie or videogame. It uses Newton's Law of Gravitation and the planets' measured orbital radii to determine their speeds, so it's a genuine test of whether gravitational forces can actually explain Kepler's results.

Try it out

Go to http://www.concord.org/activities/our-solar-system to run "Our Solar System." And if you're looking for more great activities that nourish the mind, visit our Activity Finder and search by grade or subject for inquiry-based, interactive activities using probes and models.

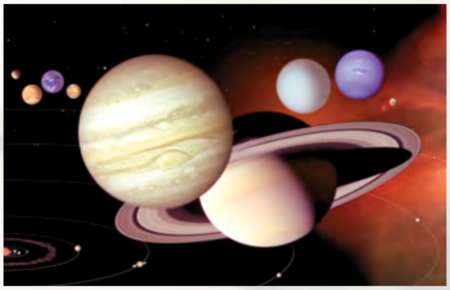

Photo credit: NASA

LINKS

Activity Finder
http://concord.org/activities

Beginning with BIG IDEAS: Are Students Ready for **Evolution?**

By Paul Horwitz and Laura O'Dwyer

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Although we originally proposed the term "Evolution Readiness" to the National Science Foundation in 2008, it still took a team of scientists, curriculum developers, measurement experts, and software developers from the Concord Consortium and Boston College several months to define readiness when we began the project. Three years later, we now have a better idea of what fourth graders are ready to learn—and what's hard for them.

For ten-year-olds the time to their next birthday can seem like forever. With this in mind, we decided not to try to convey to them the immense stretches of time required to produce major changes in species. We also realized that our young students were unlikely to embrace microscopic explanations for macroscopic phenomena—for example, that variations between organisms are caused by invisible things called genes. In the end, we settled on a collection of 11 BIG IDEAS that cover the "kid-size" aspects of evolutionary theory, leaving out the very slow and the very small.

We were aware from the start that some of our big ideas would be much harder to teach than others. Which concepts would students be able to learn? Would we find it virtually impossible to teach the more advanced concepts? In order to find out, we developed a test that included a few questions that we weren't sure any students would answer correctly.

Curriculum design

The Evolution Readiness project worked with fourth grade students in school districts in Massachusetts, Missouri, and Texas. We developed ten computer-based learning activities and complemented these with five hands-on activities, mostly adapted from existing sources, plus a set of books. The computer-based activities are educational "games" that pose challenges and allow students to manipulate a model containing organisms and environments. Different organisms are adapted to different environments and students can change the environment and observe what happens to the organisms. Like all games, ours have definite goals and provide context-sensitive hints and congratulatory messages. The games keep track of everything students do, including their answers to embedded questions, and use that information to report back to teachers and researchers.

The first five games focus on plants. We chose to start with plants for two reasons. First, by making them annuals we could have them die off every virtual year (designated by a fresh fall of virtual snow). This reinforced the idea that individual plants do not evolve to adapt to changes in their environment; rather, it is the entire population of plants that is able to evolve over many generations, due to the inherent variability of offspring in each generation. Second, we exploited the fact that plants don't move. We created virtual environments in which critical features, such as sunlight or water, varied continuously as a function of position. In such environments the virtual plant population automatically distributes itself so that plants with different characteristics grow in different places. The effect is visually striking and demonstrates that the population of plants is, over many generations, able to adapt and spread over different environments (Figure 1).

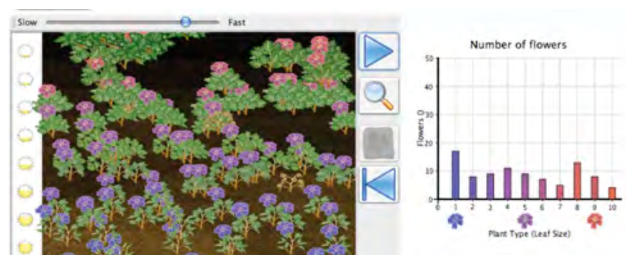

Figure 1. The plants in this model all grew from a single seed planted in the center of the field where the light level was just right for it. Some of the seeds from that plant differed from the original and grew into plants that needed a slightly different light level. Thus, the single type of plant, which could only live in the middle of the field, eventually "evolved" into many different varieties that populate the whole field.

A second set of five computer games focuses on animals. For pedagogical purposes, the main difference between plants and animals is that plants, in our model at least, depend only on abiotic (nonliving) factors, such as light and water, while animals

The learning goals of the Evolution Readiness project fall into 11 BIG IDEAS (ideas so big they're capitalized!).

1. Basic Needs of Organisms
2. Life Cycle—Birth and Death
3. Organisms and Their Environment
4. Classification of Organisms
5. Inter-specific Differences
6. Interactions Between Species
7. Intra-specific Differences
8. Adaptation/Evolution
9. Heritability of Traits
10. Reproduction
11. Descent with Modification

Figure 2. The animal games include different sized rabbits.

consume other living things—plants as well as other animals. By including animals we are able to introduce the concept of a food chain, with its related notion of competition for scarce resources. The interdependence of species at each level of the food chain means that the environment of each species is comprised, in part, of all the other species with which it interacts. Thus, evolutionary changes in one species will affect others and vice versa, resulting in a sort of "adaptation arms race" strikingly different from the "plants only" case in which the plants adapt to their nonliving environment, but the environment does not adapt to the plants.

We supplemented these computer-based activities with offline activities borrowed or adapted from existing curricula. These materials included books; plants with a very short life cycle (Fast Plants®); an 18-foot-long evolution timeline; a game called "Clipbirds" that illustrates selective pressure by challenging students to pick up different sizes of seeds using different clips; a tree of life game demonstrating common ancestry; and a food web game.

Results

In the first year of the project we created three assessment instruments and administered them to a baseline cohort of fourth grade students who had not used our activities. In the second and third years we administered the same three assessments to additional cohorts of fourth graders in the same schools and taught largely by the same teachers, but using the Evolution Readiness materials.

The three instruments were:

- The Concept Inventory for Evolution Readiness, an assessment of student content knowledge, aligned to the big ideas.
- The Elementary School Science Classroom Environment Scale, which measured the degree to which constructivist techniques were used in the science classroom, as reported by students.
- The Nature of Science Survey, which focused on whether students understood that scientific knowledge is tentative, based on real-world observations, and theory driven.

The Science Classroom Scale scores were higher in the second year than in the other two years, indicating a greater degree of constructivist teaching in that year, as reported by students. (During the second year, classes were observed by project consultants, which may account for the difference.) Results from the Nature of Science survey were statistically identical across all three years. There was no significant correlation between the Science Classroom Scale, the Nature of Science Survey, and the Concept Inventory results in any year.

On the Concept Inventory, students in the two cohorts of students who used the curriculum achieved significantly higher scores than those in the baseline group. In other words, students who used the computer games and offline activities* learned the big ideas significantly better than those who followed the traditional curriculum.

When we looked more closely at individual test items, we found that although students who had used the Evolution Readiness activities were likely to score higher on all the items than those who had not, some of those items were clearly more difficult than others for all the students. And when we mapped the items onto the big ideas the pattern was clear: some of them proved easier than others. Concepts that applied to single organisms (e.g., "Plants and animals need air and water; plants also need light and nutrients; animals also need food and shelter") or comparisons between organisms (e.g., "Individuals of the same species may differ") were the easiest to learn. In contrast, processes that involve multiple organisms

(e.g., "Selection pressure could lead to a change in the characteristics of a population") or take place over long time periods (e.g., "Different species could arise from one species if different groups had different selection pressures") were much more difficult for students to understand.

Summary

We expected that some of the concepts critical to a deep understanding of evolution would be difficult for students to grasp on first encounter. Our data confirms this.

	Sample size	Mean	Standard Deviation	Significance of difference from baseline	Effect size
Year 1 (baseline)	132	531.45	68.40	–	–
Year 2 (treatment)	186	566.14	80.07	$p < .001$	.46
Year 3 (treatment)	188	555.35	76.78	$p < .016$	.33

In fact, by ordering the Concept Inventory items by difficulty level we can pinpoint the concepts our students found most problematic. We can see exactly where they're "evolution ready" and where they're not quite ready. Which raises a challenge.

Working with elementary school students is clearly only the first step in teaching evolution. The challenge now is to build on these results to help students in later grades go from readiness to full understanding of this most surprising and fundamental of all scientific ideas.

LINKS

Evolution Readiness
http://concord.org/er

* Students in the second year used the plant games and four of the offline activities; most of the students in the third year used both plant and animal games and all five offline activities.

By Robert Tinker

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(bob@concord.org) is the founder of the Concord Consortium.

An Example of Deeply Digital Curricula: **Detergents**

Remember those devastating images of the burning Deepwater Horizon and satellite pictures of the huge oil slick in the Gulf of Mexico? Photos of volunteers gently bathing oil-soaked marine birds were heartrending. Those images grabbed our attention and captured the interest of science teachers and students alike. That kind of engagement is invaluable as an entry point to discovering the deeper scientific concepts of a whole suite of related ideas. The Gulf oil spill can launch students on a deep—and deeply digital—learning adventure.

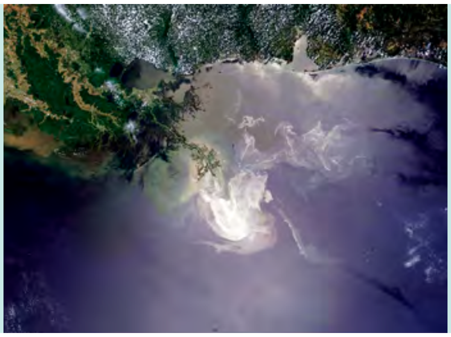

Photo credits: U.S. Coast Guard, NASA, and International Bird Rescue (www.Bird-Rescue.org)

Real-world connection

One prominent issue in news reports of the BP oil spill was the spectacular underwater real-time videos of detergents being pumped directly into the gushing wellhead a mile underwater. This was the first time wellhead injection had been tried and over a million gallons of detergent were used.

A class discussion of the use of detergents can raise many questions: Why add to the mess? What was BP hoping to accomplish? Did the detergents make the oil more toxic? What is a detergent anyway? Can the detergents explain why the oil slicks were less than expected, or that there were underwater plumes of oil never before observed, or that the oil may have disappeared faster than expected?

The model

To test whether a deeper understanding of detergents can be gained, without getting too technical, we created a simple atomic-scale model of oil, water, and detergents in NetLogo. The model shows a cross-section of oily water with a film of tan oil above blue water (Figure 1).

The basic ideas that govern detergents are that clusters of atoms that contain a charge "like" liquids that consist of charged molecules (such as water), and those that do not contain a charge "dislike" such liquid. The actual description should be "are in a lower energy state when surrounded by," but "like" is easier. When something "likes water," we say it's hydrophilic, and if it "dislikes water," it's hydrophobic. And this basic idea—seen throughout biology and chemistry—explains solubility, protein folding, self-assembly, and more (Figure 2).

In our model, the container has been shaken to produce oil drops that float around as well as some green and magenta "mystery molecules" scattered about. As students run the model, all the oil drops coalesce and rejoin the surface, making a thicker film. Most of the green molecules end up in the water while the magenta ones end up in the oil. Students learn that the green molecules are charged and the magenta molecules are not.

It is also possible to add another mystery molecule. As shown in Figure 3, the black molecules mostly end up at the surface between oil and water. Students are led to guess that this is because the black molecules are charged at one end and have an uncharged tail. Revealing the structure of the mystery molecules (Figure 4) shows that this is true. Indeed, the black molecules are essentially the green and magenta ones joined together, and this is precisely how detergents are constructed.

By adding more black molecules, every oil-water surface can be coated (Figure 5). Running the model shows that these coats interfere with the tendency of oil to coalesce, so these droplets last forever and, if the water is sufficiently agitated, no oil remains on the surface.

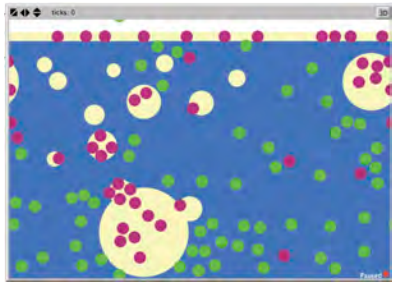

Figure 1. The detergent model showing water (blue), oil (tan), and two kinds of mystery molecules (green and magenta). Students can observe the solubility of each mystery molecule.

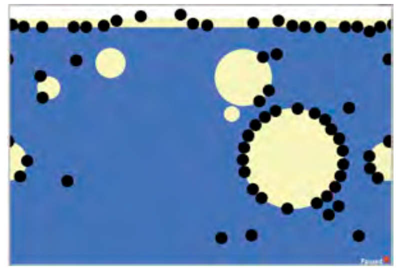

Figure 3. A third kind of mystery molecule (black) has peculiar properties.

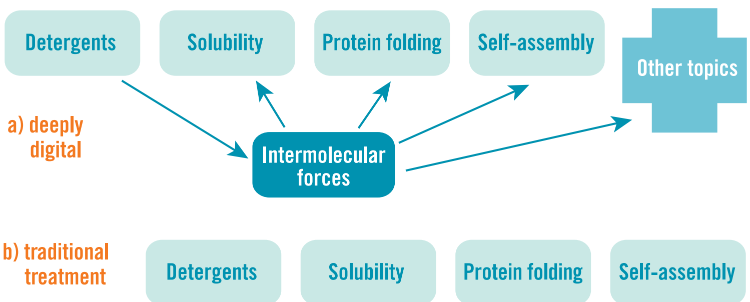

Figure 2. Our "deeply digital" treatment (a) starts with one topic and then delves deeper to get at the underlying concept. This concept allows students to understand other seemingly unrelated topics. The traditional treatment (b) addresses these concepts as separate phenomena and without explaining their underlying cause.

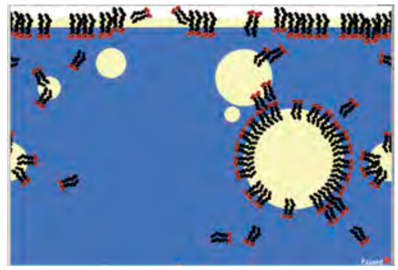

Figure 4. Revealing the black mystery molecules shows that part of each is soluble in water and the rest is soluble in oil.

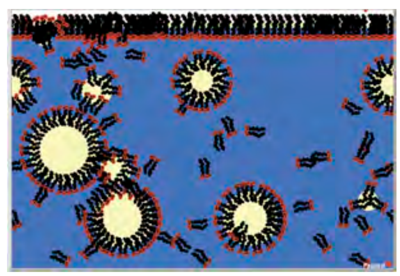

Figure 5. With enough black molecules and shaking, the oil cannot coalesce, the droplets are stabilized, and the surface oil disappears.

Going deeper

Deep concepts are difficult—that's why they're not part of traditional curricula. Usually they are relegated to advanced study and students who have mastered highly abstract, mathematical concepts. But computer models allow us to offer those same topics to beginning students in a way that is easier for them to understand.

Using our detergents model, students can make informed guesses to questions about the Gulf oil spill:

Did the detergents get rid of the oil? No, they simply dispersed it.

Why was there a smaller oil slick than expected? The detergent kept some of the oil from reaching the surface.

Why was there an underwater plume? It was likely composed of detergent-coated oil droplets.

Did the detergent react with the oil? No, the dispersion works without a chemical reaction.

Did the detergent make the oil more toxic? No, the combination was no more toxic than the oil itself (which is plenty toxic); the detergent is probably only as toxic as kitchen detergents.

Is it possible that detergents contributed to eliminating the oil? The dispersed droplets have a huge surface area that might make it easier for oil-eating bacteria to digest the oil.

While this simple model does not provide definitive answers to these questions, it does enable students as informed citizens to understand the real issues at a much deeper level than most of the TV reporters, company representatives, and environmentalists did during the crisis.

Connected ideas

Educational technology has a unique capacity to make deep concepts accessible through a combination of highly interactive models, good visualizations, and well-designed learning activities. Even a qualitative understanding of deep concepts helps students make connections between topics that appear quite unconnected. And connected ideas are easier to learn, more engaging, and give a more accurate picture of the unity of science, compared to traditional approaches that treat the same phenomena separately. Our deeply digital curriculum design focuses on teaching important, deep concepts that have broad explanatory power.

A new curriculum must, and can, delve deeper into concepts. But its greatest impact would be through reordering the content sequence around these deeper ideas, not traditional subjects. We will not have fully exploited the value of technology to science teaching and learning until a totally reorganized curriculum is implemented. But that's a topic for another time.

LINKS

VISUAL
http://concord.org/visual

Atoms, Molecules, and More with the

Molecular Workbench

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By Charles Xie and Robert Tinker

$$m_i \ddot{R}_i = -\nabla_i V(R_1, R_2, \ldots\ldots, R_n)$$

$$V_{LJ} = \frac{1}{2}\sum_{i,j,i \neq j} 4\varepsilon_{ij}\left[\left(\frac{\sigma_{ij}}{R_{ij}}\right)^{12} - \left(\frac{\sigma_{ij}}{R_{ij}}\right.\right.$$

$$V_{EL} = \frac{1}{2}\sum_{i,j,i \neq j} \frac{q_i q_j}{R_{ij}}$$

$$i\hbar \frac{\partial}{\partial t}\psi(r,t) = -\frac{\hbar^2}{2m}\nabla^2\psi(r,t) + V(r)\psi(r,t)$$

Nobel Prize winner Richard Feynman once said, "If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generations of creatures, what statement would contain the most information in the fewest words? I believe it is the atomic hypothesis . . . **that all things are made of atoms—little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another.** In that one sentence, you will see, there is an enormous amount of information about the world, if just a little imagination and thinking are applied."[1]

The wisdom of this great scientist highlights the fundamental importance of atoms as the building blocks of the world and the knowledge about them as a foundation of science. Science educators agree with him. The science of atoms and molecules constitutes a substantial part of the science content standards[2] and even more so in the new frameworks,[3] from the structure of atoms to the molecular basis of heredity. This body of knowledge and skills, known as molecular literacy and molecular reasoning, is increasingly important as science has advanced to the point that the research and development of atomic-scale systems and technologies holds the key to solving many critical problems today.

But what happens at the atomic level is difficult for students to imagine and molecular literacy focuses on unfamiliar concepts. Due to the lack of teaching tools in the past, these concepts were often taught as factual knowledge that students had to accept and memorize. Fortunately, computer technology has provided a revolutionary way to teach them.

The Molecular Workbench (MW) software is one of the most advanced tools for teaching and learning the science of atoms and molecules. MW includes a set of computational engines that accurately simulate atomic motions, quantum waves, and atomic-scale interactions based on fundamental equations and laws in physics. These engines render highly expressive dynamic visualizations of atomic-scale phenomena on the computer screen and provide rich user interfaces for exploration. MW empowers students to learn through conducting graphical "computational experiments"[4] to investigate ideas otherwise untestable in classrooms. This capacity provides opportunities for inquiry and effective pathways to molecular literacy and reasoning skills.

Teaching and Learning about Atoms and Molecules

Molecular literacy is knowledge of the science of atoms and molecules.

Molecular reasoning is a skill for applying molecular literacy to analyze and solve problems.

- Reasoning about the macro-micro connection: the ability to explain macroscopic phenomena using atomic-scale models.
- Reasoning about the structure-function relationship: the ability to correlate properties of atoms and molecules with their function.

Changing how science is taught

If a picture is worth a thousand words, a visual simulation is good for at least 10,000! Molecular Workbench significantly lowers the barrier for learning and teaching abstract concepts. Teachers can demonstrate a concept with a salient dynamic visualization without intimidating students with obscure terminology or difficult mathematics.

For example, one study conducted by the University of Illinois at Chicago showed that the seemingly complicated idea of molecular self-assembly can be taught to elementary school students if dynamic visualizations from MW are used to illustrate the key points—that molecules are moving all the time, they are "sticky" in some way, and their shapes must match for assembly. Another example is quantum tunneling. The traditional approach to teaching this concept is through mathematical analysis that few students can master. MW provides a new way to investigate how different properties affect tunneling without using any equations, making the concept accessible to more students.

Research studies of diverse students ranging from middle grades through college demonstrate that students who use well-designed MW activities gain understanding of atomic-scale phenomena and can transfer this knowledge to new contexts effectively.

1. Feynman, R. P., Leighton, R. D., & Sands, M. (1963). *The Feynman lectures on physics*. Menlo Park: Addison-Wesley.
2. National Science Education Standards, http://www.nap.edu/openbook.php?record_id=4962
3. See http://www7.nationalacademies.org/bose/Standards_Framework_Homepage.html
4. Computational Experiments for Science Education, http://www.sciencemag.org/content/332/6037/1516.full

A rich collection of curriculum materials

One of the unique strengths of MW is its ability for curriculum developers and instructional designers to create curriculum activities that lead students through well-planned investigations and explorations. A sequence of pages—containing text, multimedia, models, simulations, games, graphs, assessments, and networking capabilities—progressively develops a concept. Students can answer questions, save their work in a Web portfolio, share models with collaborators, create electronic reports, and submit them for grading.

We have developed hundreds of activities for biology, chemistry, physics, biotechnology, and nanotechnology. They're all freely available online.

The deeply digital textbook of tomorrow

These model-based activities represent what could become chapters in a next-generation digital textbook. This deeply digital vision of textbooks differs from most of the e-texts available today by including interactive explorations of models that replace static illustrations. This approach can change what students learn, making it possible to teach deeper concepts that have greater explanatory power. Thus, the textbook of tomorrow will be much more than textbooks transferred to computers—they will permit students to learn more, more deeply.

Molecular Workbench Facts

Molecular Workbench was made possible by a succession of National Science Foundation grants. It has been downloaded over 800,000 times by users worldwide. In June it was awarded a *Science* Prize for Online Resources in Education (SPORE). The SPORE prize was established by the American Association for the Advancement of Science to "encourage innovation and excellence in education, as well as to encourage the use of high-quality on-line resources by students, teachers, and the public."

Physics	Chemistry	Biology	Nanotechnology	Biotechnology
Heat & temperature	Atomic structure	Molecular recognition	Nanostructures	X-ray crystallography
Spectroscopy	Kinetic molecular theory	Lipids	Nanomachines	DNA hybridization
Electrostatics	Gas laws	Carbohydrates	Self assembly	Southern blot
Electricity	Phase change	Proteins	Scanning tunneling microscopy	ELISA
Semiconductors	Intermolecular interactions	Nucleic acids	Atomic layer chemical vapor deposition	Fluorescent tagging
Quantum tunneling	Molecular geometry	Genetic code	Sputtering	FACS
Quantum diffraction	Solubility	Transcription		Electrophoresis
Excited states & photons	Polymerization	Translation		Mass spectrometry
Photoelectric effect	Chemical reactions	Photosynthesis		

Table 1. Molecular Workbench can model a large number of scientific phenomena. The fundamental physical laws used to build Molecular Workbench engines—Newton's equation of motion, the Schrödinger equation, and more—ensure the accuracy and depth of the visual simulations.

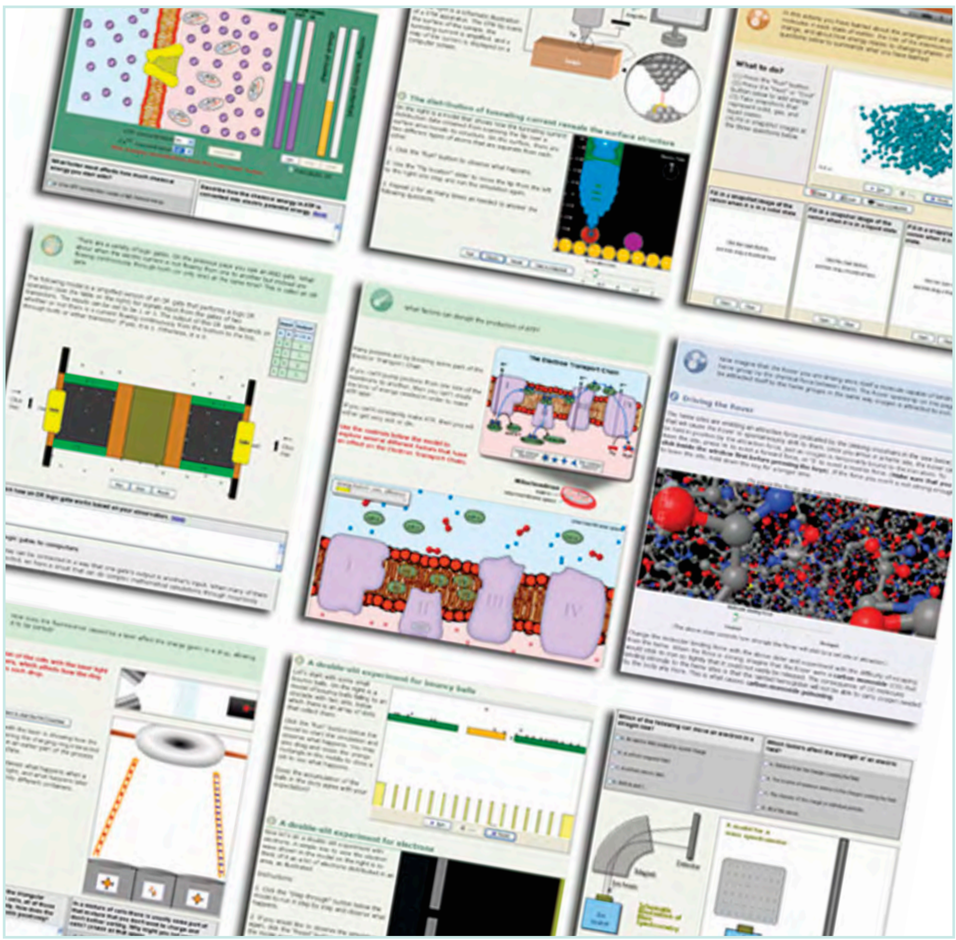
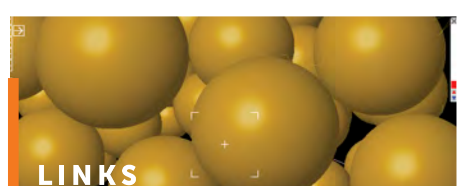


Figure 1. An example of a deeply digital textbook. Each page in a Molecular Workbench activity includes text, embedded models, assessments, and more.



Molecular Workbench
http://mw.concord.org

Probes

Give Students a Sixth Sense

By Cynthia McIntyre and Robert Tinker

Cynthia McIntyre
(cynthia@concord.org) is director of communications.

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

Here's a riddle:
Is there something that you cannot see, touch, smell, taste, or hear?

The answer:
Lots! For example, infrared light, blood pressure, CO_2, electric and magnetic fields, voltage, current, and radioactivity. And these are all particularly difficult to teach, in part because students cannot sense them directly and, therefore, lack intuitions about them.

Here's another riddle:
How can we teach about something students cannot see, touch, smell, taste, or hear?

The answer:
Use probeware to make any one of these as immediate and intuitive as something they can sense directly.

More questions (hint—the answers involve probeware):

How do I turn a computer into a general-purpose instrument? Use probeware—your computer can become a weather station, data logger, spectrometer, colorimeter, frequency meter, function generator, and much more.

How can I support open-ended student projects that might require measuring almost anything? Stock up on probes. Over 50 are available.

Is a probe-based lab better than an old-fashioned one? It can be—probes can make it possible to focus more on the science, do more experiments, measure more accurately, reduce drudgery, and see results in real time.

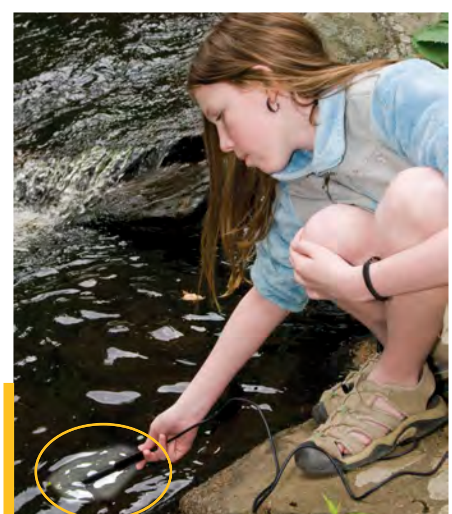
For three decades, we've been extending students' senses with probeware. In 1981, Bob Tinker designed the first microcomputer-based real-time temperature data grapher for education, and ignited a whole industry (see Innovator Interview, next page). Now called probeware or simply probes, innovative applications of probes are still an important part of our work and are available from several major vendors. (Visit Probesight, our website dedicated to probes, for research, curriculum ideas, a supplier index, and more.)

Probeware refers to the hardware and software used for real-time data acquisition, display, and analysis with a computer or calculator. If you're not familiar with probes themselves, think of a supersensitive and lightweight thermometer at the end of a wire attached to the USB port of your computer that delivers immediate and continuous temperature data on a graph. The fast-response or "surface temperature" sensor is one of the easiest to use and one of the most flexible—students can investigate phase change, thermal radiation, or the greenhouse effect, among many other phenomena. (Go to our Activity Finder at www.concord.org/activities and search for probeware to give it a try.)

The temperature sensor is just one of 50-plus probes available for classroom use. Probes give students new possibilities to explore and understand the world and to see it represented symbolically. Students can capture virtually any kind of data at their fingertips, quickly and easily. And research has demonstrated that probeware can facilitate student learning of complex relationships and can support conceptual change by strengthening student intuitions.

We started a revolution 30 years ago and we're still innovating. Recently, we solved the "Tower of Babel" problem that meant each vendor's probes would only run on their software. We created an interface that gives our graphing software access to probes from all the major vendors, so you can mix and match probes. We also combined our probe graphing software with an authoring platform that lets anyone create new learning activities that include probes.

Right now, we're working on linking probe data with software running in a Web browser, studying "mixed-reality" activities (see page 16) that connect data from hands-on experiments using probes with computer models, and continuing to research new ways probeware can support learning. We're excited about giving students a sixth sense—and a seventh and eighth, too. The next decades look even more promising for probes.



LINKS

Probesight
http://probesight.concord.org/

Innovator Interview:

Robert Tinker

(bob@concord.org)

Q. Tell us about the coffee klatch that led to the Concord Consortium.

A. For over 10 years Barbara [Tinker] and I met with a group of Concord friends on Saturday mornings. We were all interested in education, though we came at it from different angles. One worked in a medical clinic for the disadvantaged, one was a spiritual psychologist, one designed educational discs, and so forth. We were looking for new places to channel our energy, so we created the Concord Consortium as a lifeboat of sorts—and I jumped in headfirst. I read up on how to make a nonprofit and we set one up with the klatch as the board. Our part was called the "Educational Technology Lab" and, with three grants, it soon overwhelmed the others in the klatch. Those with little interest in managing a growing technology-based nonprofit graciously withdrew from the board.

Q. You ignited the whole field of probeware. How?

A. It was a direct result of a grant to TERC in 1984 called Microcomputer-Based Labs from NSF. Stephen Bannasch and I had been advocating probeware for a decade by building prototypes, giving workshops, and even participating in a funded grant to develop probeware for the "Voyage of the Mimi" project. But the MBL project provided the ignition. The grant allowed us to develop and market a dozen complete labs using probes, create the game-changing ultrasonic motion detector, stimulate research on probes by holding two conferences and giving researchers hardware, and seed competition by selling hardware kits at cost. We also invented the name "MBL" so we could track the influence of the project. The term is forgotten now because "microcomputer" is anachronistic, but for a decade it was synonymous with "probeware" and was ubiquitous. Even the Texas Instruments "calculator-based labs" or CBL was an acknowledgement that we had created a market for MBL products.

Q. You were also instrumental in inspiring Molecular Workbench. Tell us about that.

A. There had been a long history of computer simulations of atomic motion. The Apple IIe had something truly amazing. It was a hard-sphere model where atoms collided and went off in different directions. It could handle 1,000 atoms and generate realistic statistics on velocities and such, which was appealing at the college level. Though the graphics were just single pixels moving around the screen, it always stuck in my mind as a model.

In 1998 we won a grant to explore the feasibility of molecular dynamics. Boris Berenfeld found a website that looked like what we wanted. Charles Xie had created very erudite and powerful stuff on biological molecules, so on the way back from Israel where I was giving a speech, I interviewed him in Europe, and hired him on the spot. He was off and running, I just pushed him in the right direction. Charles knew intermolecular forces. That opened up a whole new world. The Molecular Workbench is very solid and really original.

Q. What do you hope for educational technology?

A. I want a deeply digital curriculum. Technology offers a new and powerful way to learn complicated concepts in a qualitative way. A lot of scientists sneer at conceptual understanding, but research in cognitive science shows that understanding deep concepts is almost always conceptual. When we take that capability and allow it to change the curriculum, we'll have real change.

Read more of Bob's interview at
http://www.concord.org/innovator-interview-bob-tinker

The Concord Consortium

25 Love Lane, Concord, MA 01742

NEWS FROM THE
CONCORD CONSORTIUM

Can Games Enhance Genetics Learning?

Genetics concepts are notoriously difficult to learn and teach. But does student motivation and learning change when you add gaming features to a science curriculum? We're delighted to collaborate with the New York Hall of Science on a new grant from the National Science Foundation. GeniGames will add game-based design elements to our Geniverse curriculum so students can learn about dragon genetics!

Conflict. Players struggle to achieve goals or outcomes of the game, often in opposition to each other, but sometimes together or in parallel. (Conflict does not mean combat.)

Narrative. A story sets the game context with plot and characters in a fictional world. Ideally, the conflict provides the opportunity for the narrative events.

Play community. Players engage in social aspects of the game play that derive not from the rules of the game, but from activities that link the game to outside contexts.

Mixed-Reality Labs Integrate Sensors and Simulations

Thanks to a new grant from the National Science Foundation, we are partnering with the University of Virginia to design a set of mixed-reality laboratory activities that integrate sensors and simulations into high school chemistry and physics classes.

We are developing activities that use real-time data from a physical experiment to control a virtual experiment. As students interact with the sensor measurement in the physical experiment, a corresponding change in the virtual experiment takes place. Other activities challenge students to match the results measured by the sensors with the results computed by the simulations. Students alternate between the two worlds, adjusting the virtual experiment to match the hands-on experiment and then changing the physical experiment to test the fidelity of the simulation.

Deeply Digital Materials Help Students at Innovative New School

Because of generous support from the Noyce Foundation, teachers at Schools for the Future Academy in Jacksonville, Florida, will adopt and modify our probe- and model-based science activities for use in their classrooms. The mission of Schools for the Future is to prove that disconnected youth in grades 8-12 can succeed in high school, college, and careers. The school uses a state-of-the-art turnaround model that integrates research-based practices in adolescent literacy, math, science, and affective development with innovative technologies, including a sophisticated student assessment and data dashboard.

Happy 15th Birthday, VHS!

The award-winning Virtual High School (VHS) originated at the Concord Consortium in 1996 in collaboration with Hudson (Massachusetts) Public Schools. In 2001, the project was spun off as the Virtual High School Global Consortium, an independent nonprofit that is now funded primarily from school memberships and continues to offer over 185 unique teacher-designed courses to over 15,000 students. Looking for the highest quality online courses for middle and high school students? Look no further than the Virtual High School (goVHS.org).

SeeingMath™ Courses for Teachers

The Concord Consortium developed the Seeing Math™ series of algebra courses for teachers that include innovative, interactive computational models for solving linear equations, quadratic functions, and more. Videos of content experts and students supplement course material. For these professional development courses, try PBS TeacherLine (pbs.org/teacherline) or Teachscape (teachscape.com).

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